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Resource-Adaptive Physics Laboratories for STEM Learning: Development and Validation for Least-Mastered Competencies

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Abstract

This study developed and validated physics laboratory experiments designed to address least mastered competencies among senior high school students. The laboratory activities integrated locally available materials, standard laboratory equipment, and virtual simulations to improve accessibility and conceptual understanding. Expert validators assessed the experiments in terms of content validity, clarity of instructions, feasibility, and alignment with students' learning abilities using a standardized evaluation tool. Revisions were made based on expert feedback prior to classroom implementation. The implementation of the validated experiments was examined using a one-group pre-test and post-test design involving Grade 12 STEM students from Antipolo City Senior High School. Results revealed high expert ratings across all validation criteria and a statistically significant improvement in students' post-test scores compared to pre-test results. These findings indicate an improvement in students' understanding of challenging physics concepts following the implementation of the validated laboratory experiments. The study highlights the value of combining low-cost materials, simulations, and conventional equipment to produce adaptable laboratory activities for secondary physics instruction. More broadly, this resource-adaptive approach offers a transferable model for strengthening equitable and inquiry-oriented STEM laboratory learning across diverse educational contexts, particularly where access to conventional laboratory resources is limited.

Keywords: physics education laboratory experiments, least mastered competencies, instructional materials

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INTRODUCTION

Physics education has also been identified as the most difficult field of science to learn because it's abstract and highly dependent on mathematics (Canright & Brahmia, 2023; De Jong et al., 2013). Students tend to find it hard to relate theoretical concepts to practical applications, which results in long-term challenges to developing basic skills (Canright & Brahmia, 2023; De Jong et al., 2013). More specifically, lab classes are essential in developing a conceptual understanding and scientific inquiry, but most classrooms are constrained by resources, course design, and opportunity for experimentation (Wieman & Holmes, 2015).

At the Philippine level, nationwide testing and classroom assessments always indicate that physics is one of the least learned subject matter domains in secondary education. Contributing to gaps in student achievement are insufficient lab facilities, limited experiment design training for teachers, and the focus on memorization (Adedoyin et al., 2022; Kaur & Zhao, 2023). To respond to these needs, there is an increasing demand for high-quality and tested instructional materials, especially laboratory experiments—that address students' learning problems directly and facilitate competency development.

Research at both national and regional levels in the Philippines has shown continued challenges in physics teaching practices that impact both laboratory involvement and conceptual understanding. Sanchez

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and Del Rosario (2018) showed that high school learners in Region IV-A showed challenges with the fundamental kinematics since they did not have laboratory experiments and learning materials contextualized. Manalo and Medina (2020) noted that modular learning strategies exhibited strong effectiveness for\ instructing force and motion to students from resource-constrained schools. Navarro and colleagues (2021) noted that science competencies were significantly improved when inquiry-based methods were integrated into module instruction across the country. The current study bases its support on these findings to develop a physics lab experiment that integrates real-world teacher practices together with student needs.

The quality of physics laboratory instruction greatly depends on teacher competencies, including their knowledge, skills, and attitudes (Nipales, 2019). Teachers need to create inquiry-based learning spaces for students in order to enhance students' comprehension. However, non-specialist teachers, who are most commonly assigned to teach physics, do not necessarily have conceptual knowledge to a significant degree, making laboratory instruction less efficient.

Previous studies have highlighted the need to design laboratory experiments that are not only feasible within school environments and local communities but also responsive to students' learning needs. Recent international research has emphasized that physical and virtual laboratories offer complementary affordances for STEM learning. Physical laboratories provide opportunities for direct manipulation and interaction with concrete materials, whereas virtual laboratories can facilitate visualization, flexibility, and exploration of phenomena that may be difficult to observe directly (Muilwijk & Lazonder, 2023; Pavlou & Zacharia, 2024). A systematic review by Rosli and Ishak (2024) likewise identified the growing use of virtual laboratories in science education and their potential to connect theoretical and practical learning. However, research continues to call for more purposeful integration of physical and virtual laboratory experiences according to learning objectives and contextual needs (Pavlou & Zacharia, 2024).

Despite these developments, limited empirical work has focused on integrating locally available materials, standard laboratory equipment, and virtual simulations within a structured instructional framework specifically designed to address students' least-mastered physics competencies. The present study examines a resource-adaptive approach to physics laboratory design that aligns least-mastered competencies with locally available materials, conventional laboratory equipment, and virtual simulations. The REFLECT instructional model provides a pedagogical sequence for organizing these resources around conceptual identification, inquiry, experimentation, evaluation, communication, and application. The study contributes empirical evidence concerning the feasibility, perceived usability, and learning outcomes associated with this integrated approach in a resource-constrained secondary STEM education setting. This resource-adaptive design responds to the practical realities of schools with varying levels of laboratory resources while maintaining opportunities for inquiry-oriented STEM learning.

The present study aims to design, develop, and validate a set of physics laboratory experiments targeted at students' least mastered competencies. Specifically, the study examined the validity and reliability of the developed experiments through expert evaluation and pilot testing. By integrating locally available materials, standard laboratory equipment, and virtual simulations within a REFLECT-guided framework, the study contributes a context-responsive approach to physics laboratory learning that may be relevant to other educational settings where access to conventional laboratory resources is limited.

Research Objectives

This study aimed to develop and validate physics laboratory experiments designed to address the least mastered competencies among senior high school students. Specifically, it sought to determine the effectiveness of the developed laboratory activities in improving students' conceptual understanding of physics concepts through expert validation and analysis of students' learning gains.

Specifically, the study aimed to:

1. Develop physics laboratory experiments aligned with the identified least mastered competencies using locally available materials, standard laboratory equipment, and virtual simulations.
2. Evaluate the validity of the developed laboratory experiments in terms of content, clarity of instructions, feasibility, and alignment with students' learning abilities as assessed by experts.
3. Determine the effectiveness of the validated laboratory experiments in improving students' physics achievement based on pre-test and post-test results.

LITERATURE REVIEW

Physics is widely recognized as one of the most challenging subjects for secondary students due to its abstract concepts and reliance on mathematical reasoning. Numerous studies have documented persistent learning difficulties and misconceptions among students, particularly in mechanics, energy, and motion-related topics. These challenges often result in low mastery of essential competencies and limited conceptual understanding, especially when instruction relies heavily on lecture-based approaches.

In the Philippine context, multiple research studies have documented ongoing issues with physics education. According to Diate and Mordeno (2021) numerous Filipino physics teachers experience significant teaching challenges and lack necessary competencies in their field. The educational challenges prompted Gerada (2021) to create and test instructional modules which focus on senior high school teachers. The research conducted by Lumampao (2023) revealed that students who participated in 5Es learning activities developed better scientific understanding and enhanced their ability to use scientific processes. The study by Magalong and Prudente (2020) demonstrated that combining mobile technology with traditional instruction methods creates better understanding of fundamental physics concepts such as energy and momentum among students.

Laboratory activities have long been regarded as an essential component of effective physics instruction. Research indicates that well-designed laboratory experiences promote active engagement, enhance conceptual understanding, and support the development of scientific reasoning skills (Hofstein & Lunetta, 2004). By allowing students to observe physical phenomena directly and test theoretical principles through experimentation, laboratory-based learning helps bridge the gap between abstract concepts and real-world applications (Wieman & Holmes, 2015). Liu and Sun (2021) observe that effective teacher competencies such as planning, experimentation facilitation, and professional values directly determine student learning outcomes. Teachers must also be culturally aware and creative in classroom practices (Ole, 2020). As emphasized in the article of Ole & Gallos (2021), the best measure to check the effectiveness of Physics teachers in teaching during these challenging times is to check the conceptual understanding of Grade 12-Senior High School (SHS) students in Science, Technology, Engineering, and Math (STEM) track. Students must have conceptual information regarding all the instructional functions of laboratories prior to conducting experiments.

Despite their recognized value, laboratory activities are often constrained by limited resources, inadequate equipment, and insufficient laboratory space, particularly in public secondary schools. Recent international research has examined how physical and virtual laboratory environments can be used independently or in combination to support STEM learning. Muilwijk and Lazonder (2023), through a meta-analysis of 35 studies, found no overall advantage of physical or virtual investigation for conceptual knowledge acquisition, suggesting that the choice of laboratory modality should be considered in relation to instructional and contextual conditions. Pavlou and Zacharia (2024) similarly emphasized that physical and virtual laboratories provide different but complementary affordances and that their selection or combination should be aligned with learning objectives. In addition, Rosli and Ishak (2024), through a systematic review of virtual laboratories in science education, identified their potential to connect theoretical and practical learning while

providing students with opportunities for flexible experimentation. These findings suggest that physical and virtual laboratory environments need not be viewed as competing alternatives; rather, they can be strategically combined to respond to specific learning objectives and contextual constraints.

Building on this international literature, the present study adopts a resource-adaptive approach by integrating locally available materials, standard laboratory equipment, and virtual simulations within a REFLECT-guided instructional framework. This approach differs from simply substituting virtual simulations for physical experimentation. Instead, the resources are used as complementary components of laboratory activities designed around students' least-mastered physics competencies. Such integration provides a potential way of maintaining hands-on and inquiry-oriented STEM learning even in settings where conventional laboratory resources are limited.

RESEARCH METHOD

Design

This study employed quantitative instructional development and evaluation design comprising laboratory activity development, expert validation, initial pilot testing, and classroom implementation. Changes in students' physics achievement were examined using a one-group pre-test–post-test design, while expert ratings and student perceptions were analyzed descriptively. As the study did not include a comparison group, the pre-test–post-test analysis was intended to identify changes associated with implementation rather than establish causal effectiveness. The study followed a sequence of design and development, expert validation, initial pilot testing, classroom implementation, and evaluation. Quantitative data were obtained through expert evaluation, pre-test and post-test assessments, and a student perception survey.

Ethical procedures were observed throughout the study. Permission to conduct the research was obtained from the school administration, and informed consent was secured from the participating students and their parents. Participation in the classroom implementation was voluntary.

The development of the physics experiments was guided by the REFLECT instructional model, which had been formulated in a prior phase of the research. REFLECT stands for Recognizing the concept, Engaging in discussions, Facilitating inquiry, Learning through execution, Evaluating results, Communicating findings, and Think critically and applying. These phases were integrated into the design of each experiment to make sure that learning went beyond procedural implementation towards greater conceptual comprehension. For instance, every activity started with the identification of the intended physics concept, then deliberate questions for peer discussion, inquiry time, and hands-on action. Reflection and communication activities were also included in the experiments to allow students to analyze findings, exchange experiences, and transfer learning into new situations. By using the REFLECT framework to connect the experiments, the materials attempted to be both pedagogically solid and sensitive to students' least mastered abilities. Although the REFLECT instructional model is referenced in this study, it is not discussed in full detail because the model itself was previously formulated based on an analysis of teachers' instructional practices and challenges in teaching physics. The present study does not focus on developing or validating the REFLECT model; rather, it utilizes the model as a guiding framework for designing physics laboratory experiments. The components of the REFLECT model informed the sequencing and structure of the laboratory activities to ensure alignment with actual classroom practices and instructional needs.

Sampling Techniques and Participants of the Study

Total enumerative sampling was used for the main classroom implementation. The study involved 137 Grade 12 STEM students from three sections of Antipolo City Senior High School during School Year 2024–2025.

The three sections constituted the participants in the main implementation of the developed laboratory experiments.

Four Grade 12 STEM sections were available during the study period. One section, comprising 45 students, was used for the initial pilot testing of the laboratory experiments, while the remaining three sections, comprising 137 students, participated in the main classroom implementation and final pilot testing. The initial pilot testing was conducted to identify issues related to the clarity, feasibility, and workability of the laboratory activities before their implementation with the three sections. The study was conducted from August to October 2024.

Procedure

Phase 1: Design and Experiment Development

The physics laboratory experiments were designed based on the least-mastered competencies identified in the Senior High School Physics curriculum. Each experiment was developed using the principles of the REFLECT instructional model, with activities structured to promote conceptual identification, inquiry, hands-on implementation, evaluation, communication, and application. The initial drafts included learning objectives, required materials, step-by-step procedures, guide questions, and expected outcomes.

The experiments were designed with consideration for the availability of resources in the school setting. Locally available materials, standard laboratory equipment, and virtual simulations were incorporated where appropriate to support accessibility, feasibility, and conceptual learning.

Table 1. Designed laboratory experiments based on least mastered competencies

Least Mastered Competencie	Using Locally available materials school	Using lab apparatus in	Using Physics simulations
Perform Addition of vectors		1	1
Solve for unknown quantities in equations involving one-dimensional uniformly accelerated motion	1	1	1
Use Newton's Laws of gravitation to infer gravitational force, weight, and acceleration due to gravity		1	1
Calculate range, time of flight, and maximum heights of projectiles	1		1
Solve problems involving work, energy, and power	1	1	
Relate the momentum, impulse, force, and time of contact in a system		1	
Apply the Concept of Buoyancy and Archimedes Principle	1		
Relate the amplitude, frequency, period displacement, velocity, and acceleratio of oscillating system			1
Define mechanical wave, longitudinal wave, transverse wave, periodic wave, and sinusoidal waves	1		1

Phase 2. Expert Validation of the Laboratory Experiments

The initial laboratory experiment drafts were submitted to a panel of expert validators consisting of physics educators, curriculum experts, and science education specialists. The validators evaluated the laboratory experiments using a standardized evaluation tool based on four criteria: content correctness, clarity of instructions, feasibility, and relevance to the targeted competencies. Responses were recorded using a four-point-point Likert scale. The response categories and corresponding numerical interpretation ranges were established before data analysis and applied consistently to the expert evaluation results. The results and recommendations from the expert evaluation were used to revise the laboratory experiments before pilot testing.

Phase 3. Initial Pilot Testing

One Grade 12 STEM section, consisting of 45 students, was used for the initial pilot testing of the laboratory experiments. This phase was conducted to identify issues related to the clarity of instructions, feasibility, workability, and logistical requirements of the activities before the main classroom implementation. Observations and feedback obtained during the initial pilot testing were considered in refining the laboratory experiments before their implementation with the three Grade 12 STEM sections.

Phase 4. Final Pilot Testing and Main Classroom Implementation

Three Grade 12 STEM sections comprising 137 students participated in the final pilot testing and main classroom implementation. Fifteen newly designed physics laboratory experiments were implemented over six weeks with 137 Grade 12 STEM students. The experiments addressed the identified least-mastered competencies through activities involving locally available materials, conventional laboratory apparatus, virtual simulations, or combinations of these resources, as appropriate to the intended learning objectives. Table 1 presents the competency–resource alignment; the correspondence between the nine listed competencies and the fifteen implemented experiments should be specified to clarify the instructional design. The activities involved guided instruction, hands-on experimentation, and application of theoretical concepts. A pre-test was administered before the implementation to establish students' baseline performance, followed by a post-test after the implementation to assess changes in their performance on the targeted physics competencies. A student perception survey was also administered after the implementation to obtain feedback regarding the clarity, usability, relevance, and perceived usefulness of the laboratory activities. The results of the pre-test, post-test, and student perception survey were analyzed to evaluate students' performance and perceptions following the implementation of the developed laboratory experiments.

Data Collection

Quantitative data were gathered primarily through expert evaluation, pre-test and post-test assessments, and a student perception survey. The pre-test was administered before the classroom implementation of the developed laboratory experiments to establish the students' baseline performance on the targeted least-mastered competencies. Following the implementation, the post-test was administered to determine changes in students' performance.

The pre-test and post-test scores were tabulated and statistically analyzed using a paired-samples t-test to determine whether a statistically significant difference existed between students' pre-test and post-test scores following the implementation of the laboratory experiments.

A student perception survey was also administered after the implementation. The survey responses were summarized using descriptive statistics, including mean and standard deviation, to describe students' perceptions of the laboratory activities in terms of their usability, relevance, and acceptability.

Research Instrument

The study used the following instruments and materials for data collection and evaluation: (1) a standardized evaluation tool for expert validation of the developed laboratory experiments, (2) a 50-item pre-test and post-test in Physics, and (3) a student perception survey questionnaire. The developed laboratory experiments served as the instructional materials implemented during the classroom phase of the study.

The expert evaluation tool was used to assess the laboratory experiments in terms of content correctness, clarity of instructions, feasibility, and relevance to the targeted competencies. The pre-test and post-test were used to assess students' performance on the identified least-mastered competencies, while the student

perception survey was administered after implementation to gather students' perceptions of the developed laboratory activities.

The researcher-prepared lesson plans were used as guides for instructional delivery during the laboratory activities. The research instruments underwent validation to ensure their content accuracy, clarity, and alignment with the objectives of the study.

Validation and Reliability Test of the Research Instruments

To establish the content validity of the researcher-developed instruments and laboratory experiments, five expert validators were selected based on their field of specialization, academic qualifications, and years of professional experience. The selection criteria included: (1) specialization in Physics or science education, (2) experience in instructional materials development or curriculum design, (3) experience in teaching or supervising science instruction, and (4) experience in assessment and evaluation. The panel consisted of Physics experts, science education specialists, and experienced master teachers in Physics.

The validators evaluated the developed laboratory experiments and research instruments in terms of their appropriateness, clarity, content accuracy, and alignment with the objectives of the study. Their comments and recommendations were considered in revising and improving the instruments and laboratory activities before implementation.

The 50-item pre-test/post-test was pilot-tested with 45 Grade 12 STEM students from one section prior to the main classroom implementation. The internal consistency of the test was determined using Cronbach's alpha. The analysis yielded a Cronbach's alpha coefficient of 0.888, indicating good internal consistency and supporting the suitability of the test for measuring students' performance on the targeted physics competencies.

Table 2. Result of Test Reliability Using Cronbach Alpha

Statistic	Value
Cronbach's Alpha	0.888
Number of Items	50
Reliability Interpretation	Good

FINDING AND DISCUSSION

Designed Laboratory Experiments in Physics

The laboratory experiment design was grounded in the least acquired skills in physics from students' performance records. Each experiment was meant to offer structured opportunities for learners to actively investigate and utilize the aimed concepts. In developing the activities, the researcher based them on the sequence of a laboratory structure that involved objectives, list of necessary materials, step-by-step protocols, guide questions, and expected outcomes.

In designing the experiments, careful consideration was also given to the availability of resources in the school setting. Whenever feasible, activities made use of locally found materials to ensure the experiments were cost-efficient and sustainable. To supplement hands-on exercises, online simulations were also incorporated so that students could see abstract ideas and take their learning further than the physical realm. Standard lab equipment found in schools was also used to provide consistency with

available facilities and curriculum needs. The integration of locally available materials, conventional laboratory apparatus, and virtual simulations illustrates a resource-adaptive strategy in which laboratory resources are selected according to competency requirements and available instructional conditions. Rather than treating these resources as interchangeable substitutes, the approach positions them as potentially complementary means of supporting observation, manipulation, conceptual visualization, and inquiry. This design principle may inform the development of physics laboratory activities in schools with differing levels of resource availability, although its applicability beyond the present setting requires further investigation.

To strengthen the instructional value of the experiments, the activities were designed in a sequence that corresponds to sensible learning progression. The students were initially introduced to the important concepts, invited to engage in discussions, led through the procedure execution, and subsequently requested to interpret results, report findings, and consider applications. This design was intended to support pedagogically meaningful laboratory experiences by connecting feasible experimental procedures with opportunities for conceptual inquiry, collaborative discussion, and reflection. However, the extent to which these activities independently enhanced critical thinking was not directly established by the measures employed in this study.

Table 3. Results of Science Teachers and Specialists Responses on the Evaluation of Designed Laboratory Activities

Statement	Mean	SD	Adjectival rating	Interpretation
1. The objectives in the laboratory experiments are behaviorally stated	3.87	.342	Strongly Agree	High
2. The objectives are clear and relevant to the laboratory experiment	3.87	.342	Strongly Agree	High
3. The objectives are measurable and attainable	3.87	.342	Strongly Agree	High
4. The procedure on how to go about the laboratory experiments are clearly presented	3.87	.342	Strongly Agree	High
5. The steps in the procedure are easy to follow even without much help from the teacher	3.56	.512	Strongly Agree	High
6. The illustrations and diagrams are provided and well laid out, properly drawn and labeled	3.25	.447	Agree	Moderately High
7. The laboratory experiments are logically arranged	3.69	.479	Strongly Agree	High
8. The questioning in the laboratory experiments can lead the students to the concept being presented	3.81	.403	Strongly Agree	High
9. The language used in the laboratory experiment is suitable to the students' level of comprehension	3.87	.342	Strongly Agree	High
10. The laboratory experiments can arouse the students' curiosity and interest	3.75	.447	Strongly Agree	High
11. The laboratory experiments can develop students' critical thinking	3.87	.342	Strongly Agree	High
12. The laboratory experiments give opportunity for the students to discover for themselves the concept being studied	3.94	.250	Strongly Agree	High
13. The number of questions is enough to test the understanding of the concepts learned from the experiment	3.81	.403	Strongly Agree	High
14. The style or format of the laboratory experiment is easy to read and follow	3.94	.250	Strongly Agree	High
15. The locally available materials used in the laboratory experiments save money and time	3.81	.403	Strongly Agree	High

Statement	Mean	SD	Adjectival rating	Interpretation
16. The locally available materials used in the laboratory experiments are environment friendly	3.81	.403	Strongly Agree	High
17. The procedure in the laboratory experiment is easy to follow using laboratory apparatuses in school	3.81	.403	Strongly Agree	High
18. The laboratory experiment using laboratory apparatuses guide the learners to perform well during the laboratory proper	3.81	.403	Strongly Agree	High
19. The laboratory experiment using laboratory apparatuses guide the learners to perform well during the laboratory proper	3.50	.516	Strongly Agree	High
20. The laboratory experiment using physics simulation helps students develop critical thinking skills and encourage scientific inquiry	3.87	.342	Strongly Agree	High
Overall Mean	**3.78**	**.217**	**Strongly Agree**	**High**

Note. Values and wording follow the supplied table image. Items 18 and 19 have identical statements in the source, but different means and SDs; please

The results of the evaluation of the designed laboratory experiments reflect the overall quality of the developed activities. Teachers and experts described the experiments as explicit, logically structured, and stimulating, with strong emphasis on student inquiry and exploration. Recent studies have emphasized that inquiry-oriented and well-structured laboratory activities significantly enhance students' conceptual understanding and engagement in physics and science learning (Makransky et al., 2020; Zacharia et al., 2022). Notably, the highest-rated aspects were the format and readability of the experiments and the opportunities for individual exploration (both M = 3.94, SD = 0.250), indicating that clear presentation and active student involvement are particularly valued by educators and specialists. Clear instructional design and well-organized laboratory materials have been identified as critical factors influencing the effectiveness and usability of science laboratory activities (Abrahams et al., 2021; Wieman, 2021).

The utilization of locally sourced materials and easily accessible physical equipment further enhanced the feasibility and sustainability of the experiments. This finding aligns with recent literature emphasizing the importance of context-responsive and resource-efficient laboratory designs, especially in school settings with limited facilities (Mupa & Chinooneka, 2020; UNESCO, 2021). However, the results also revealed areas for improvement, particularly in the quality of visual aids such as drawings and diagrams (M = 3.25, SD = 0.447). Contemporary research highlights that clear and accurate visual representations are essential for supporting students' conceptual understanding in physics; thus, improving diagrams and visual supports may further enhance the pedagogical effectiveness of the laboratory activities (Gilbert & Justi, 2021; Tang et al., 2020). Addressing these limitations is expected to improve the overall instructional quality of the designed experiments and promote more effective learning in physics education.

Pilot Testing of the Designed Laboratory Experiments

Initial Pilot Testing

One Grade 12 STEM section consisting of 45 students participated in the initial pilot testing of the laboratory experiments. This phase focused on identifying areas for improvement, particularly regarding the clarity of instructions, feasibility, workability, and logistical requirements of the activities. Observations and feedback obtained during the initial pilot testing were considered in refining the laboratory experiments before their implementation with the three Grade 12 STEM sections.

Final Pilot Testing

Three Grade 12 STEM sections comprising 137 students participated in the final pilot testing. Fifteen newly designed laboratory experiments were implemented over a period of six weeks. The activities involved guided instruction, hands-on experimentation, and application of theoretical concepts. A pre-test was administered before the implementation to establish students' baseline performance, followed by a post-test after the implementation to assess changes in their performance on the targeted physics competencies.

Table 4. STEM Students Perception on the Implementation of the Designed Laboratory Experiment

Statement	Mean	SD	Adjectival Rating	Interpretation
1. The laboratory experiment encourages maximum participation among members within the group.	3.50	.502	Agree	Moderately High
2. The procedure of the lab experiment for Physics simulation leads you to navigate and understand physics concepts.	3.30	.460	Agree	Moderately High
3. The experiment assists you in developing independence as you explored physics simulation guided by the laboratory procedure of the newly designed laboratory experiment.	3.35	.479	Agree	Moderately High
4. The lab experiment helps you manipulate local, cheap, and readily available materials.	3.29	.456	Agree	Moderately High
5. The laboratory procedure in the laboratory experiment is easy to follow using laboratory apparatuses in school.	3.36	.481	Agree	Moderately High
6. The lab experiment using lab apparatuses guides you to perform well during the laboratory proper.	3.45	.499	Agree	Moderately High
7. The laboratory experiments are logically arranged.	3.36	.483	Agree	Moderately High
8. The laboratory experiment is suitable enough for both individual or group activity.	3.35	.479	Agree	Moderately High
9. You are able to quantitatively tabulate data using the steps from the lab experiment.	3.27	.446	Agree	Moderately High
10. The materials used for the laboratory experiment prove easy to manipulate even without the close supervision of the science teacher.	3.22	.415	Agree	Moderately High
Overall Mean	3.35	—	Agree	Moderately High

The STEM students' perceptions of the implementation of the designed laboratory experiments indicate generally positive responses toward the activities. The overall mean rating of 3.35 (SD = 0.284), with an adjectival rating of Agree and an interpretation of Moderately High, suggests that students perceive the laboratory activities as beneficial to their learning. This finding aligns with recent studies emphasizing that well-designed and structured laboratory experiences positively influence students' engagement and understanding of physics concepts (Zacharia et al., 2022; Wieman, 2021). Students consistently reported that the activities were organized, interesting, and helpful in studying physics principles, supporting contemporary research that highlights the role of coherent laboratory design and active engagement in enhancing students' learning experiences in STEM education (Abrahams et al., 2021; Makransky et al., 2020).

Table 5. Outcomes of the Utilization of the Newly Designed Laboratory Experiments in Physics

	Mean	S.D.	t-value	p-value	Sig
Pre-Test	19.91	3.953	-35.624	P = 0.000 < 0.05	S
Post Test	40.50	5.391			

The outcomes of the utilization of the newly designed laboratory experiments in Physics, as evidenced through pilot testing, demonstrate a substantial improvement in students' academic performance. The results show a marked increase in mean scores from the Pre-Test (M = 19.91, SD = 3.953) to the Post-Test (M = 40.50, SD = 5.391), indicating significant gains in students' understanding of physics concepts and problem-solving abilities following the implementation of the laboratory experiments. Similar findings have been reported in recent studies, which highlight that inquiry-based and hands-on laboratory experiences significantly enhance students' conceptual understanding and learning outcomes in physics education (Zacharia et al., 2022; Wieman, 2021).

A paired-samples t-test indicated a statistically significant difference between students' pre-test scores (M = 19.91, SD = 3.953) and post-test scores (M = 40.50, SD = 5.391), $t(136) = -35.624$, $p < .001$. The mean increase of 20.59 points indicates a substantial improvement in measured physics achievement following the implementation of the developed laboratory activities. Nevertheless, the absence of a comparison group limits the extent to which this improvement can be attributed specifically to the intervention. This result confirms that the observed improvement in students' performance is statistically significant and unlikely to be attributed to chance. Contemporary research supports that structured laboratory interventions grounded in inquiry-based learning principles contribute to meaningful learning gains by promoting active engagement, conceptual clarity, and the application of theoretical knowledge to practical situations (Abrahams et al., 2021; Makransky et al., 2020). Overall, the findings indicate a statistically significant improvement in students' performance following the implementation of the laboratory experiments developed.

Based on the evaluation of the newly developed laboratory experiments, a number of worthwhile feedback and suggestions resulted. Students in general were positively inclined, although the lowest-scoring item presented an area for greater facilitation of independent handling of materials and suggested that teacher supervision is still valuable in laboratory work. Participants highlighted the efficacy of employing locally available materials, which improved understanding, participation, and implementation of physics principles into real-life contexts by virtue of being within reach and affordable. Physics simulations were also commended for enabling students to delve into and visualize intricate ideas, achieving greater comprehension through prolonged interaction with theories. Application of laboratory equipment was also viewed as helpful in enhancing students' hands-on learning, precision, problem-solving skills, and confidence in performing experiments. Additional recommendations involved the inclusion of more technology-based experiments, and more experimental activities

CONCLUSIONS

This study developed and validated physics laboratory experiments designed to address students' least-mastered competencies in physics. The integration of locally available materials, standard laboratory equipment, and virtual simulations made the activities accessible, practical, and adaptable to real classroom settings. Expert validation confirmed the quality of the developed experiments in terms of content accuracy, clarity of instructions, and suitability to students' learning abilities. The observed improvement in students' post-test performance following the implementation of the experiments indicates enhanced learning outcomes across selected challenging physics topics. The findings provide preliminary empirical support for the feasibility and educational relevance of integrating locally available materials, conventional laboratory equipment, and

virtual simulations within a REFLECT-guided physics laboratory design. Expert evaluations and student perceptions indicated generally favorable assessments, while pre-test–post-test results demonstrated improved achievement following implementation. The principal contribution of the study lies in illustrating how competency-targeted laboratory activities can be organized across different resource modalities. Nevertheless, the single-school setting and absence of a comparison group limit causal interpretation and broader generalization.

The findings should be interpreted in light of the study's one-group pre-test/post-test design. Because no comparison group was included, the observed improvement cannot be attributed solely to the developed laboratory experiments. The results therefore indicate improvement associated with the implementation of the intervention rather than definitive evidence of a causal effect. Future research may employ comparison or control groups, larger and more diverse samples, and longer implementation periods to further examine the contribution and transferability of the resource-adaptive laboratory approach across different STEM educational contexts.

LIMITATION & FURTHER RESEARCH

This study was limited to one senior high school and a relatively small group of participants, which may restrict the generalizability and transferability of the findings to other educational contexts. The implementation focused on selected least-mastered competencies in physics and employed a one-group pre-test/post-test design; therefore, the observed improvement cannot be attributed solely to the developed laboratory experiments in the absence of a comparison group. The study also examined short-term learning outcomes within a limited implementation period. Future studies may involve multiple schools, larger and more diverse samples, comparison or control groups, and longer implementation periods to examine sustained learning outcomes and strengthen evidence regarding the contribution of resource-adaptive laboratory approaches to STEM learning. Further research may also extend the instructional design framework to other physics topics, grade levels, or science disciplines to examine its applicability across varied educational contexts.

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