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Engaging University Students in Practical Physics Labs through Motivational Active Learning

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Abstract

The COVID-19 pandemic had a significant impact on student's motivation to learn. As a result, the in-person laboratory session evolved into a virtual laboratory session. Despite this effort, many students struggled with the home front effects, such as communication gaps, digital literacy issues, unfavorable home environments, parental participation, etc. This led to the adoption of an enhanced motivation strategy to lessen the consequences of the pandemic on students in the science, technology, engineering, and mathematics (STEM) fields of study. As such, several studies used software tools like machine learning, the Internet of Things (IoT), technology-enabled active learning (TEAL), and other methods to improve students' motivation. These approaches could limit students from acquiring hands-on skills, which lowers their technical proficiency—a vital skill for STEM students. However, only a few studies have used Active Learning Pedagogical tools to improve student learning in practical physics labs, especially in historically black colleges and universities (HBCUs). Also, the difficulty undergraduate students have in making connections between their theory teachings and their practical exercises, as well as how pertinent these lab sessions are to their everyday lives, has led to the conclusion that physics experiments are highly abstract. This study used low-cost, interactive, code-free, portable technology to improve students' practical experiences and report how these experiments are applied in everyday activities. The study involved 50 STEM students registered for the Introduction to physics laboratory course. According to the students' feedback and the motivated strategy for learning questionnaires adopted, they were very motivated and had less anxiety with enhanced critical thinking.

Introduction

Educators are saddled with the responsibility of ensuring every learning objective is met while creating an engaging student environment [1]. Educators must ensure that every experiment is designed with practical applications in mind and implemented in a safe environment. This aids the instructors in facilitating critical thinking amongst the learners, ensuring that they can proffer solutions to essential questions. These guides and resources are models that support progressive learning and peer-to-peer collaborations. Also, they can foster an inclusive learning atmosphere and encourage continuous improvement. Laboratory sessions are an integral part of the rich learning experience that every university student must encounter while interfacing with several topics in the field of physics [2]. The role of physical laboratories is simply to cultivate students' technical skills and improve their scientific thinking towards the course in the subject. It helps enhance their understanding and heightens their motivation for the fundamental concepts. It is, therefore, important that the appropriate technologies are employed during these laboratory sessions.

Active learning is one of the recent approaches that educators have adopted to increase student motivation [3]. It is the use of different instructional techniques that increases the level of student engagement and interaction during their learning sessions. This pedagogy focuses on the student, rather on the instructor as the case with the traditional form of leraning [4]. This has brought a significant improvement during the learning process of many students. Active learning is a pedagogical tool that has helped promote ‘students’ cognitive capabilities when it comes to mastery of the content [5]. Meaningful conversations, proper reflection, and content mastery are products of this learning mode [6].

Experiment-centric-pedagogy (ECP), an instructional technique that facilitates activite learning, offers an alternate route for acquiring technical skills and information both inside and outside of the classroom. ECP enabls students with different learning styles to learn at their own pace and in their own settings. Instructors participating in the above initiative have also used a similar approach to promote experiential learning in classes where their objective is to acquaint students with general STEM ideas. ECP has become an effective educational method that provides a tangible experience for students and causes a significant rise in their motivation [7]. Studies have demonstrated that implementing an experiment-centric teaching style can enhance students’ academic performance and cultivate more positive attitudes towards learning [8]. Additionally, learning from experiment modules assists in simplifying and making difficult ideas more approachable for students, boosting their self-assurance and enthusiasm to study more [9]. Under the broad category of experiential education, ECP has been viewed as an Active Learning approach.

There will be remarkable changes in the landscape of physics education as more settings embrace best practices, such as the paradigm shift from the teacher-centered model to the learner-centered approach. The use of learning environments which have a high quality of research and interactions have been pivotal to these transitions [10]. However, interactive engagement environments have proven to be quite complex due to various factors such as the interpersonal dynamics between the instructors and students [11]. The resistance of students towards active learning in physics classrooms is a topic that has been discussed with the use of employing a framework [12]. There could be diverse reasons that could cause such friction from varied experiences and expectations.

However, there is a pedagogical tool which transends the complexity of various technologies to achieve active classroom learning. This is known as inexpensive hands-on electronic instrumentation, which is more straightforward to use and keeps students’ curiosity levels elevated during the learning process. The physics topics are organized so that each experiment has a customized instrumentation to achieve the required learning goals.

Purpose of the paper

This paper addresses an essential gap in the literature regarding the implementation of active learning pedagogy (ALP) at historically black colleges and universities, HBCUs, specifically around physics education and home front utilization of inexpensive analog instruments for learning. There is insufficient research evidence about both the implementation and the impact of ALP in HBCUs, despite having noted that it is increasingly being recognized as an instructional method that promotes student engagement and learning outcomes in various educational contexts. This study aims to demonstrate how experimental-centric pedagogy addresses this shortcoming.

Furthermore, the paper aims to investigate the potential value of Experiment Centric Pedagogy (ECP) in raising student motivation and engagement for STEM learning in HBCU environments. With a concentration on active involvement and hands-on experimentation, the study looks at answering how ECP is used to help students learn in a supportive and ideal environment within the unique academic setting of HBCUs [13]. This paper subsequently, attempts to advance pedagogical strategies that address the specific demands and difficulties of physics education in HBCUs through an in-depth evaluation of ALP and ECP practices to enhance the educational experiences and results of students in STEM fields.

Literature Review

In a survey by Brawner et al., [14] on teaching practices and involvement in faculty development activities, it was noted that sixty percent (60%) of participating engineering professors said they used active learning in some capacity in their instruction. One of the study's major findings was that assigning students into small groups to solve problems collaboratively does not automatically solve the larger issue of student motivation.

Even though active learning is a valuable teaching strategy, it is important to understand that instructing students well involves addressing a variety of motivational styles [15]. The complexity of student motivation, which encompasses intrinsic, social, achievement, and instrumental elements, may be excessive for active learning tactics alone. Teachers must consider these motivating factors to establish an environment for learning where learners are genuinely motivated and engaged.

Motivation is divided into four main categories by Biggs and Moore [15]:
1. Intrinsic Motivation: Learning motivated by an innate curiosity or sincere interest in the task is known as intrinsic motivation. Learners are driven by a natural curiosity to learn about and comprehend the material.
2. Social Motivation: In this category students discover how to please their peers or the instructor. . Their engagement is motivated by other people's acknowledgment and approbation.

3. Achievement Motivation: The primary motivating factor behind achievement motivation is the desire to improve ’”” ’one’s performance better thanothers during the learning process. The urge to perform better than peers can drive ”””’students’ motivation.

4. Instrumental Motivation: Seeking rewards outside of the immediate activity is a key component of learning for instrumental motivation. This can be aiming for higher grades, seeking a well-paying job more frequently, or receiving other additional benefits.

Figure 1 [16] illustrates the concept of engagement as a complex interplay between social contexts and individual experiences. Engagement is portrayed as a consequence and a predictor of significant academic, social, and emotional outcomes. In this conceptualization, engagement becomes a crucial factor influencing the causal relationships between students’ individual experiences and their behaviors in school and beyond [17].

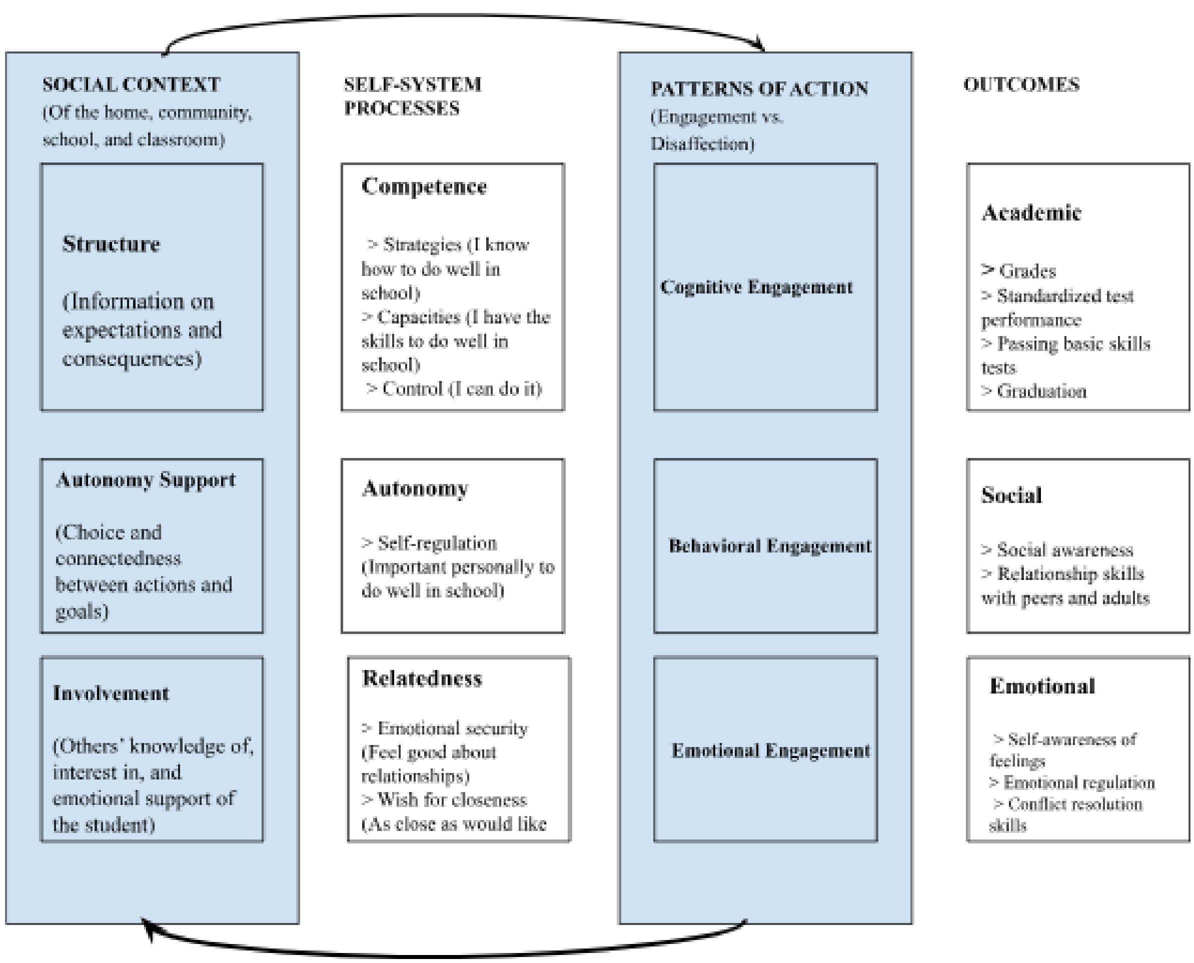

Figure 1: The Various Aspects of Student Engagement [16]

As opined by Bandura [18], one activity cannot fully address the complex chain of the cognitive processes that make up motivation. Self-efficacy, or the conviction that one can bring about positive results through one's own decision-making is a key motivator [19]. Self-efficacy affects people's effort levels and their ability to endure in the face of adversity. Active learning pedagogies are known to put the students in learning environments that tends to serve as either a challenge to overcome or tasks to achieve in support of learning to meet the objectives set by instructors. According to [20], educators must use tactics that increase effectiveness. As a result, to fully engage the students in active learning, they must be given or included in pertinent tasks that can build their skills and self-confidence.

The findings from the study of the impact of curiosity and external regulation on intrinsic motivation highlight a strong correlation between intrinsic motivation and curiosity [21], thus aligning with the earlier research by Shroof et al. [22], which identified a positive relationship between intrinsic drive and curiosity as one of the six components studied. Increasing curiosity raises intrinsic motivation, enhancing pupils' learning and academic achievement. Furthermore, according to Litman [23], learning out of curiosity is thought to be inherently satisfying and extremely enjoyable because it dispels ignorance and ambiguity,.

Methodology

The study was conducted in one of the nation's historically black colleges and universities with the goal of enhancing the learning approach of undergraduates in physics education by means of experiment-centered pedagogy. This study employed a pre-and-post-test design in two foundation classes that was purposely selected. The research focused on two basic experiments: Simple Pendulum and Hooke's Law.

Simple Pendulum Experiment

The study uses a simple experimental kit with a pendulum bob, retort stand with clamp, string, and portable timer. It is meant for students to easily assemble and execute in a variety of contexts. With theis equipment's help, students could conduct a hands-on inquiry into the pendulum oscillation periods at different string lengths and determine the acceleration caused by gravity. Compared with the traditional method that depends on digital timing and sensor technologies for data capture, the study stressed accuracy in measurement and data collection, therefore recommending repeated experiments to reduce timing errors and strengthen data reliability.

The approach used in the experiment comprised hanging a pendulum bob from a pre-measured length of thread (Figure 2). A ruler was used to measure the string's length, and to provide stability, the free end was secured firmly with a cork to a retort stand. The pendulum's time to complete ten oscillations was measured and recorded as t_1 to determine the oscillation period. Replicating this process yielded a second time measurement, t2, and the goal was to minimize timing errors by repetition. The oscillation period was subsequently calculated by taking the average of these readings.

After the data collection, an analysis was carried out by plotting the square of the period versus the length of the string. This visual depiction made the estimation of the acceleration resulting from gravity pulling on the bob less complex. Equations such as these were used to evaluate the experiment results by analyzing the gradient of the graph to determine the link between these variables. Using this method, the gravitational acceleration could be measured quantitatively, demonstrating how the pendulum's length affected its oscillatory oscillation.

The equations are stated below:

$$T = \frac{t_{avg}}{n} \tag{1}$$

$$T = 2\pi\sqrt{\frac{l}{g}} \tag{2}$$

$$T^2 = 4\pi^2\frac{l}{g} \tag{3}$$

$$g = 4\pi^2\frac{l}{T^2} \tag{4}$$

where T is the oscillation period, t_{avg} is the average oscillation duration, l is the length of the string, n is the number of oscillations, and g is the gravitational acceleration.

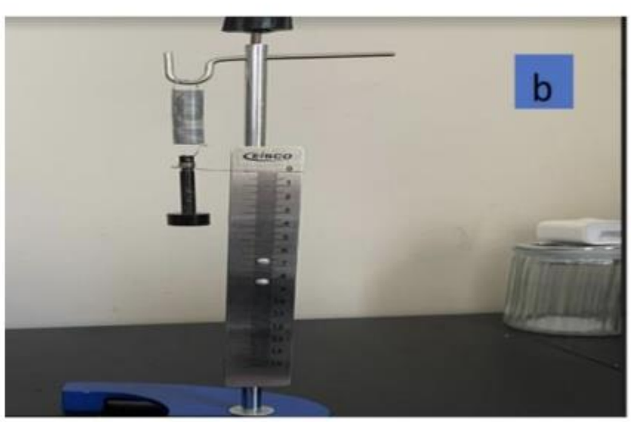

Figure 2: Simple Pendulum Experiment Setup

Ohm’s Law Experiment

The objective of the experiment was to determine the relationship between voltage, current, and resistance to illustrate Ohm’s Law. To carry out the experiment, students utilized a breadboard (Figure 3), resistors with different ohms, an Analog Device Active Learning Module Education Demonstration (ADALM) 1000 device (Figure 4), and ALICE software. The ADALM 1000 is a USB-powered educational device that is been used to teach Ohm’s Law and other basic electrical engineering topics. The ADALM 1000 was specifically used for several projects because of its multipurpose function. When combined with ALICE (A Learning Interface for Circuit Exploration) software, students may create signals, measure voltages, and see real-time circuit behaviors, which makes hands-on learning easier (Figure 5). The ADALM 1000 can be used to measure the currents that arise from applying various voltages across a resistor in an Ohm’s Law experiment. Plotting these measurements helps students better comprehend electrical resistance by allowing them to see the linear relationship between voltage and current, as stated in Ohm’s Law.

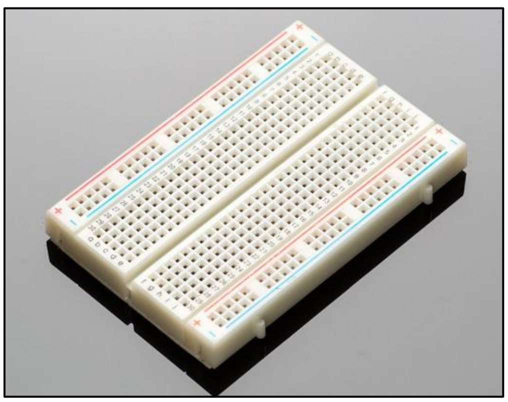

Figure 3: An electronic breadboard

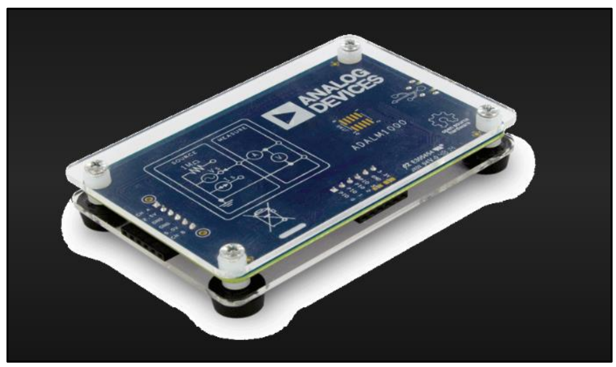

Figure 4: ADALM 1000 device

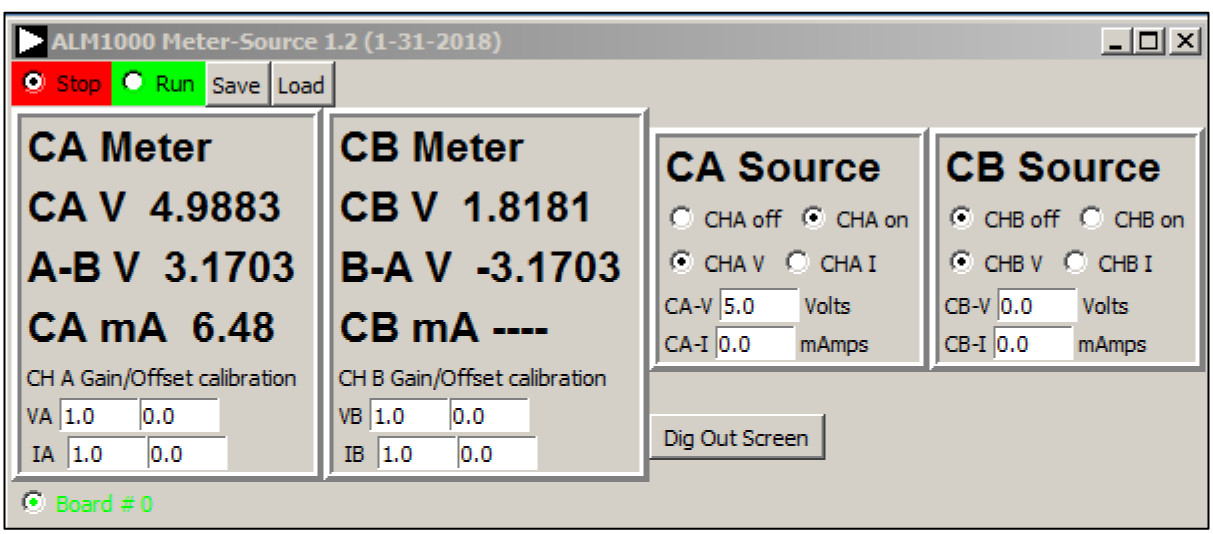

Figure 5: A Metric Reading on the ALICE software interface

Steps to determine resistance values include attaching resistors to the breadboard, applying currents, and measuring the voltages that occur. As the experiment advances, more complex arrangements such as parallel and series resistor sets are used. Applying Ohm's Law practically aims to improve students' awareness of electrical fundamentals.

Data Collection and Analysis

Forty eight undergraduate physics students undertook the two experiment modules during the spring and fall semesters of 2023. The study adopted the Motivated Strategies for Learning Questionnaire (MSLQ) [24], which consists of seven Likert scales that evaluate college students' motivational orientations and how they apply learning strategies in their academic courses. The motivational subscales include test anxiety (TA), metacognition (MC), intrinsic goal orientation (IGO), extrinsic goal orientation (EGO), task value (TV), expectancy component (EC), peer learning and cooperation (PLC), and task value (TV). Pre- and post-self-assessments were carried out to determine how well the pedagogy performed. Some of the items under each subscale are presented in Table 1.

Results

The effect of the two different ECP-based modules covered in this study on student motivation level strategy is seen in Figure 6. Figure 6 shows a bar chart that compares the scores from the pre and post-test for the following categories: IGO, TV (task value), EC, TA, CT, MC, and PLC (peer learning and collaboration) (Table 1). Figure 6 equally shows a visible rise in each category's scores, indicating an improvement in the subscale under evaluation.

Table 1: Sample Questions of MLSQ

Subscales	Sample Questions
Intrinsic Goal Orientation (IGO)	In a class like this, I prefer course material that really challenges me so I can learn new things.
	In a class like this, I prefer course material that arouses my curiosity, even if it is difficult to learn.
Expectancy component (EC)	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.
	I expect to do well in this class.
Test Anxiety (TA)	I have an uneasy, upset feeling when I take an exam.
	I feel my heart beating fast when I take an exam.
Critical Thinking (CT)	I often find myself questioning things I hear or read in this course to decide if I find them convincing.
	I try to play around with ideas of my own related to what I am learning in this course.
Metacognition (MC)	Before I study new course material thoroughly, I often skim it to see how it is organized.
	If course materials are difficult to understand, I change the way I read the material.

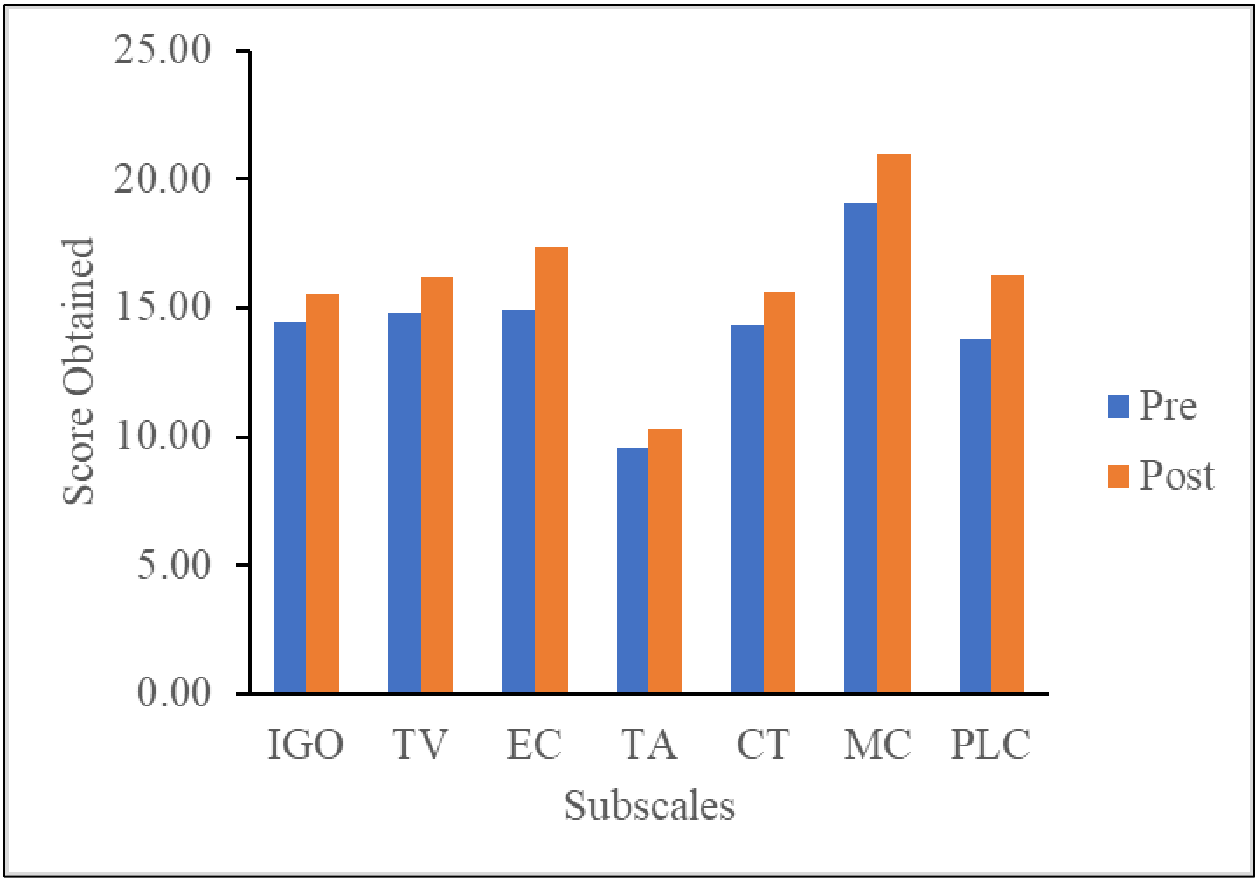

Figure 6: Summary of Subscale Scores

The paired sample t-test result in Table 2 showed that on all the subscales, there was an increase in the post-test response. The mean difference in the post-pretest scores ranged between 0.75 and 2.50. The result also indicated a significant increase in motivation subscales task value, expectancy component, metacognition, peer learning and collaboration ($p<0.05$).

Table 2: Pair Sample of Pre- and Post-Test Results

	Mean Difference (post-pre)	Std. Deviation	t	df	Sig. (2-tailed)
Intrinsic Goal Orientation	1.06	4.40	1.67	47	.10
Task Value	1.44	4.75	2.10	47	.04*
Expectancy Component	2.42	6.14	2.73	47	.01*
Test Anxiety	0.75	4.52	1.15	47	.26
Critical Thinking	1.29	4.60	1.95	47	.06
Metacognition	1.90	6.13	2.14	47	.04*
Peer Learning and Collaboration	2.50	4.64	3.73	47	.00*

* Significant difference exists

Discussion

The rise in scores may indicate that the ECP experiments positively impacted the students' motivational orientations and learning techniques in HBCUs. After working on the two ECP modules, students may have been more driven by internal causes such as interest or personal fulfillment, as evidenced by the increase in Intrinsic Goal Orientation. It implies that following the ECP-based trials, students felt that learning was more fulfilling in and of itself, pointing to a shift in favor of intrinsic motivation. It is also possible that they saw higher benefits from their efforts from other sources (extrinsic motivation) which is not expressly labeled. These extrinsic sources could include grades or approval in their learning after the studies.

Students' perceptions of the tasks' value increased after using the ECP technique, demonstrated by the improvement in task value scores following the training. The increase in the expectancy component indicates that following the ECP-based training, students were more confident in their abilities and had higher expectations for their accomplishment. It is interesting to note that test anxiety also increases, which is usually undesirable. Nevertheless, this could result from greater involvement and worry about performing well, which the ECP approach might unintentionally exacerbate, or it could reflect a heightened awareness of performance post-intervention. The significant improvement in metacognition (MC), a crucial aspect of deep learning, suggests that students were better able to control their learning and were more conscious of their thought processes following the ECP experiments. The significant increase in peer learning and collaboration following the intervention suggests that ECP may help with peer learning and collaboration, which is important in active learning environments.

From a statistical standpoint, the study examined the *p*-values and t-test data. The increase in intrinsic goal orientation scores has a *p*-value of 0.101, indicating that the shift may have resulted from chance rather than statistical significance at the 0.05 level. The task value displays a *p*-value of 0.041, slightly below the 0.05 cutoff, suggesting that students' values of the task have increased statistically significantly after the ECP. The expectancy component indicates a highly significant increase in pupils' expectations of success, with a p-value of 0.009, far below the 0.05 level. There was no statistically significant improvement in the test anxiety levels of the students following the ECP intervention, as indicated by the test anxiety p-value of 0.256. The critical thinking p-value is 0.058, just above the 0.05 level and indicates that any improvement in critical thinking abilities is probably not statistically significant. The ECP significantly increased students' use of metacognitive methods, as reflected by the metacognition *p*-value of 0.037. A highly statistically significant increase in peer learning and collaboration is shown by a p-value of 0.001, showing that the ECP technique had a considerable impact on students' cooperative learning.

Conclusion

In conclusion, the p-values and t-tests indicate that the ECP had a statistically significant positive effect on most of the motivational constructs measured, except for internal goal orientation and test anxiety, which did not change significantly, and critical thinking, which was marginally non-significant. These statistical results provide strong evidence supporting the efficacy of ECP in enhancing specific aspects of student motivation. The overall analysis of this chart suggests that the ECP-based experiments had a beneficial effect on various dimensions of student motivation.

Acknowledgments

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