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Comparison of the Effectiveness of In-Person and Remote Labs for Undergraduate Physics Students at an HBC

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Enhancing student engagement and enthusiasm in undergraduate physics laboratory experiments at a historically black university by using hands-on devices via experiment-centric pedagogy

Abstract

Policy reports have identified unique changes in undergraduate physics laboratory course arrangements that will better serve the demands of a diverse and expanding student body. To achieve this, we remotely incorporate a hands-on device laboratory option and contrast it with the conventional devices utilized in classroom lab settings. A quasiexperimental, observational quantitative study was conducted to measure students' epistemological views as well as their beliefs about socialization and help-seeking in remote, i.e., experiment-centric pedagogy (ECP), and in-person (non-ECP), modes of experimentation, to ascertain whether students using this hands-on device had similar perspectives to the usage of the traditional device in terms of select attitudinal measures. Here, we present a comparison of the efficacy of a hands-on integrated mode of conducting physics experiments via experiment-centric pedagogy (ECP) with the traditional laboratory mode (non-ECP) of teaching undergraduate students enrolled in the Introduction to Physics Experiment. We conclude that these two approaches are complementary to one another. Undergraduate students who were enrolled in the Introduction to Physics laboratory practical ($N = 30$) were a case study to elicit their epistemological beliefs about physics laboratory work and their views on social engagement and academic anxiety. Parametric and nonparametric comparisons of central tendency were employed to measure the mean differences between students using the ECP mode and non-ECP laboratory mode. It shows that the overall percentage mean experience of the students with the use of the ECP lab method was more than that of the non-ECP method. The paired sample t test result shows that there is a high significance value of <5% *p* value, which signifies the positive effect of the hands-on lab via the ECP approach. The instructor-student action reveals an enhancement in the students' engagement via COPUS and feedback analysis.

Keywords:

Experiment-centric pedagogy, hands-on kits, MSLQ, COPUS, motivation

Introduction

Following the outbreak of COVID-19, conducting lab classes emerged as a major challenge. Switching to a remote-only mode with virtual experiments and simulations was very limiting for the instructors and students. The key advantages of this approach were access to equipment, flexibility on when and how experiments are conducted, and the curiosity-driven engagement fostered. However, this approach lacks one-on-one engagement, academic dishonesty, and the use of specialized equipment [1], [2]. It established a difference and, in some respects, increased student engagement. The development of troubleshooting skills and confidence in setting experiments are a few key observations [3]–[5].

The COVID-19 pandemic, which hinders knowledge transfer to students by restricting mobility and providing significant logistical and safety issues, has rendered this traditional mode of instruction ineffective. With little to no time to consider the effects of the transitions on the effectiveness of learning and teaching, the pandemic forced all instructors online to use hands-on devices [6]. As a result, it opens a unique window of time for learning about the difficulties and opportunities that university students and instructors faced because of virtual lab experiences. It has therefore aided educators in having hybrid courses and teaching pedagogies to protect student and staff safety while preserving learning standards. Therefore, closing this gap is necessary to avoid further setbacks [7], [8].

Industries have recently had a significant demand for technical expertise workers. Therefore, educational institutions now need to reassess their curricula and hands-on STEM device applications [9]–[11]. Students are encouraged to take the initiative to comprehend and build more in-depth information and skills needed for scientific applications. Hence, an undergraduate course should incorporate applied laboratory implementation applications. As such, educators are responsible for ensuring that students acquire a strong sense of learning motivation and scientific inquiry skills [12]. School laboratories are a crucial part of any STEM education. They enhance students' engagement in a variety of experimental learning skills, such as conception and experimentation followed by reflection, analysis, and data interpretation. Establishing the worth of the laboratory equipment in the department is crucial before starting a comparison of lab modalities. Topics in the laboratory manual for Introduction to Physics practical are written for undergraduate students; laboratories are used as a platform to reinforce the lecture material.

However, in many instances, learning more effective observational and recording techniques, deductive reasoning, and hypothesis formation are the key objectives of the laboratory experience [13], [14].

The experimental learning units in science, technology, engineering, and mathematics (STEM) are extensive and can take the form of hands-on pedagogies, field visits, practical training and projects, schematic design, and more [3], [11], [15]. STEM professions require course knowledge to grasp the growth of specific experimentation skills in addition to the ideal understanding. Hands-on labs make it simpler for students to acquire fundamental science concepts and meet learning objectives, but they lack sufficient instrumentation. Additionally, offering educational materials to boost their skills might give undergraduate STEM students a dynamic learning method with more freedom. However, not all institutions can perform hands-on labs because of time limitations in distributing devices to each student, finance restrictions, or increased class sizes. Over the years, researchers have carried out several hands-on lab experiments to evaluate students' motivation and curiosities [16]–[18].

Recent technological advancements and improvements that support alternate modalities for providing lab experiences have helped laboratory and hands-on education experiences in virtual STEM domains. Currently, remote labs (where real, physical equipment is controlled from a distance), virtual reality, and other technologies help to facilitate virtual laboratories [19], [20]. The use of student resources such as laptops and other mobile devices in hands-on platforms makes it possible for students to have access to hands-on learning experiences all the time, anywhere. Remote labs offer cost-effectiveness, increased availability and accessibility, and improved safety for students [21]. The utilization of a virtual lab by fifteen graduate students at the Department of Primary Education of Athens University was described by [22]. Both an in-person lab and a virtual lab were used in the research, and it was discovered that the virtual lab provided the best results when compared to the in-person lab. Students have benefited greatly from using virtual labs since they give them access to spaces where they can utilize the internet to study and practice conventional survey technologies remotely. Experiment-centric pedagogy (ECP) is a new teaching methodology that makes use of the hands-on device to engage, motivate, increase curiosity, and increase the success rate of students. It was discovered that using hands-on equipment through experiment-centric pedagogy (ECP) to teach a variety of

STEM subjects remotely demonstrates a good influence of this teaching pedagogy on students' motivation, curiosity, and success rate [3], [4].

For some students, the transition from high school to university might be difficult in the setting of university education. The difficulties of this transition are made more difficult by the high number of students who originate from low-income homes and the underfunded, occasionally disorganized nature of the educational system [20]. To effectively provide course content to a broad and scattered cohort, educational schools are increasingly integrating the usage of hands-on devices remotely. Therefore, substantial work must be accomplished to establish and assess the impact of the home front on students' knowledge acquisition [23].

The main research questions guiding this study were as follows:

a. How does using a hands-on device via ECP mode engage students and improve their technical understanding compared to using the traditional laboratory device?
b. How does the classroom observation protocol for undergraduate STEM (COPUS) assess the level of instructor-student interaction?

Experimental Concept and Theoretical Background

This study was designed with the application of a hands-on kit consisting of a pendulum bob, retort stand with clamp, string, and portable stopwatch for the ECP mode, while the traditional mode (non-ECP) consists of Logger Pro software, retort stand, pendulum bob, string, and a Photogate for sensing the bob's motion. This experiment focuses on the determination of acceleration due to gravity and how the bob string's length depends on the period of oscillation of a simple pendulum experiment. Two different sessions were employed in this study. The first session, which serves as the control experiment, makes use of traditional laboratory devices on-site while the second mode employs the use of hands-on devices (ECP mode) at home. We use a remote approach for the ECP mode to investigate how the students decipher how to solve a technical problem with little or no supervision via hands-on kits. In the ECP mode, the students were told to assemble the components as shown in their manual. The pendulum bob was attached to a string at a given length, measured by the ruler, and the free end of the string was attached firmly to the retort stand with the help of a cork. The time (t_1) of oscillations was obtained for 10 complete oscillations, and the experiment was repeated to achieve the second time, t_1. This was done to minimize the source of errors in timing. Thereafter, the average of the time was calculated to obtain the period of oscillations. The graph of the square of the period versus the length was plotted to evaluate the acceleration due to the gravity of the bob via the gradient of the graph. This was achieved through the equations below[24]:

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

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

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

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

where T represents that period of oscillation, t_{avg} signifies the average time taken for one complete oscillation, l is the string's length, n is the number of oscillations, and g represents the acceleration due to gravity. However, the non-ECP approach utilizes a software device called Logger Pro installed on the lab's system to measure the period of oscillations of the bob as the bob passes through the photogate. Here, the setup was done by the students following the instructions given in the manual and with the help of the instructor. As the bob swings across the photogate, the Logger Pro senses the motion and displays it in the form of dots on the screen. The students highlight at least 10 dots, and the software automatically analyses the average period of oscillation of the bob at that length. The graph of period square vs length was also plotted to obtain the free fall gravitational acceleration. Both experimental modes were performed for six various values of given lengths.

Participants, Deployment, and Identifications

In this study, 30 STEM undergraduate students who enrolled in the Introductory to Physics laboratory practical participated. Thirty students participated in both the non-ECP lab experiment and the ECP remote lab experiment. Six important Likert constructs, including intrinsic goal orientation (IGO), extrinsic goal orientation (EGO), task value (TV), expectancy component (EC), test anxiety (TA), and critical thinking (CT), were included in the questionnaires that were created, sent, and collected electronically by survey monkeys. This technique was created to help STEM instructors characterize students' levels of interest, drive, curiosity, aptitude, and success.

However, the instructor-student interactions in both modes of lab experiments were assessed using the Classroom Observation Protocol for Undergraduate STEM (COPUS), as shown in Table 1. The benefit of this approach is that instructors can review their lessons after every class to address any shortcomings. Additionally, this approach can be used to contact students to gauge their engagement level during lessons. Cameras were also set up to verify laboratory actions to ensure correct data capture. A signature assignment was utilized to investigate how well the students were retained using the two approaches. This method was created and employed by [25]. Additionally, a rubric was created to evaluate each student's laboratory report to characterize their absorption and documentation skills.

The scenario

Support for our study came from an instructor who oversees undergraduate physics practice and a doctoral student who oversees class observation for COPUS data collection. A graduate student with expertise in developing and collecting survey questions. Here, the instructor experimented while the students were remotely linked during the ECP lab mode. Due to the hands-on ECP kit used in this study, the students were able to conduct their experiment at home on shared dining and study tables with their housemates. However, the instructor gives lectures and practical demonstrations for the in-person class on how to use the lab apparatus to collect their experimental results.

The pre-and posttest questionnaire

To fully understand student motivation and self-evaluation in the two methodologies, it is important to first understand how students view the course. Students' psychological and cognitive involvement is thus vital [26]. The same six Motivation Strategies for Learning Questionnaire (MSLQ) constructs were included in the pre- and posttest surveys. These constructs were used to compare the differences between non-ECP and ECP lab modes. The components were created to assess knowledge, comprehension, application, motivation, and success rate among other educational aims. The MSLQ structures used in this study are listed in Table 2, along with the subdivision questions [3], [27], [28]. This MSLQ acts as a guide to pinpoint the source of motivation and how learning strategies are utilized in different contexts, both in terms of content and population; to enhance understanding of motivational constructs;

Table 1: Illustration of COPUS used to evaluate the instructor-student interaction.

Students are Doing	
L	Listening to instructor/taking notes, etc.
AnQ	Student answering a question posed by the instructor with the rest of the class lister
SQ	Student asks a question
WC	Engaged in whole class discussion by offering explanations, opinion, judgment, etc
Ind	Individual thinking/problem solving.
CG	Discuss clicker question in groups of 2 or more students
WG	Working in groups on worksheet activity
OG	Other assigned group activity, such as responding to instructor question
Prd	Making a prediction about the outcome of demo or experiment
SP	Presentation by student(s)
TQ	Test or quiz
W	Waiting
O	Other – explain in comments
Instructor is Doing	
Lec	Lecturing
RtW	Real-time writing on board, doc. projector, etc.
Fup	Follow-up/feedback on clicker question or activity to entire class
PQ	Posing non-clicker question to students (non-rhetorical)
CQ	Asking a clicker question
AnQ	Listening to and answering student questions with entire class listening
MG	Moving through class guiding ongoing student work during active learning task
1o1	One-on-one extended discussion with one or a few individuals
D/V	Showing or conducting a demo, experiment, simulation, video, or animation
Adm	Administration (assign homework, return tests, etc.)
W	Waiting when there is an opportunity for an instructor
O	Other – explain in comments

Table 2: Tabular representation of MSLQ constructs and questions.

S/N	Constructs	MSLQ CODE	Questions
1	Intrinsic Goal Orientation (IGO)	IGO 1	In a class like this, I prefer course material that challenges me so I can learn new things.
		IGO 2	In a class like this, I prefer course material that arouses my curiosity, even if it is difficult to learn.
		IGO 3	The most satisfying thing for me in this course is trying to understand the content as thoroughly as possible.
2	Extrinsic Goal Orientation (EGO)	EGO 1	Getting a good grade in this class is the most satisfying thing for me right now.
		EGO 2	The most important thing for me right is now improving my overall grade point average.
		EGO 3	I want to do well in this class because it is important to show my ability to my family, friends, employer, or others.
3	Task Value (TV)	T V 1	I need to learn the course material in this class.
		T V 2	I am very interested in the content area of this course.
		T V 3	I like the subject matter of this course.
4	Expectancy Component (EC)	EC 1	I believe I will receive an excellent grade in this class.
		EC 2	I'm confident I can do an excellent job on the assignments and tests in this course.
		EC 3	I expect to do well in this class.
5	Test Anxiety (TA)	TA 1	I have an uneasy, upset feeling when I take an exam.
		TA 2	I feel my heart beating fast when I take an exam.
6	Critical Thinking (CT)	CT 1	I often find myself questioning things I hear or read in this course to decide if I find them convincing.
		CT 2	I try to play around with ideas of my own related to what I am learning in this course.
		CT 3	Whenever I read or hear an assertion or conclusion in this class, I think about possible alternatives.

and to assess the effects of various teaching features on motivation and cognition. Thus, it is acknowledged that both the theory and the statistical findings support the conclusions reached through the application of this study [29].

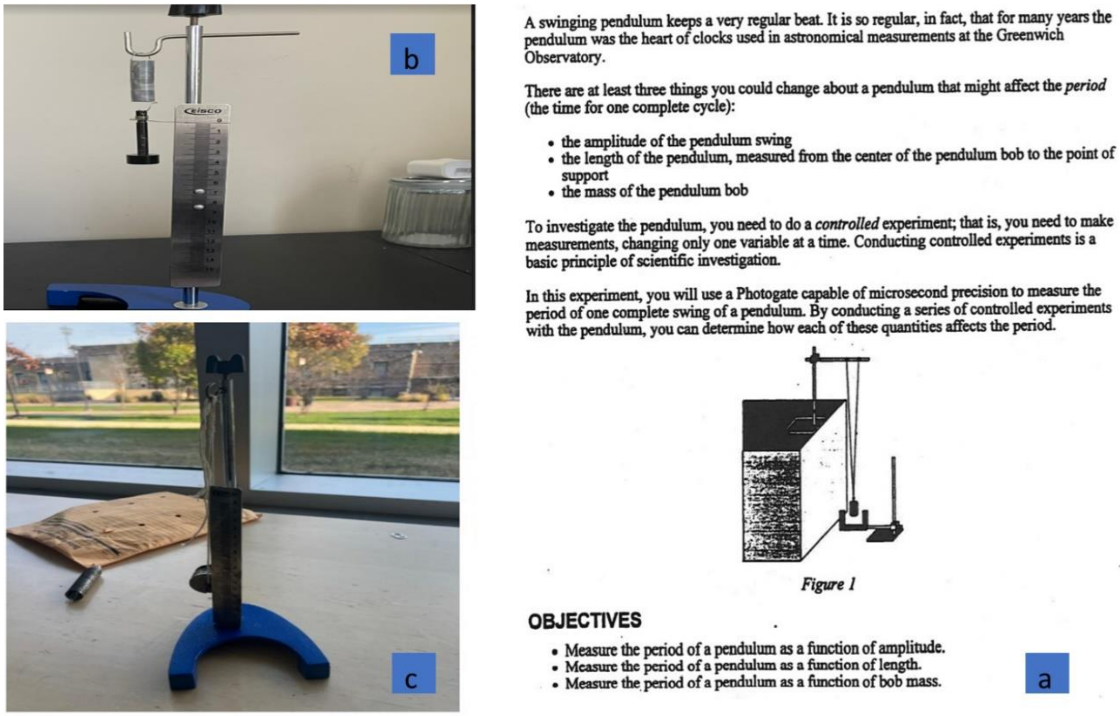
Methodology

The instructor informed the students about the exciting study that was done in the spring and fall of the academic session by giving practical applications of a simple pendulum in their daily lives such as the playground swing, a plucked guitar string, and a ball bearing rolling down a curved bowl, to mention a few. For the non-ECP mode, the students were grouped into 2 groups for a total of 10 groups. Before implementation, the MSLQ was sent to the student. This acts as the pretest survey before the experiment. It was done to determine how familiar the students are with the intended experiment and what they anticipate achieving. The instructor guided students by using physics laboratory equipment to collect data for the simple harmonic motion experiment. A post-experiment survey was conducted to evaluate the major students' constructs associated with motivation and success. Students were also given an assessment to assess their degree of interest, motivation, and involvement in the actual lab. Above all, class observation was conducted to evaluate the interaction between the instructor and students. In the non-ECP mode, the practical session was computerized, where Logger Pro software was used to acquire data and measure all the physical parameters as the pendulum bob moved across the Photogate sensor. Although this method is quick, it does not improve students' technical knowledge. A similar experimentation strategy has also been documented in the literature [3], [21].

On the other hand, the ECP type of experiment allows for a new pedagogical model that promotes a more complete integration of theory and laboratory experience. Here, each student logs in to a timed canvas containing the instructions for the experiment. The result of their experiments was to be turned in before the time elapses. This was done to reduce academic dishonesty. However, students were advised not to sort search engines for answers especially in the theory aspect. Their answers were first vetted via Turnitin and Chatgbt software to check for academic dishonesty. This motivates the students to be self-dependent and develops answering skills to technical questions. The ECP mode via hands-on devices opens new avenues for inquiry-based learning that enhances and deepens student learning of fundamentals. As a result, each student was given a hands-on kit for the experiment. Here, the instructor explains how to couple the components together and how to read and measure accurately some of the tools, such as stopwatches and measuring rulers, and how to reduce sources of errors, to mention a few. This was done virtually, where all students turned on their cameras as the instructor explained and slightly demonstrated the setup. To determine the gravitational acceleration, a stopwatch (mobile phone) was utilized at different lengths over time to determine the relationship between the period and the length of the pendulum bob. This increases their interest in using hands-on tools to address laboratory challenges. Students pay close attention to the stopwatch and the bob's movements as they count the number of oscillations. This approach enhances students' technical proficiency in measuring and analyzing physical quantities and troubleshooting. As such, increasing technical expertise [5].

In both modes, the experiment was timed for 2 hrs for the students to turn in their results and laboratory report. A posttest survey was automatically sent via Canvas following the submission of their lab report, which occurred automatically. The students were given a signature assignment, which was graded for both lab modes. Their lab report was evaluated and graded using a previously published rubric [3], [4]. Furthermore, for both experimental techniques, minutes were recorded using COPUS and were watched by a graduate student with a camera. Electronic data collection and analysis were used for all data.

The laboratory handbook utilized for the experiments is shown in Figure 1(a-c), along with examples of the ECP lab setups made by different students. This setup is basic and plain forward for students, and they appreciated the ECP lab because they had control of their schedule, even though they had a deadline to submit their results. Additionally, because it requires little space to operate, using this hands-on tool allows students to experiment on shared dining tables that are shared with roommates. Figure 2(a-d) presents the visual setup, output, and demonstration from the non-ECP lab experiment. Figure 2a shows group discussions by the students. This does not develop individual strength in thinking, hence reducing motivation and curiosity. Students were seen experimenting in the lab, as shown in Figure 2b using the photogate application on the system, while another student operated the computer. The data points collected by the photogate are shown in Figure 2c; the average of these data points corresponds to the average period of oscillation of the pendulum bob. Because the machine performed all analysis in this lab method as opposed to the ECP lab where each student took stock of what was happening as the bob moved back and forth and how to minimize and identify errors, this lowers the students' technical proficiency in the non-ECP mode. Figure 2d shows the lecturer extensively writing on the board to explain the experiment in depth. Along the way, it became apparent that the students were getting tired of the lengthy write-ups. As such, the instructor moved to walk them through the setup.



A swinging pendulum keeps a very regular beat. It is so regular, in fact, that for many years the pendulum was the heart of clocks used in astronomical measurements at the Greenwich Observatory.

There are at least three things you could change about a pendulum that might affect the *period* (the time for one complete cycle):

- the amplitude of the pendulum swing
- the length of the pendulum, measured from the center of the pendulum bob to the point of support
- the mass of the pendulum bob

To investigate the pendulum, you need to do a *controlled* experiment; that is, you need to make measurements, changing only one variable at a time. Conducting controlled experiments is a basic principle of scientific investigation.

In this experiment, you will use a Photogate capable of microsecond precision to measure the period of one complete swing of a pendulum. By conducting a series of controlled experiments with the pendulum, you can determine how each of these quantities affects the period.

Figure 1

OBJECTIVES

- Measure the period of a pendulum as a function of amplitude.
- Measure the period of a pendulum as a function of length.
- Measure the period of a pendulum as a function of bob mass.

Figure 1 (a-c): ECP mode experimental display and the laboratory manual for the non-ECP mode

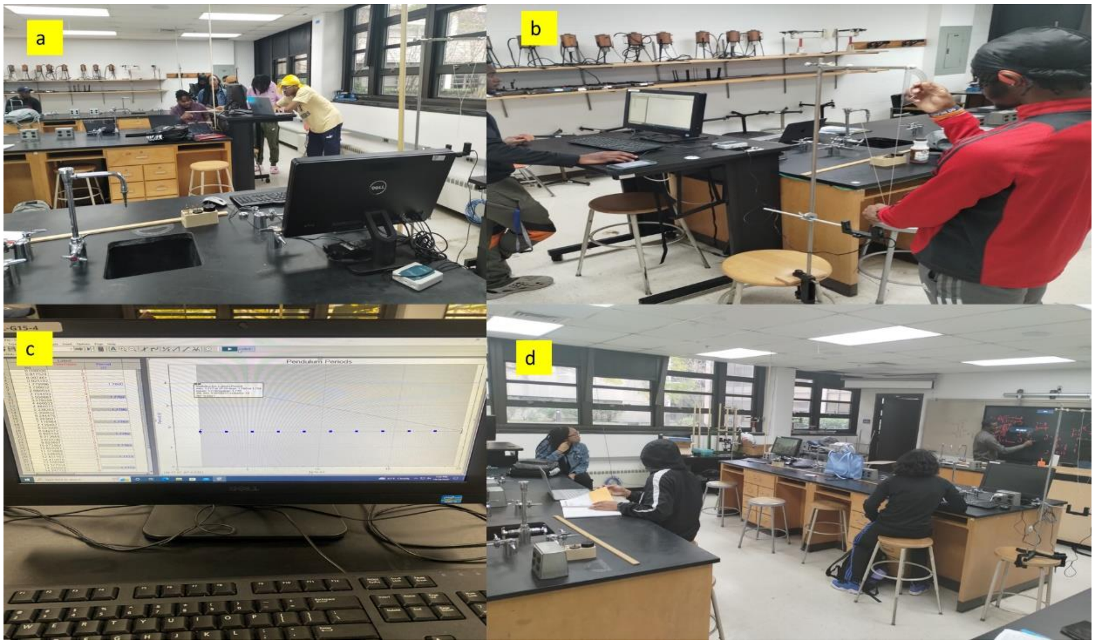


Figure 2 (a-d): non-ECP mode experimental setup and the simulation

Results and Discussion

The impact of ECP on student learning and key constructs related to students' motivation and engagement were investigated. Based on the scales of the MSLQ constructs, the familiarization of the devices used in the ECP and non-ECP modes of the experiment was studied. In this analysis, A denotes "I have seen a personal instrument, also known as Logger Pro, Arduino, M1K, M2K, or others", and B denotes "I have used a personal instrument, such as Logger Pro, Arduino, M1K, or M2K", C denotes "I have heard about personal instruments and their uses", D denotes that "I have used phone apps in class, such as a stopwatch", and E denotes that "I have used Logger Pro, simple harmonic motion kits, Arduino, M1K, or M2K". The student's experience with the use of the devices was evaluated based on the mean percentage agreed upon for both phases of the experiment. We employed a Likert scale of 1-7, where 1-4 denotes "true of me, i.e., agree" while 5-7 implies "not true of me, i.e., disagree".

Figure 1 shows the results from the analysis that evaluates the percentage sum agreed upon in the non-ECP and ECP lab experience. It shows that 57.3% of students agreed with the familiarization and usage of the hands-on devices compared to 32.7% of students who were reckoned with the traditional lab devices. This shows that the students had been exposed to the use of hands-on devices even before they enrolled in the course. Hence, their hands-on device application experiences should be increased to solve practical problems. This demonstrates how interactive tools are frequently used to boost students' information retention, curiosity, and motivation. [30], [31] also enumerated the familiarization and use of hands-on lab kits by students with pros and cons. It was reported that a large population of the students were familiar with the use of the hands-on kits.

The posttest survey was evaluated between the two moods as shown in Table 3. It displays the average results of the MSLQ subscale constructs for the non-ECP and ECP lab experiments. The Likert scale of 1-7, where 1-4 denotes ‘very true of me, i.e., agree’ while 5-7 implies ‘not all true of me, i.e., disagree’, was administered in the survey. Here, we present the MSLQ subscale’s average. The average value of the posttest was observed to be higher with a value of 84.65% for the ECP mode and 83.29% for the non-ECP mode. This difference might be because of the ease of use of the hands-on device that does not require the use of a computer or the internet. Thus, most of the students were fully engaged in hands-on device usage.

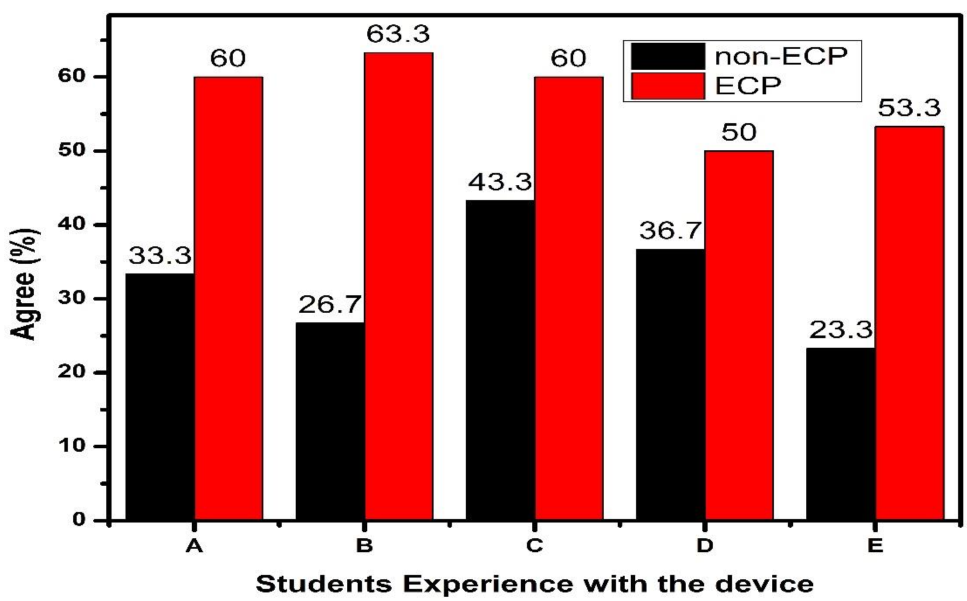


Figure 1: Bars showing students’ experience with the use of the hands-on kits.

Generally, some of the shortcomings of the non-ECP lab might be because of insufficient device usage for individual students and the time allotted to decipher how to simulate the system to achieve the desired results [32]–[34]. However, the ECP lab showed that by the conclusion of the experiment, the student's critical thinking had increased, and their anxiety had decreased when a hands-on device was employed. This demonstrates the comfort level attained to thinking deeply in solving technical problems when using hands-on tools [35], [36]. This explains the high levels of motivation, zeal, and dedication displayed by students when using hands-on devices. The findings of this study are consistent with the claim that students who participate in hands-on lab experiments are more motivated and produce higher learning outcomes than those who used traditional lab equipment [3], [37], [38].

The motivations behind students' engagement in the learning process and their perceptions of the task's importance, usefulness, interest, and associated task demand all play a role in task value. The baseline differences between students in the posttest of both modes are disclosed by a paired sample t test, as shown in Table 4. Intrinsic goal orientation, extrinsic goal orientation, and task value are scientifically noteworthy below the 5% threshold with values of 7%, 0.8%, and 0.4%, respectively, which shows the statistical significance of the constructs.

Table 3: Changes in student Motivation Strategies

MSLQ CONSTRUCT	**MSLQ CODE**	% Agree in non-ECP mode (posttest) N=30	% Agree in ECP mode (posttest) N = 30
INTRINSIC GOAL ORIENTATION	IGO 1	86	93
	IGO 2	86	90
	IGO 3	87	83
EXTRINSIC GOAL ORIENTATION	EGO 1	80	93
	EGO 2	86	96
	EGO 3	86	87
TASK VALUE	T V 1	96	93
	T V 2	76	93
	T V 3	73	83
Expectancy Component	EC 1	93	73
	EC 2	90	90

	EC 3	96	83
Test Anxiety	TA 1	80	73
	TA 2	80	70
Critical Thinking	CT 1	75	76
	CT 2	76	83
	CT 3	70	80

However, the expectancy component, test anxiety, and critical thinking indicate no significant difference between the constructs. The standard deviation also shows how dispersed the data set is. This was also reported by [5].

Utilizing COPUS, the instructor-student relationship was assessed. As seen in Figure 2a, the instructor took a few minutes to access the logger pro software on his computer and couple his hands-on equipment virtually before the class could begin. Students in the non-ECP laboratory paid closer attention to the instructor than they did in the ECP lab. In the non-

Table 4: Paired sample T Test of the MSLQ data

Paired Samples Test							
N = 30			95% Confidence Interval of the Difference				
Construct	Mean	Std. Deviation	Lower	Upper	t	Df	Sig. (2-tailed)
IGO non-ECP/ECP	-0.68889	2.0037	-1.43708	0.05931	-1.883	29	0.07
EGO non-ECP/ECP	-0.91111	1.75061	-1.5648	-0.25742	-2.851	29	0.008
TV non-ECP/ECP	-1.06667	1.84121	-1.75418	-0.37915	-3.173	29	0.004
EC non-ECP/ECP	-0.14444	1.62283	-0.75042	0.46153	-0.488	29	0.63
TA non-ECP/ECP	-0.05	1.57759	-0.63908	0.53908	-0.174	29	0.863
CT non-ECP/ECP	-0.41111	1.82718	-1.09339	0.27117	-1.232	29	0.228

ECP laboratory setting and other group activities (OG) were more prominent. This happened because of an inadequate implementation tool. Additionally, there were more queries in the non-ECP lab. This might be a result of them using unfamiliar devices to collect data for analysis. However, the ECP lab has a greater impact on students' thinking (IND), question-answering skills (ANQ), demonstration skills (DV), and short tests (TQ). This might be due to the students' deep thinking while completing the activity, which accounts for a better outcome on the ECP lab short test. The instructor asked them questions about how to couple the device and how to attempt some tasks from the manual. Students' demonstration (DV) shows a significant influence of 75% of the student's actions. This demonstrates how invested they were in carrying out the experiment, which heightens their desire to produce the intended results. Similar results have also been reported in the literature [5], [39], [40]. However, this mode does not take into consideration exam malpractice that could emanate from surfing the internet for likely solutions, one-on-one interaction with the instructor, and other academic dishonesties [41]. As such, these drawbacks were insignificant because there was a time frame for each student to turn in their results via Canvas. Additionally, the reduction in students' actions could be ascribed to the

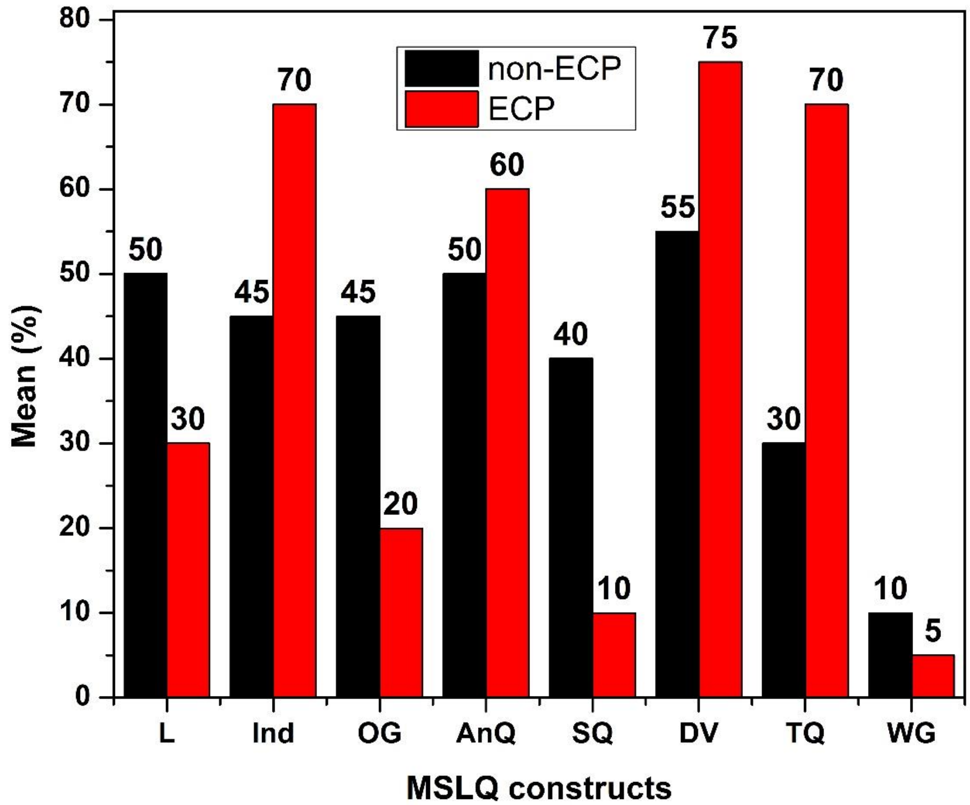


Figure 2a: COPUS of the non-ECP lab and ECP lab results of students.

inadequate device to engage each student. COPUS also revealed that some of the students were not carried along with the experimental procedure, and some showed no interest in engaging the device but were interested in the documentation of the displayed result. The non-ECP method gives room for collaborative work done for the desired output.

Figure 2b graphically depicts the instructor's activities during the non-ECP lab and ECP lab classes. This outcome demonstrates that the instructor focused more on lecturing (LEC) in the non-ECP lab than in the ECP lab. In comparison to the ECP lab, real-time writing (RTW) on the board was more noticeable in the non-ECP lab because it was necessary to thoroughly describe the experiment's methodology in the non-ECP lab. Less explanation was, however, provided to the students in the ECP lab to determine their proficiency in solving experimental issues. In the non-ECP lab, the instructor asks more questions (PQ) to gauge students' degree of understanding of what to do, which results in more questions for the instructors to respond to. In contrast to the non-ECP lab mode, movement within the ECP class (MG) was limited to a certain area. As a result, the instructor was less tired, and productivity was increased by welcoming more queries from the students. In the non-ECP lab, there were 30% one-on-one interactions (101) and 10% in the ECP lab. This demonstrates the comprehension level of the students who signed up for the ECP lab. When performing the demonstrations (DV) in the ECP session as opposed to the non-ECP session, a 35% difference was seen. The instructor's demonstrations using practical tools were given more weight than his lectures in the non-ECP lab experiences. In the non-ECP lab, the instructor took more time to explain how to navigate the system to collect and analyze the data. This also reduced the practical engagement time of the student with the devices in the lab. Hence, it demonstrates the efficiency of utilizing hands-on tools through an ECP lab [14], [42], [43].

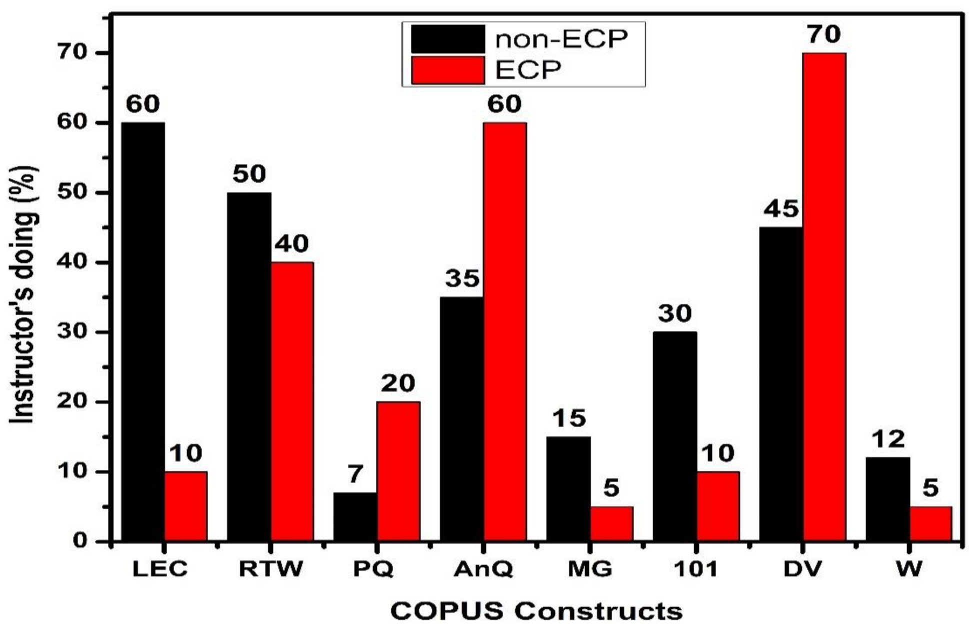


Figure 2b: COPUS showing ECP and non-ECP lab results of the instructor’s actions.

After that, a comparison of the student's experience using the hands-on devices at home against the conventional device utilized in the lab was made. As a result, Table 5 details their success rate, motivation, and experience with the ECP hands-on gadget. We can infer that 91.2% of the students who used the hands-on device agreed that it had a favorable effect on their success rate, as opposed to 89.4% of the students who used the traditional device in the lab. This supports the idea that using hands-on equipment in distance learning labs increases students' motivation, curiosity, and success rate.

To buttress their success rate evaluation, Figure 3 depicts the investigation of the student's lab reports' results. This evaluation was conducted using a set of guidelines that serve as a check when preparing a typical lab report. It has several constructs, where A stands for "describes the hypothesis being tested," B for "formulates adequate simulation or experiment and hypothesis," C for "accept reasonable variance between numerical or experimental results and predictions of hypothesis," D for "understands the functions and limitations of the computer or laboratory tool/equipment used," E is “the proper use of laboratory tools/equipment or computer simulation”, F indicates “organizing experimental or simulation data mathematically or graphically to interpret it”, G indicates “recognizing the relationship in precision between input and output data”, and H “indicates identifying the sources of error”. In this analysis, a pass mark of 25% was applied. Nearly every lab report that was submitted was excellent and adequate. Less than 25% of students were observed to have trouble with some components of the experiment, which is why their lab report performance was subpar. This beneficial outcome also explains the instructor's strong influence on the student’s success in the ECP lab experiment. [44]–[46] also reported a similar result.

Table 5: Students’ perception of the use of the traditional device in class and hands-on devices remotely

Student Perception using lab tools and hands-on kits	% Agree (non-ECP lab)	% Agree (ECP lab)
The device (Arduino, M1K, M2k, or others) provided opportunities to practice content	86.7	90.0
The use of the device (Arduino, M1K, M2k, or others) reflected course content	86.7	86.0
The use of the device (Arduino, M1K, M2k, or others) was relevant to my academic area	90.0	92.0
The use of the device (Arduino, M1K, M2k, or others) reflected real practice	83.3	91.0
The time allotted for the device (Arduino, M1K, M2k, or others) use was adequate	90.0	93.3
The use of the device (Arduino, M1K, M2k, or others) suited my learning goals	90.0	90.0
My knowledge has increased because of the use of the devices (Arduino, M1K, M2k, or others)	93.3	93.3
My confidence in the content area has increased because of the use of the devices (Arduino, M1K, M2k, or others)	93.3	94.5
The device (Arduino, M1K, Mk, or others) is important in my preparation for my future career	86.8	93.3
Using the devices (Arduino, M1K, M2k, or others) motivated me to learn the content	90.0	90.0
It helped me to develop skills in problem-solving in this subject area	88.5	93.3
Think about problems in graphical/pictorial or practical ways	93.3	89.6
Learn how the device (Arduino, M1K, M2k, or others) is used in practical applications	86.7	93.3
It helps to recall course content	93.3	93.3
Using such devices help improve grades	93.3	88.0
Develop confidence in the content area	90.0	88.0
Become motivated to learn course content	86.7	93.3
Develop interest in the subject area	86.7	90.0
Using such devices help complete lab assignments	90.0	90.0
Percentage Average	89.4	91.2

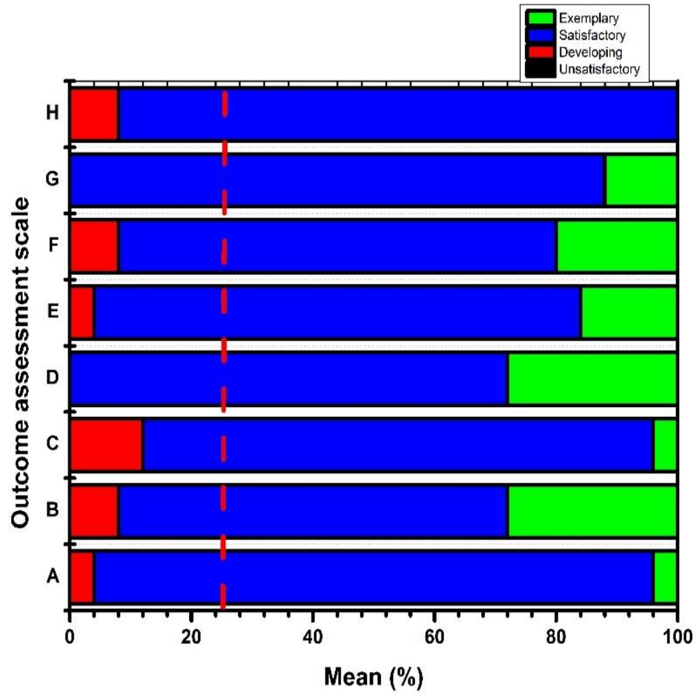


Figure 3: Outcome assessment of students' laboratory reports

Conclusion

Owing to the COVID-19 pandemic, undergraduate practical classes have faced tremendous difficulties and significant changes. Strict precautions were put in place to stop the transmission of the virus, including a lockdown policy, social withdrawal, and campus closure. Because of this, online education has emerged as a cutting-edge teaching strategy during the pandemic. Nevertheless, several studies have suggested that online education benefits students' learning processes, particularly when practical tools are used in their lab lessons. We also evaluated the impact of both ECP lab and non-ECP lab experiences. According to reports, the students in the ECP lab were more engaged, and their learning abilities increased. The open-ended queries about their experiences revealed this. Students receive research instruction so they can assess their ideas. It appears that the most effective way to perform experiments among students is to use portable technology via experiment-centric pedagogy. Students were able to assemble the components, evaluate, consider them, and choose their approach. The use of digital hands-on tools is essential due to the preferred learning style of the alpha generation. The capacity to replicate the experiment's results under various conditions and the result's quick visibility are two of the primary advantages. However, the level of academic dishonesty and one-on-one interaction between student and instructor was not fully addressed in this approach.

The sample t test result shows that the intrinsic goal orientation, extrinsic goal orientation, and task value are scientifically significant with *p* values of 7%, 0.8%, and 0.4% respectively, which shows the potency of using hands-on devices in undergraduate physics labs. This explains the student's intense drive when using the hands-on tool. Comparing the students' ECP mode participation to their non-ECP mode, COPUS found that the student's thinking was significantly improved. Additionally, it was noted that the instructor frequently gave lectures, wrote on the board, gave one-on-one attention to students, demonstrated, and responded to their questions in the ECP lab mode. This explains why it is part of our objective to help students become more engaged, motivated, curious, and technically knowledgeable. In particular, the outcome assessment showed an improvement in the technical writing of their lab report as reviewed from their feedback. This improves how STEM students use hands-on equipment to document their technical reports. However, academic dishonesty cannot be overlooked in the ECP remote class, as this might also account for the difference.

Therefore, while employing a hands-on device remotely for a lab session, the experiment-centric pedagogy style of education has been seen to boost students' learning skills, curiosity, engagement, motivation, and critical thinking as well as reduce students' academic anxiety.

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