Enhancing self-efficacy among civil engineering undergraduates using hand-on pedagogy

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Abstract

Self-efficacy is defined as an individual belief in their ability to succeed in tasks and it is pivotal in shaping student performance in engineering disciplines. In civil engineering education, where the focus is traditionally on theoretical frameworks, the need for a dynamic approach that fosters both practical skills and confidence among students has become increasingly essential. This research examines the elements influencing self-efficacy in civil engineering undergraduates and assesses the effectiveness of a hands-on pedagogical model grounded in experiential learning. Utilizing a quantitative research design, this study implemented the Motivated Strategy for Learning Questionnaires (MSLQ) alongside a pre-test and post-test framework. Data will be collected from a number of civil engineering students engaged in courses that emphasize hands-on experiences. The analysis will be conducted using the Statistical Package for Social Sciences (SPSS) to determine changes in self-efficacy scores, employing inferential statistical methods at a confidence level of 95%.

The results of this study will provide valued insights into the impact of experiential learning on self- efficacy in civil engineering students by recognizing this key factor that influences confidence in their academic and practical capabilities, the study will contribute to the development of more effective educational strategies. Ultimately, this research aims to support a shift toward more hands-on, student-centered pedagogical approaches in engineering education, fostering both competence and confidence in future civil engineers.

Keywords: Self-efficacy, Hands-On Pedagogy, Engineering Education.

Introduction

Self-efficacy, or the belief in one's ability to succeed in specific tasks, plays a crucial role in shaping student outcomes in challenging educational programs such as in engineering. Undergraduate civil engineering students are often confronted with rigorous theoretical concepts and complex problem-solving scenarios, which can undermine their confidence if not adequately supported by practical learning experiences. Self-efficacy influences not only a student's motivation and persistence but also their ability to approach difficult subjects with resilience and confidence [1]. This is particularly vital in civil engineering education, where a combination of analytical proficiency and hands-on skills are crucial for academic success and future professional competence [2].

Research has shown that students with high self-efficacy tend to approach challenges more effectively, exert greater effort, and persist longer in the face of adversity [1]. Moreso, students with low self-efficacy are more likely to struggle with the rigorous demands of civil engineering programs, which can result in decreased performance and even program attrition [3]. Therefore, promoting self-efficacy in civil engineering students is not only important for their immediate academic success but also for improving retention rates and ensuring they are well-prepared to meet the challenges of the engineering profession [4] [5]. The need to strengthen both theoretical understanding and practical skills in civil engineering shows the importance of a balanced pedagogical approach, that is, the one that integrates experiential learning with traditional instruction.

One promising way to enhance self-efficacy is through the implementation of hands-on pedagogical approaches that actively engage students in experiential learning. Hands-on learning involves activities like Capstone projects, field exercises, modeling, simulation exercise and laboratory experimentation, providing students with tangible experiences that reinforce theoretical concepts. A primary purpose of hands-on activities is to provide learners with actual experiences that allow them to apply engineering skills in real-world contexts, thereby reinforcing their knowledge and enabling them to directly observe the outcomes of their efforts, which leads to deeper learning [6]. These activities not only help students better understand course material but also encourage students to apply theoretical concepts in tangible ways, thereby reinforcing their understanding and boosting their confidence in solving real-world engineering problems. By engaging directly with engineering tools and techniques, students develop a sense of competence and ownership over their learning journey, which enhances their belief in their engineering abilities.

In this study, a hands-on approach called Experiment-Centric Pedagogy (ECP) was implemented. This pedagogy has been found to actively engage learners by utilizing affordable, safe, and portable electronics in various educational settings (classrooms or laboratories). ECP combines problem-solving exercises and constructive learning methods with a hands-on, portable multifunction tool that can be used in place of larger and complex laboratory apparatus. Over a two-year period, a civil engineering program that integrated hands-on learning through projects, lab exercises, and fieldwork showed substantial gains in students' self-reported efficacy. Survey data, collected using validated self-efficacy rating scales, indicated significant improvements across various categories, including technical skills, problem-solving ability, teamwork, and confidence. These findings highlight the potential of hands-on learning strategies to improve retention and performance among civil engineering students. Additionally, incorporating structured activities that encourage student reflection and peer learning may further enhance these outcomes, contributing to a more student-centered and effective civil engineering education.

Theoretical Framework

Social Cognitive Theory

Bandura's Social Cognitive Theory (SCT) provides a foundational framework for understanding how individuals acquire and regulate behaviors through the dynamic interaction of personal, behavioral, and environmental factors.[7]. This theory emphasizes the importance of observational learning, self-efficacy, and self-regulation in shaping behavior. Central to SCT is the concept of self-efficacy, which refers to an individual's belief in their ability to successfully perform specific tasks. Self-efficacy plays a crucial role in influencing motivation, effort, persistence, and resilience, particularly in educational settings. It is a psychological construct that significantly impacts students' learning experiences and outcomes [8].

According to Bandura's social cognitive theory, self-efficacy is developed and reinforced through four key mechanisms: mastery experiences, vicarious experiences, verbal persuasion, and physiological and emotional states [9]. Mastery experiences are considered the most influential source of self-efficacy. They involve personal success in overcoming challenges, which strengthens belief in one's capabilities. [10]. For civil engineering students, hands-on learning activities like capstone projects and laboratory experiments serve as vital mastery experiences, allowing them to apply theoretical knowledge and observe tangible outcomes.

Vicarious experiences, derived from observing the successes of peers or mentors, also contribute to self-efficacy development. Collaborative engineering tasks often provide opportunities for students to learn from and emulate others, thereby reinforcing their confidence [11]. Verbal persuasion, such as constructive feedback and encouragement from instructors, further supports self-efficacy by affirming students' capabilities when paired with progress evidence [12].

Finally, physiological and emotional states play a significant role. Stress and anxiety, which are common in rigorous engineering programs, can negatively impact self-efficacy. However, hands-on pedagogies help mitigate these challenges by fostering an engaging and supportive environment that empowers students and reduces stress.

Relating social cognitive theory to this study, the Experiment-Centric Pedagogy (ECP) aligns with these self-efficacy mechanisms by offering mastery experiences through practical tasks, promoting vicarious learning in team settings, utilizing verbal persuasion via instructor feedback, and reducing stress through interactive and accessible learning methods. Experiment-centric pedagogy emphasizes experiential learning through hands-on activities, allowing students to learn by doing, which is crucial for mastery experiences [13]. This alignment underscores the value of ECP in enhancing self-efficacy among civil engineering students.

In collaborative engineering activities, students often work in teams where they can learn from and emulate their peers, reinforcing their own confidence. Verbal persuasion, such as constructive feedback from instructors, further bolsters students' belief in their capabilities when paired with evidence of progress. [14].

Lastly, physiological and emotional states significantly impact self-efficacy, as highlighted in recent research from Corbi et al., [15]. Engineering students often experience heightened stress and anxiety due to the rigorous demands of their curriculum, which can negatively affect their confidence and performance [16]. A study by Olivera-Carhuaz *et al*., [17] emphasizes the role of anxiety, dysthymia, and negative affect in shaping academic self-efficacy, particularly among engineering students. The findings from the study underscore the need for pedagogical approaches that address these emotional challenges. Hands-on pedagogies, such as Experiment-Centric Pedagogy which help to mitigate these negative states by fostering an engaging and supportive learning environment where students feel empowered, motivated, and more in control of their learning process.

By framing this study within Social Cognitive Theory, the Experiment-Centric Pedagogy (ECP) aligns with the theoretical underpinnings of self-efficacy development. ECP provides students with mastery experiences through practical tasks, facilitates vicarious learning in team settings, incorporates verbal persuasion through instructor feedback, and reduces stress by making learning interactive and accessible. This shows the importance of ECP as an effective strategy for enhancing self-efficacy in civil engineering education.

Engineering learners' self-efficacy, according to research, is a predictor of their outcome expectations, interests, and goals. [18]. highlights the relationship between self-efficacy beliefs and performance attainments among first-year engineering students in programming courses, suggesting that higher self-efficacy directly correlates with better academic performance, reinforcing the importance of designing interventions that enhance self-efficacy to improve student outcomes across engineering disciplines. Self-efficacy is a result of effective learning experiences, not simply a path to success. High-achieving college learners had a greater self-efficacy score than low-achieving learners [4]. These findings complement the theory that four factors influence self-efficacy beliefs: past performance, peer models, social persuasion, and physiological arousal. The goal of ECP is to create an intervention that boosts engineering self-efficacy and achievement using developed learning activities. According to social cognitive theory, this strategy enhances student confidence, motivation, and academic outcomes. Mastery experiences resulting from active skill development and overcoming obstacles provide the most significant self-efficacy improvements.

The theory is classified into three factors: Personal, behavioral, and environmental, as illustrated in Figure 1.

1. Personal Factors - These encompass an individual's beliefs, self-efficacy, knowledge, expectations, objectives, and intentions. Personal factors significantly influence how learners perceive and engage with educational activities. Self-efficacy, a key human trait, drives motivation and perseverance, helping students navigate challenges and achieve goals.

2. Environmental Factors - External social and physical variables that shape behavior fall under environmental factors. These include the social environment, family, friends, culture, and media—and the physical environment, technology, and resources. These factors can reward, penalize, model, or enable specific behaviors, allowing students to immerse themselves in experimental settings like classrooms and laboratories.

3. Behavioral Factors - Behavioral factors refer to the actions students take in response to internal cognitive processes and external inputs. Behavioral capability involves the knowledge and skills required to perform an activity. Through active engagement in experiments, learners enhance their mastery, fostering greater competence and self-belief.

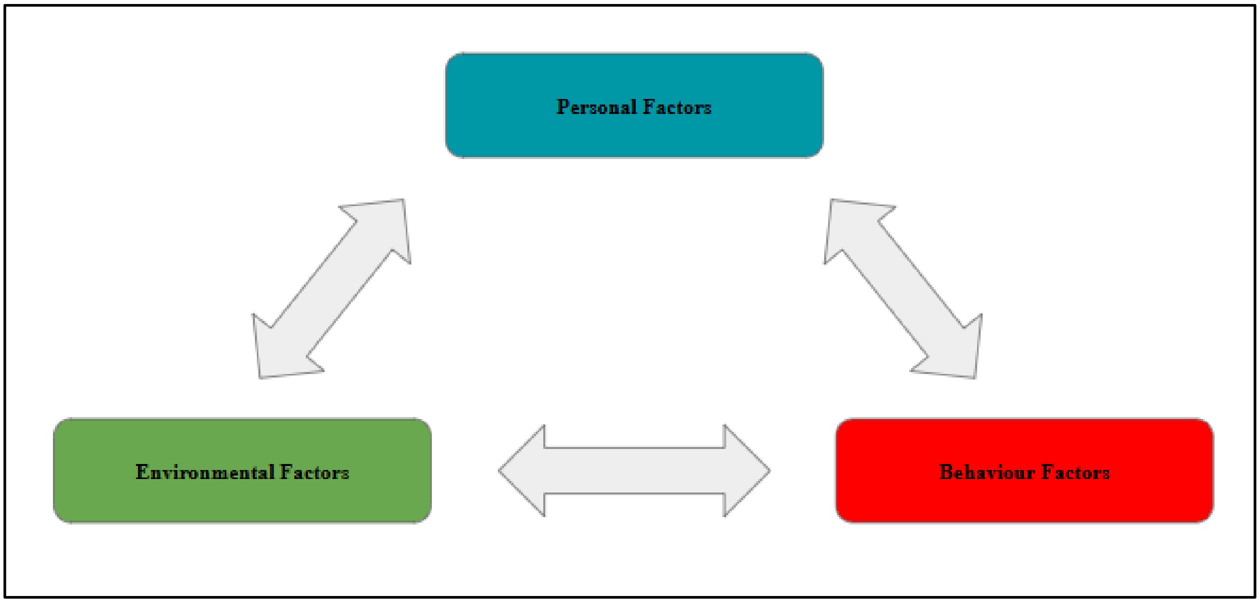


Figure 1: Social Cognitive Theory

These three factors collectively form a comprehensive framework for understanding how social cognitive theory informs self-efficacy development in engineering education.

Kolb's Experiential Learning Cycle

While Social Cognitive Theory explains the development of self-efficacy, Kolb's Experiential Learning Cycle (1984) provides a framework for understanding how students process and retain knowledge through experience-based learning. The theory is based on the principle that knowledge is created through the transformation of experience, which is particularly relevant in disciplines like civil engineering, where students must integrate theoretical knowledge with practical applications to succeed [19]. Kolb's model identifies four stages of the experiential learning process, each of which contributes to the development of skills and understanding [20]. These stages provide a pathway for learning that allows students to engage with material in a dynamic and comprehensive manner:

1**. Concrete Experience (Feeling)**: This stage involves direct engagement in a task, where students acquire hands-on knowledge by participating in real-world or simulated activities. Rather than passive learning through lectures, learners physically interact with materials, tools, and situations, creating rich sensory experiences. In civil engineering education, this stage may include tasks such as:

- Conducting laboratory experiments (e.g., stress analysis of beams or pH testing of solutions)
- Completing capstone projects, fieldwork, and on-site investigations
- Participating in simulations or hands-on demonstrations related to engineering design

These experiences provide opportunities for students to develop mastery over engineering concepts through active participation, which is one of the strongest sources of self-efficacy under Bandura's Social Cognitive Theory [21].

2. **Reflective Observation (Watching)**: After participating in a task, learners move to the stage of reflective observation, where they analyze and reflect on their experiences to identify key insights. Reflection allows learners to consider what worked, what did not, and what could be improved in future applications. During this stage, students connect their experiences to theoretical models or concepts [22]. In civil engineering education may include:

- Reviewing and analyzing laboratory results to draw conclusions about properties or behavior
- Writing reflective reports after experiments or fieldwork, documenting key observations and challenges

- Participating in post-experiment discussions or peer evaluations to compare and contrast outcomes.

This stage helps students build critical thinking and analytical skills, which are vital for problem-solving and decision-making in engineering tasks.

3. **Abstract Conceptualization (Thinking)**: In this stage, students synthesize their observations and experiences to develop or refine conceptual models. Learners begin to understand the theoretical foundations behind their experiences and apply general principles to explain the outcomes they observed. This stage bridges the gap between practical application and conceptual understanding.

For civil engineering students, this stage may involve:

- Applying theoretical formulas (e.g., Hooke's Law for material elasticity) to explain laboratory findings
- Studying structural models and relating them to real-world observations, such as deflection behavior under different loading conditions
- Formulating hypotheses or theoretical explanations for unexpected experimental results

By understanding the underlying mechanics and models, learners can transfer their knowledge to new and unfamiliar situations, which is essential for success in the dynamic field of engineering.

4. **Active Experimentation (Doing)**: This stage is characterized by the application of newly developed concepts in real-world situations. Learners experiment with their ideas and solutions, testing their hypotheses in a practical environment to see how they work in practice. This stage

helps learners solidify their knowledge and improve their problem-solving skills through trial and error.

In civil engineering, active experimentation may include:

- Conducting new experiments to validate hypotheses or explore alternative methods
- Testing theoretical calculations by designing and constructing models or prototypes
- Applying engineering concepts to solve real-world design problems in capstone or industry-sponsored projects.

These stages create a continuous learning cycle that enhances students' cognitive processing and application of engineering principles. The Experiment-Centric Pedagogy (ECP) aligns with Kolb’s Learning Styles in Civil Engineering Education

Integrating Learning Styles into Hands-On Pedagogy

The effectiveness of hands-on pedagogy in enhancing self-efficacy among civil engineering students can be further understood through the lens of Kolb’s Experiential Learning Theory (ELT). Kolb’s framework categorizes learners into four types: Accommodators, Assimilators, Convergers, and Divergers, each of whom processes information differently based on experience, reflection, conceptualization, and experimentation [23]. This classification is crucial in civil engineering education, where students engage in both theoretical and practical learning environments. Kolb’s model identifies four learning styles, which explain how learners prefer to interact with and process information. These styles are based on the combination of two key dimensions:

- Grasping Experience (Concrete vs. Abstract): Whether a learner prefers direct experience or conceptual learning.
- Transforming Experience (Active vs. Reflective): Whether a learner prefers active experimentation or reflective observation.

Kolb's model also classifies learners into four distinct learning styles, depending on how they prefer to process and interact with information:

- Accommodators (Concrete Experience + Active Experimentation): Thrive on hands-on activities and solving problems through trial and error. These learners benefit from fieldwork, laboratory experiments, and real-world problem-solving activities.
- Convergers (Abstract Conceptualization + Active Experimentation): Prefer practical applications of concepts and excel at finding solutions. Design projects and simulations appeal to these learners because they combine theory with action.
- Divergers (Concrete Experience + Reflective Observation): Prefer observing, brainstorming, and analyzing situations. These learners are best served through peer discussions, collaborative learning, and reflective exercises.
- Assimilators (Abstract Conceptualization + Reflective Observation): Prefer logical, structured learning that emphasizes abstract concepts. These learners benefit from theoretical explanations and structured laboratory reports, where they can analyze results with conceptual clarity.

In a civil engineering context, understanding these learning styles is critical for designing educational interventions that support learning diversity. The four learning styles identified in Kolb's model which are Accommodators, Assimilators, Convergers, and Divergers interacted differently with the hands-on pedagogical approach. Accommodators, who prefer active experimentation and hands-on experience, benefited the most from laboratory work and field projects, where they could engage directly with engineering concepts. Convergers, known for their problem-solving skills and preference for technical applications, responded well to simulation exercises and structural analysis tasks that required applying theoretical principles to solve engineering problems.

However, Assimilators, who thrive on structured, theory-driven learning, may have required additional conceptual scaffolding before engaging in hands-on tasks. This might mean that supplementing the hands-on approach with guided discussions or pre-laboratory conceptual sessions could enhance their learning experience. Similarly, Divergers, who excel in reflective observation and brainstorming, would have benefited from more structured post-experiment discussions or peer review exercises to strengthen their understanding. This shows the need for a more adaptive hands-on pedagogy that accommodates different cognitive processing styles among civil engineering students. By tailoring tasks to appeal to different learning styles, instructors can ensure that all students are engaged, motivated, and capable of succeeding, which is directly tied to improvements in self-efficacy and academic performance [24].

By integrating Kolb’s Learning Cycle into civil engineering education, this study highlights how hands-on pedagogy can accommodate different learning styles. The ECP approach fosters an inclusive learning environment, ensuring all learners engage with engineering concepts in ways that align with their cognitive preferences [13].

Methodology

This study was conducted at one of America's historically Black colleges and universities (HBCUs) using a quantitative pre-posttest single-group design. The implementation of Experiment-Centric Pedagogy (ECP) took place within the Civil Engineering department between 2021 and 2023. ECP was integrated into four courses: Statics (CEGR 202), Mechanics of Materials and Lab (CEGR 212), Structural Analysis I and Lab (CEGR 324), and Environmental Engineering I and Lab (CEGR 338).

These experiments aimed to enhance learners' mastery and self-efficacy through active participation, problem-solving, and the practical application of theoretical knowledge. By engaging in these hands-on experiments, learners actively participated in the learning process, collaborated with peers, and asked questions, creating a bridge between theoretical concepts and practical application. This approach helped students understand the real-world relevance of their coursework.

The courses combined lecture and laboratory components. Lectures covered fundamental design principles and applications of unit operations in environmental and structural engineering processes, including water, wastewater, air, solid waste treatment, beam deflection, equilibrium of forces, and remediation, as well as sustainability and watershed protection. Laboratory sessions involved applying concepts from general chemistry, mathematics, physics, and biology to analyze water and wastewater quality and evaluate beam deflection, cantilever properties, and salinity. Table 1 outlines the courses where ECP was implemented, and the corresponding number of students enrolled in each class.

According to Author, Figure 2 represents the organized module framework for putting ECP into practice. Using a four-step module development process, this framework offers a methodical way to create learning experiences that are both effective and captivating. Using a series of questions known as the signature assignment, which is given both before and after the experiment, the instructor first explains the experiment and evaluates the students' past knowledge. The experiment's results are then explained and illustrated. Throughout the procedure, students actively participate in the activity. In order to assess the students' comprehension of the experiment, the instructor then gives the same set of questions again.

Table 1: Implementation of Civil Engineering Courses

Semester (Year)	Course Code	Course Title	Frequency, N	Percentage, %
Fall (2021)	CEGR 324	Structural Analysis I & Lab	9	17.30
	CEGR 338	Environment Engineering I & Lab	8	15.38
Fall (2022)	CEGR 202	Statics	7	13.46
	CEGR 338	Environment Engineering I & Lab	8	15.38
Spring (2022)	CEGR 212	Mechanics of Materials and Lab	7	13.46
	CEGR 338	Environment Engineering I & Lab	7	13.46
Spring (2023)	CEGR 338	Environment Engineering I & Lab	6	11.54
		Total Students	52	100%

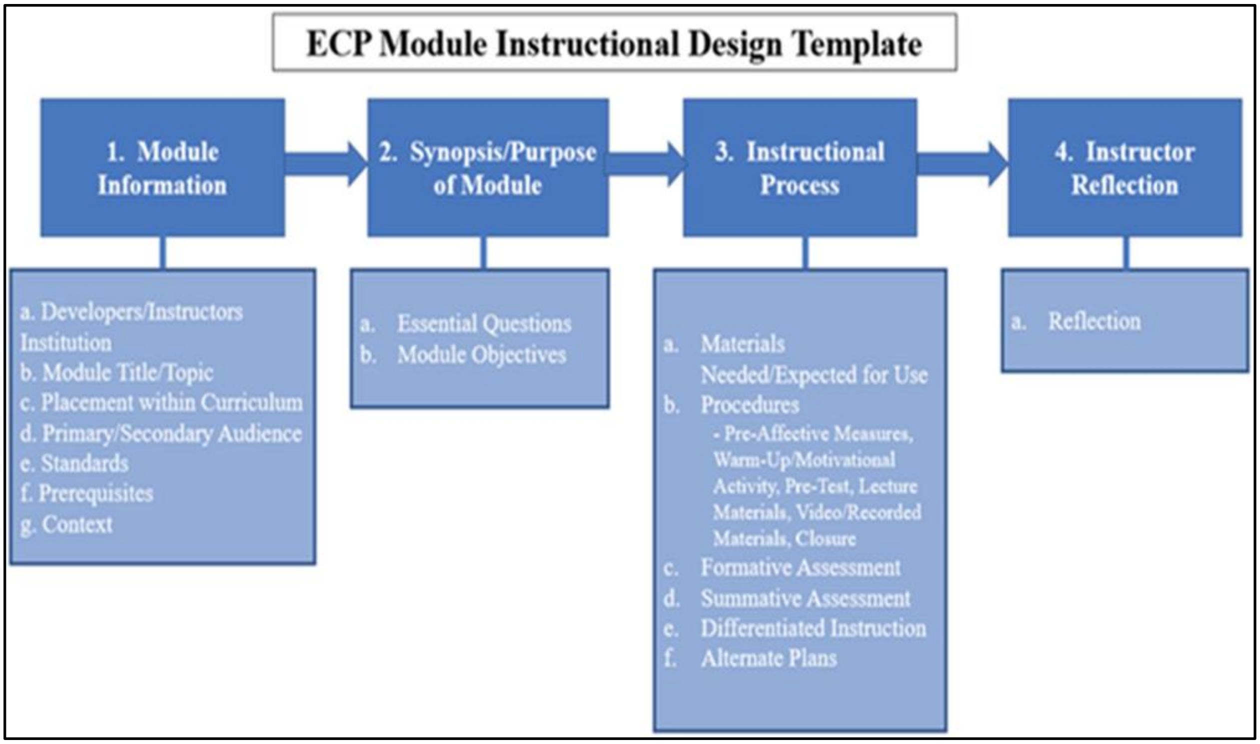


Figure 2: ECP Design Template

Experiment Conducted:

pH

This experiment was conducted in CEGR 338. Learners used an analog pH meter, buffer solution, and ALICE throughout the lab session. A pH meter has a special probe capped with a membrane sensitive to hydrogen ions. Before the commencement of the experiment, instructors introduced learners to basic pH concepts such as buffer solutions, acidity, and basicity to help them understand the experiment. The acidity and basicity of a solution are indicated by its pH value, which ranges from 0 to 14. An acidic solution has a value between 0 and 7, whereas a basic solution has a value between 7 and 14. This means that the higher the pH value, the more basic the solution, and the lower the pH value, the more acidic the solution. For example, deionized water is considered a neutral solution because its pH is precisely 7. The ALICE voltmeter software reads the corresponding potential difference of the control pH buffer standards (4, 7, 10) and other solutions being tested. A graph is plotted using the values from the known buffer standards by plotting voltage against pH buffer. The equation of the straight line derived from the graph is then used to determine the pH of an initially unknown solution when the probe is used to measure the voltage. Learners are expected to test various home-based solvents (See Figure 3).

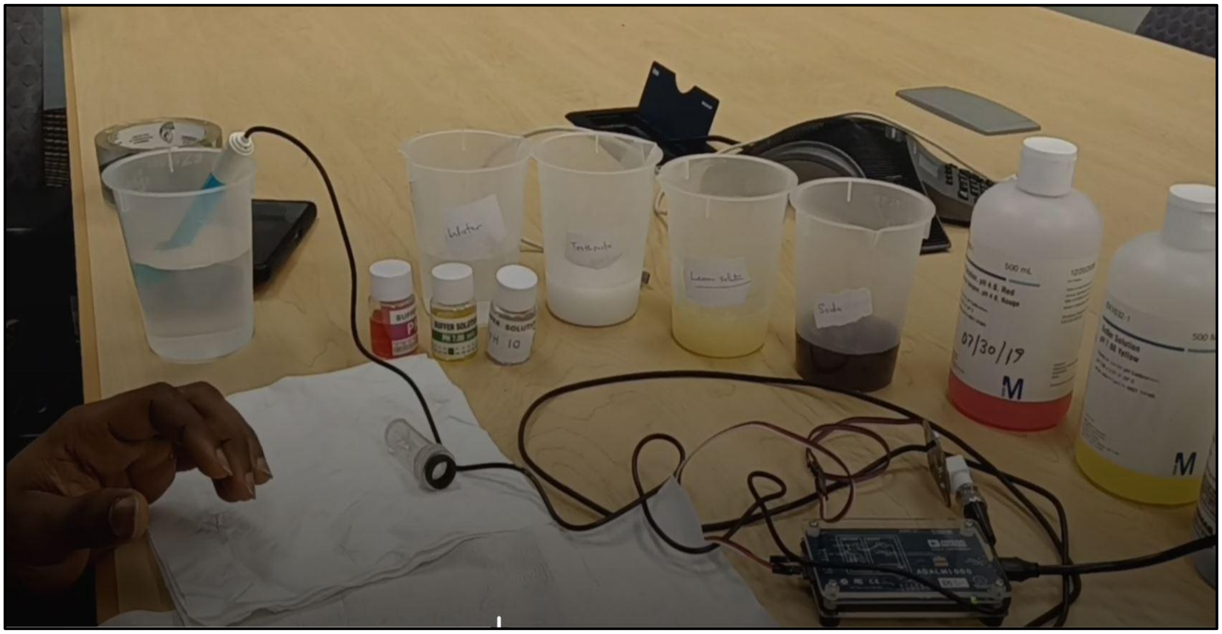


Figure 3: Experimental setup during pH

Stress Induced in a Cantilever Beam

This experiment was conducted in CEGR 202. Learners used an ADALM 1000, a strain gauge, a dial gauge, weights, and a cantilever beam throughout the lab session. A cantilever beam is a structural member fixed at one end while free at the other, commonly subjected to various types of loading. This experiment focused on analyzing the stress induced in a cantilever beam under applied forces and validating theoretical calculations. Before the commencement of the experiment, instructors explained key concepts such as tension, compression, strain, and deflection to familiarize learners with the procedure. Stress and strain were introduced as fundamental mechanical properties, with stress defined as the internal force per unit area and strain as the deformation per unit length caused by stress. During the experiment, the cantilever beam was loaded at its free end, and the resulting strain was measured using a strain gauge connected to the ALICE software. The software displayed voltage readings corresponding to the strain induced by the applied force. A dial gauge measured the deflection at the free end. Learners recorded the readings for various loads and plotted graphs to establish relationships between stress, strain, and deflection.

Figure 4: Experimental setup of a student carrying out stress induced in a cantilever.

The results were analyzed by deriving the equation of the line from the stress-strain curve and comparing it with theoretical values. This allowed learners to validate the mechanical behavior of the beam under stress. Learners also tested different materials and recorded variations in stress-strain relationships. The hands-on activity enabled learners to directly observe the behavior of structural elements under load, bridging the gap between theory and practice. This approach allowed them to develop critical thinking and problem-solving skills in structural analysis. Figure 4 shows the experimental setup and key devices used.

Modulus of Elasticity of a Steel Beam

This experiment was conducted in CEGR 324. Learners used a steel beam, weights, and dial gauge, throughout the session. The modulus of elasticity, also known as Young's modulus, measures a material's ability to resist deformation under stress. It is calculated as the ratio of stress to strain within the elastic limit of the material. Before starting the experiment, instructors provided an overview of elasticity, Hooke's Law, and the stress-strain relationship, ensuring learners understood the theoretical basis for calculating the modulus of elasticity. During the experiment, learners applied incremental loads to the steel beam while measuring the resulting deflection using a dial gauge. The strain gauge connected to the beam measured strain, while stress was calculated based on the applied load and the beam's cross-sectional area. The readings from the strain gauge were recorded using ALICE software, which converted voltage signals into strain values. Learners plotted stress versus strain and derived the slope of the linear region of the graph to calculate the modulus of elasticity. By comparing their results with theoretical values, they gained insights into the material's behavior under loading conditions.

This hands-on activity reinforced learners' understanding of material properties, enabling them to apply theoretical principles to practical scenarios. Figure 5 depicts the experimental setup.

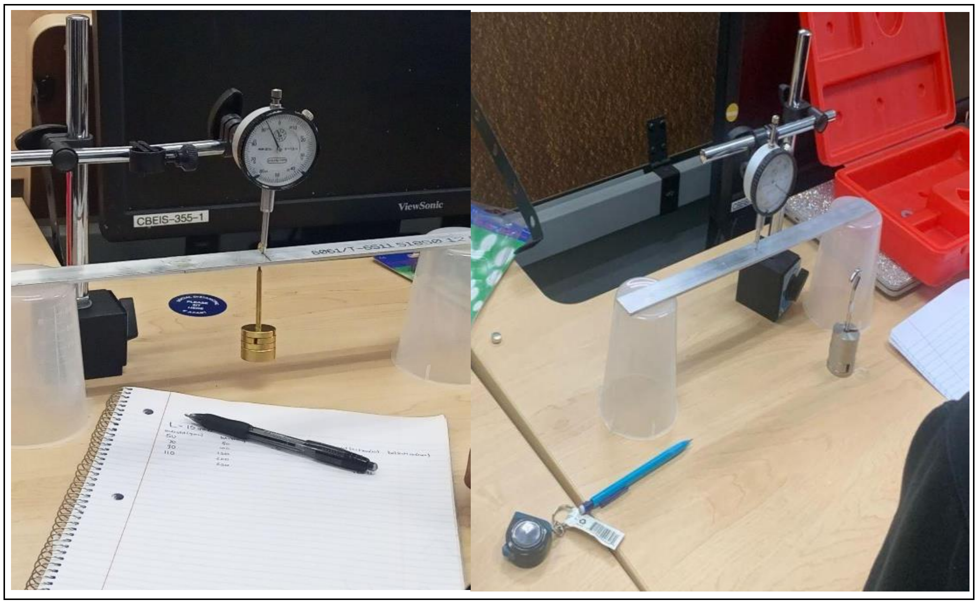


Figure 5: Experimental setup of Modulus of Elasticity of a Steel Beam

Total Dissolved Solids (TDS) and Hardness of Water Experiment

This experiment was conducted in CEGR 338. Throughout the Lab session, the learner utilized a TDS/Conductivity probe (sensor), Arduino board, calibration solutions, and water samples. Total dissolved solids (TDS) measure the concentration of dissolved substances in water, while water hardness indicates the presence of calcium and magnesium ions. Instructors introduced learners to the concepts of water quality analysis, explaining how TDS and hardness impact environmental and human health. During the experiment, learners calibrated the TDS sensor using standard solutions of known concentrations. They then measured TDS and hardness for various water samples by immersing the sensor into each solution. The Arduino board recorded the sensor's voltage output, which was converted into concentration values. Learners plotted the calibration curve and analyzed the results to assess water quality. By comparing the TDS and hardness values of different samples, they identified trends and discussed potential environmental implications.

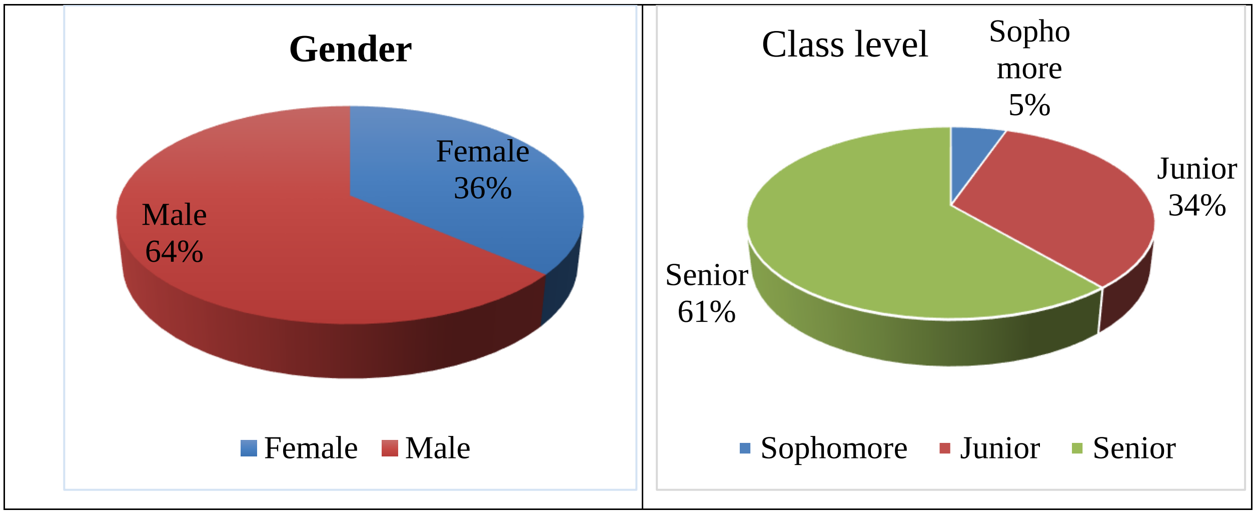
This hands-on experience provided learners with practical skills in water quality assessment, preparing them for roles in environmental engineering. Figure 6 shows the TDS sensor setup.

Data Collection

This study made use of the Motivated Strategies for Learning Questionnaire (MSLQ), which has been validated [25]. Before and after the experiment, 68 students completed the questionnaire administered electronically but 52 students were used after cleaning the dataset. The MSLQ uses a 7-point Likert scale to assess important learning and motivational elements, such as the self-efficacy of the student. In this study, the construct on Learners' self-efficacy was particularly represented using the EC concept. This subscale consists of three 7-point Likert scale items: "I believe I will receive an excellent grade in this class," "I'm confident I can do an excellent job on the assignments and tests in this course," and "I expect to do well in this class." Responses were collected, cleaned, and analyzed using the Statistical Package for the Social Sciences (SPSS IBM v27).

Data Analysis

Assessing the normality of data is a crucial step before conducting any statistical analysis [26]. The data collected was subjected to a normality test to ensure the proper statistical approach was adopted afterwards. Shapiro-Wilk test (W) was used to assess whether the dataset follows a normal distribution. W is known for its reliability and power in detecting departures from normality, especially in small to moderate-sized samples [27]. The normality was conducted at a confidence level of 95.0%. Box plots used for visualizing the data distribution. The Wilcoxon Signed-Rank test, a non-parametric t-paired test was used to determine the inferential statistics on the pre-posttest at 95% significance level.



(a) (b)

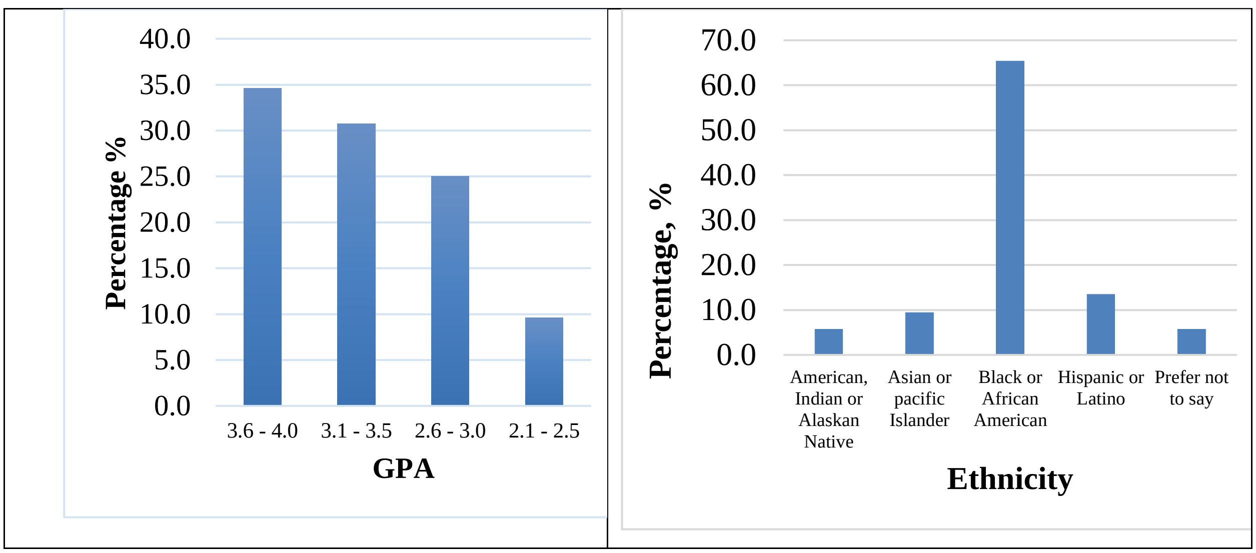


Figure 6 (a - d): The charts of the socio-demographic distribution of the study. (a) is the gender; (b) Class level of the participants; (c) grade point average (GPA) of the students; (d) their ethnicity.

The socio-demographic characteristics of participants are summarized in Figure 6 (a-d). All of participants were in Civil Engineering (100%). The GPA distribution showed that 34.6% of participants had a GPA between 3.6 and 4.0, 30.8% had a GPA between 3.1 and 3.5, 25.0% had a GPA between 2.6 and 3.0, and 9.6% had a GPA between 2.1 and 2.5. In terms of gender, 36.5%

of the participants were female, and 63.5% were male. The class levels of the participants were predominantly seniors (67.3%), followed by juniors (36.9%) and sophomores (5.8%). The ethnic composition of the sample included Black or African American (65.4%), Hispanic or Latino (13.5%), Asian or Pacific Islander (9.5%), American Indian or Alaskan Native (5.8%), and those who preferred not to say (5.8%).

Normality Test & Distribution for Self-Efficacy Domains

Table 3: Normality Test for Pre & Post-Test Efficacy

Self-Efficacy Domains	W	df	p
Pre-test (IGO, TV, EC, TA, CT, MC, PLC)	0.981	52	0.554
Post-test (IGO, TV, EC, TA, CT, MC, PLC)	0.914	52	0.001

W = Shapiro-Wilk Test Statistics, IGO: Intrinsic Goal Orientation, TV: Task Value, EC: Expectancy Component, TA: Test Anxiety, CT: Critical Thinking, MC: Metacognition, PLC: Peer Learning/Collaborating, IEC: Interest Epistemic Curiosity, DEC: Deprivation Epistemic Curiosity

The normality of test scores (pre and post) was assessed. A Shapiro-Wilk Test showed that the pre-test scores were normally distributed W (53) = 0.981, p = 0.554. Whereas a significant departure from normality was observed in the post-test scores, W (53) = 0.914, p = 0.001. This suggests that non-parametric statistics like the Wilcoxon Signed Rank Test would be suitable for further analysis. See Table 3

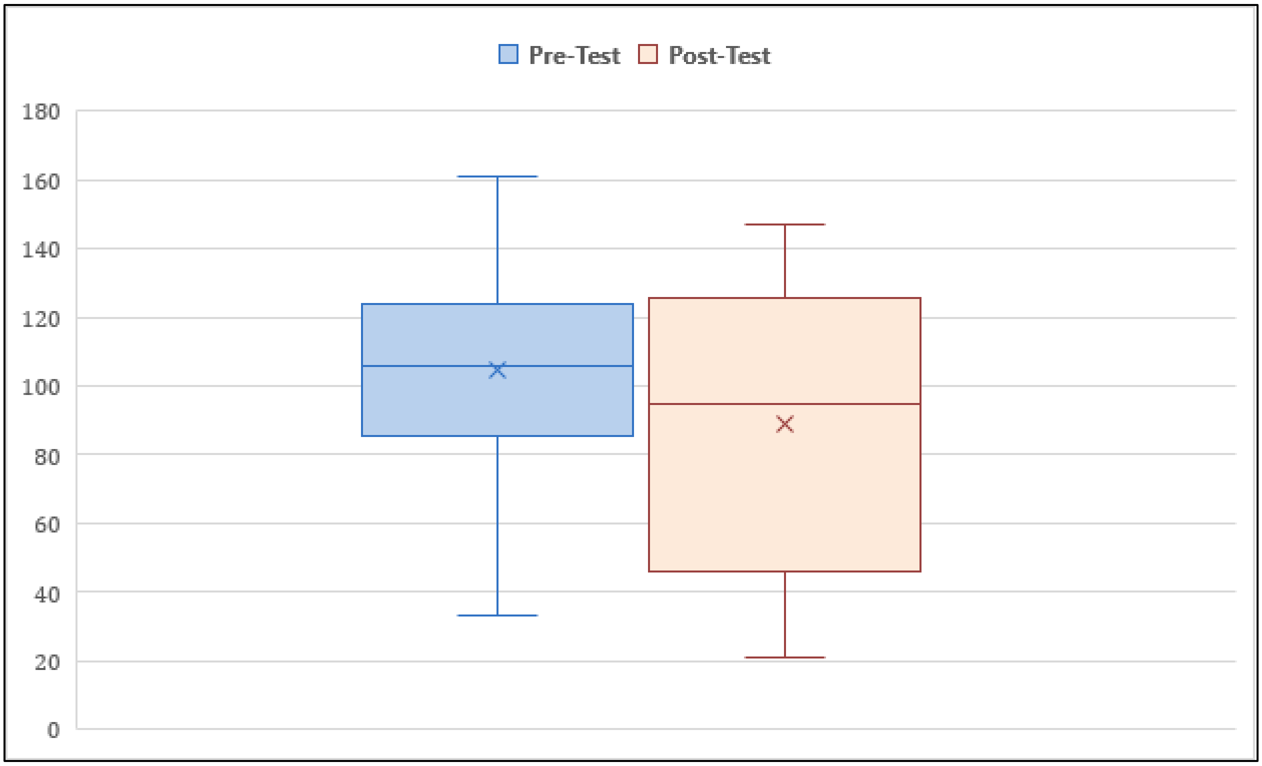


Figure 7: Box-plot Diagram showing Distribution of Pre & Post Test Self-efficacy Domain

Figure 7 provides a visual summary of the pre-test and post-test scores. The pre-test, the median score is slightly above the mean score, which is the middle value of the pretest dataset. The "X" mark indicates the mean score, which is slightly below the median, suggesting a slight skew in the data. Also, the post-test boxplot illustrates the distribution of self-efficacy scores after the intervention. Like the pre-test, the median score is slightly above the mean score, suggesting a slight skew in the data.

Table 4: Wilcoxon Signed-Rank Test (N = 52)

Pair Comparison	MR -ve	SR -ve	MR +ve	SR +ve	Z	*p*
Intrinsic Goal Orientation	24.48	661.0	19.35	329.0	-1.939	0.052
Task Value	23.62	803.0	12.50	100.0	-4.401	0.000
Expectancy Component	18.41	405.0	17.31	225.0	-1.476	0.140
Test Anxiety	20.32	345.5	23.10	600.0	-1.541	0.123
Critical Thinking	31.03	589.5	17.13	445.5	-0.814	0.416
Metacognition	24.60	738.0	18.00	252.0	-2.838	0.005
Peer Learning/Collaborating	24.70	617.5	16.79	285.5	-2.079	0.038
Interest Epistemic Curiosity	16.09	354.0	4.80	24.0	-3.970	0.000
Deprivation Epistemic Curiosity	8.50	17.0	7.33	88.0	-2.279	0.023

Sample size (N), Mean Rank Negative (MR -ve), Mean Rank Positive (MR +ve), Sum of Mean Ranks Negative (SR -ve), Sum of Mean Rank Positive (SR +ve), Z - score (Z), and Significance (p)

The Wilcoxon Signed-Rank Test was conducted to determine whether there were significant differences between pre-test and post-test scores across multiple pairs. The results are summarized in Table 4. The results suggest that there were significant differences in the paired variables for Task Value (Z = -4.401, *p* = 0.000), Metacognition (Z = -2.838, *p* = 0.005), Peer Learning/Collaborating (Z = -2.838, *p* = 0.038), and Interest Epistemic Curiosity (Z = -3.970, *p* = 0.000), and Deprivation Epistemic Curiosity pair (Z = -2.27, *p* = 0.023). No significant differences were found for Intrinsic Goal Orientation (Z = -1.939, *p* = 0.052), Expectancy Component (Z = -

1.476, *p* = 0.140), Test Anxiety (Z = -1.541, *p* = 0.123), and Critical Thinking pairs (Z = -0.814, *p* = 0.416). A negative Z-score indicates a decrease in the post-test after the intervention was administered.

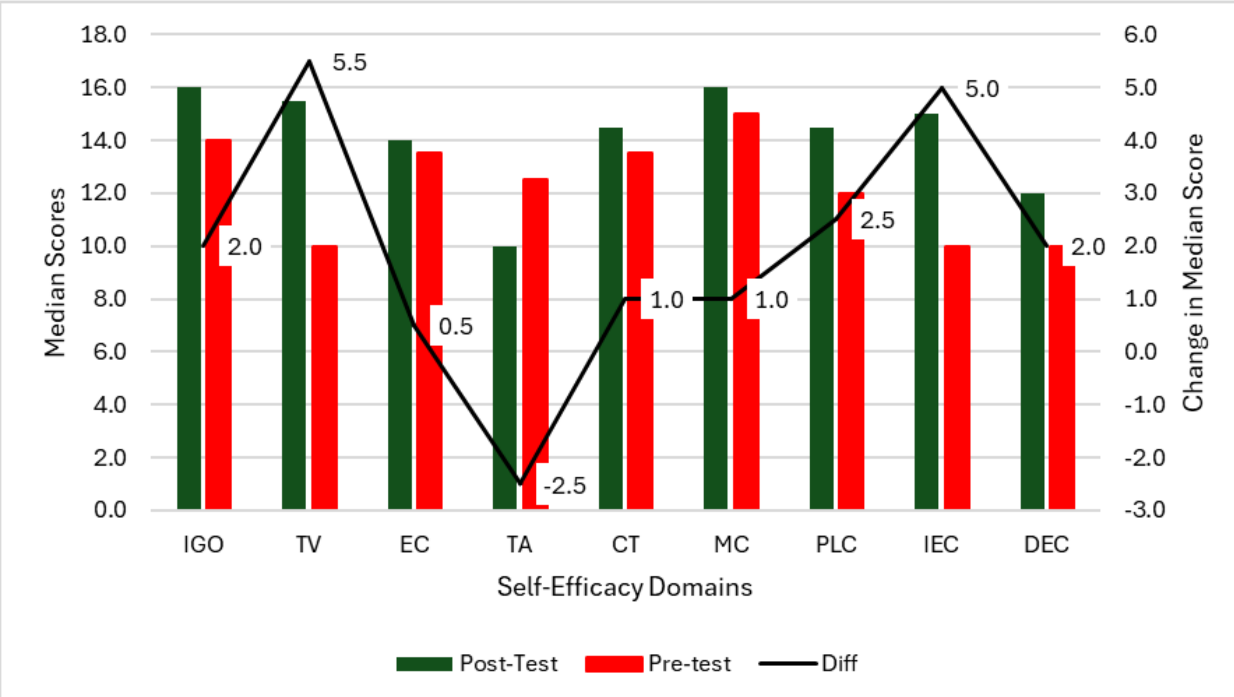


Figure 8: Comparison of Pre-Test and Post-Test Median Scores Across Self-Efficacy Domains

Figure 8 shows a bar chart comparing pre-test and post-test median scores across various self-efficacy domains, with a line graph indicating the difference in median scores between the pre-test and post-test. The self-efficacy domains are labelled as IGO, TV, EC, TA, CT, MC, PLC, IEC, and DEC. The y-axis on the left represents the median scores, while the y-axis on the right represents the change in median scores. The pre-test scores are represented by blue bars, the post-test scores by orange bars, and the differences by a green line.

The chart visually demonstrates the changes in self-efficacy across different domains before and after an intervention or period of time, highlighting areas of improvement or decline.

Table 5: Spearman's Rho Correlation Coefficients Among Current GPA, Class Level, Pre-Test Efficacy, and Post-Test Efficacy

Spearman's rho		Current GPA	Class level	Pre-test Efficacy	Post-test Efficacy
Current GPA	Correlation Coefficient	--			
	Sig. (2-tailed)				
	N	52			
Class level	Correlation Coefficient	0.235	--		
	Sig. (2-tailed)	0.093			
	N	52	52		
Pre-test Efficacy	Correlation Coefficient	-0.084	-0.082	--	
	Sig. (2-tailed)	0.554	0.565		
	N	52	52	52	
Post-test Efficacy	Correlation Coefficient	0.013	.352*	0.058	--
	Sig. (2-tailed)	0.928	0.010	0.684	
	N	52	52	52	52

*. *Correlation is significant at the 0.05 level (2-tailed).*

A Spearman's rho correlation analysis was conducted to examine the relationships between current GPA, class level, pre-test efficacy, and post-test efficacy. The results are summarized in Table 5. The findings suggest that class level is significantly correlated with post-test efficacy ($r_s = 0.352$, $p = 0.010$), while other correlations were not statistically significant.

Discussion

This study highlights the characteristics of the student body, which was drawn from a historically Black university. Table 1 reveals that 65.4% of the participants identified as Black or African American. This aligns with the mission of historically Black colleges and universities (HBCUs) to provide educational opportunities for underrepresented groups, although it may limit the broader applicability of the findings to the larger engineering community. [13] The results of this study highlight the significant role of hands-on pedagogical approaches in improving self-efficacy among civil engineering undergraduates. Conducted at a historically Black university, the study also sheds light on the unique traits of the selected student body, including their resilience, collaborative tendencies, and adaptive learning capabilities. Pre-test and post-test analyses, conducted across multiple domains of self-efficacy, reveal meaningful improvements following the implementation of the Experiment-Centric Pedagogy (ECP).

While the MSLQ provided valuable insights into changes in self-efficacy, its sole reliance on self-report presents a limitation in capturing actual skill acquisition. Self-efficacy is closely linked to perceived competence, but the study did not incorporate performance-based measures to verify whether students' increased confidence translated into improved engineering skills. Different learning styles may have experienced self-efficacy gains in ways that the MSLQ did not fully capture. For example, Accommodators and Convergers, who benefit most from hands-on and problem-solving experiences, likely found the experiential approach directly reinforcing. However, Assimilators and Divergers, who rely more on conceptual understanding and reflection, may not have experienced the same self-efficacy gains without additional structured reflection or theoretical reinforcement.

The central tenet of Bandura's self-efficacy theory is that by exhibiting personal capability, mastery experiences increase efficacy beliefs. In this study, the self-efficacy scores from the pre-test to the post-test aligns with this theory, highlighting the value of hands-on activities in creating meaningful mastery experiences. However, unexpected declines in certain post-test scores suggest complex dynamics at play. According to qualitative research, students' engineering self-efficacy is increased through active learning when they are able to apply concepts in meaningful ways [14].

But without a control group, it is impossible to identify changes solely to educational intervention. The effects of experiment-centric pedagogy could be better understood by using control groups.

One plausible explanation is the students' reliance on external aids, such as search engines, during the pre-test phase, which may have artificially inflated their initial scores. This reliance highlights a potential gap in critical thinking and authentic engagement when students complete surveys independently. Furthermore, feedback collected from participants indicated that the post-test, perceived as unrelated to their grades, lacked the motivational significance needed to ensure thoughtful and reflective responses. As a result, some students may have filled out the post-test hastily, leading to less accurate representations of their actual capabilities.

Other parameters, such as performance across criteria like Task value, Metacognition, and Peer learning, also provided valuable insights. Task value scores exhibited variability, indicating inconsistencies in how students connected hands-on activities to their overall learning goals. Metacognition scores revealed a lack of internalized strategies for reflective learning, while the decline in Peer learning scores suggested insufficient emphasis on structured peer interactions during the intervention.

Given that mastery experiences often accumulate over time, the positive correlation between pre-test self-efficacy and advanced class levels observed in this study aligns with Bandura's framework. Students with more exposure to hands-on tasks may have already developed stronger efficacy beliefs. Interestingly, subgroup analysis showed higher increases in efficacy among females, which aligns with prior research suggesting that active learning methods help reduce gender disparities in engineering fields. However, the small sample size limits the generalizability of these findings.

The findings suggest that a one-size-fits-all hands-on approach may not fully optimize self-efficacy gains for all learning styles. While experiential learning effectively reinforced self-efficacy for students who thrive on active experimentation, others may benefit from additional reflective or conceptual reinforcement. To ensure that all civil engineering students experience meaningful self-efficacy gains, future studies should explore other models that combine hands-on activities with structured reflection, theoretical discussions, and peer engagement.

The large effect observed (d=1.03) underscores the high practical significance of this intervention. Nevertheless, the reliance on self-report measures introduces potential biases. Incorporating objective competence measures and long-term monitoring in future studies that incorporate other self-efficacy alternatives, such as task-based performance evaluation, peer feedback mechanisms and structured reflection by the student could provide a more robust evaluation of the intervention's impact. This preliminary research offers a promising foundation for understanding the nuanced effects of hands-on pedagogical methods on engineering self-efficacy.

Conclusion

This study demonstrates the effectiveness of hands-on pedagogical approaches, specifically the Experiment-Centric Pedagogy (ECP), in enhancing self-efficacy among civil engineering undergraduates. By actively engaging students through projects, laboratory exercises, and fieldwork, ECP has proven to significantly improve key self-efficacy domains, including Task Value, Metacognition, and Peer Learning/Collaborating.

The findings underscore Bandura's social cognitive theory, which shows the critical role of experiential learning in fostering confidence, technical skills, and collaborative abilities in engineering education. Active participation in engineering practices tends to equip transportation engineering students with confidence-building skills and vicarious learning possibilities. Obtaining data, using hands-on tools, and working on complicated tasks provided students with tangible evidence of their growing skill [19]. These improvements are not only vital for students' academic success but also essential for preparing competent and confident engineers capable of addressing real-world challenges.

However, the study also highlights areas for further exploration, particularly in addressing intrinsic motivational factors and test-related anxieties. Future research should focus on integrating complementary pedagogical strategies, such as mindfulness training or structured peer mentoring, to further enhance the holistic development of engineering students. Finally, this research reaffirms the need for a paradigm shift in engineering education, one that prioritizes hands-on, student-centered learning approaches to cultivate both competence and confidence in future civil engineers.

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