



Integration of Physical and Simulation-Based Laboratory Activities as Predictors of Score Gains in Science

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Abstract

This study examined the integration of physical and simulation-based laboratory activities as predictors of students' gain scores in science among Grade 12 STEM students at St. Paul University Surigao during Academic Year 2025–2026. The study determined students' conceptual understanding, science process skills, application of scientific knowledge, and the extent to which integrated laboratory activities were implemented in science instruction. A one-group pretest-posttest design with descriptive-correlational components was used. The participants were 184 Grade 12 STEM students selected through total enumeration. Data were collected using validated pretest and posttest assessments, laboratory worksheets, performance-based rubrics, survey questionnaires, and lesson plans. Mean, standard deviation, Wilcoxon signed-rank test, and Spearman's rank correlation coefficient were used for analysis. Findings showed that students reached very high levels of conceptual understanding, science process skills, and application of scientific knowledge after the implementation of integrated laboratory activities. The extent of integration was also rated very satisfactory across instructional planning and implementation, learning engagement and participation, resource utilization and accessibility, and assessment and feedback mechanisms. A significant difference was found between pretest and posttest scores, indicating that the integrated laboratory approach improved students' conceptual understanding. However, no significant relationships were found among conceptual understanding, science process skills, and application of scientific knowledge. The study concludes that integrating physical and simulation-based laboratory activities enhances science learning outcomes and provides meaningful laboratory experiences for learners.

Keywords: Gain Scores, Laboratory Activities, Science Education, Simulation-Based Laboratory, Physical Laboratory, Conceptual Understanding

1. Introduction

Science education is expected to develop scientific literacy, conceptual understanding, inquiry competence, and the capacity to apply knowledge to real situations. However, science instruction in many Philippine schools continues to face constraints linked to limited laboratory facilities, outdated equipment, large class sizes, and insufficient opportunities for students to translate theoretical ideas into observable and measurable outcomes. These conditions weaken students' score gains and may reduce the quality of laboratory-based learning.

The integration of physical and simulation-based laboratory activities offers a practical response to these limitations. Physical laboratory activities allow students to manipulate real equipment, observe phenomena directly, and develop hands-on skills. Simulation-based activities, on the other hand, provide interactive visualization, safe repetition, and opportunities to explore abstract scientific concepts that may be difficult to demonstrate using physical materials alone. When both modalities are combined, learners are given concrete experiences and digital representations that may strengthen conceptual understanding, science process skills, and the application of scientific knowledge.

The study focused on Grade 12 STEM students and examined whether the integration of physical and simulation-based laboratory activities predicted score gains in science. It also assessed the extent of integration across instructional planning and implementation, learning engagement and participation, resource utilization and accessibility, and assessment and feedback mechanisms.

2. Theoretical and Conceptual Framework

The study was anchored on Constructivist Learning Theory and Experiential Learning Theory. Constructivism explains that learners actively construct knowledge through interaction, exploration, and reflection. In science instruction, this means that students build understanding when they manipulate materials, observe outcomes, ask questions, and connect their experiences with scientific principles. Experiential Learning Theory further supports laboratory-based learning because it views learning as the transformation of experience into knowledge through concrete activity, reflection, conceptualization, and application.

The conceptual framework positions integrated physical and simulation-based laboratory activities as the main instructional intervention. The expected outcomes include improved conceptual understanding, stronger science process skills, better application of scientific knowledge, and increased score gains in science. The model also recognizes implementation domains such as instructional planning, engagement, resource use, and assessment-feedback mechanisms as conditions that support meaningful laboratory instruction.

Conceptual Framework for Integrated Physical and Simulation-Based Laboratory Activities

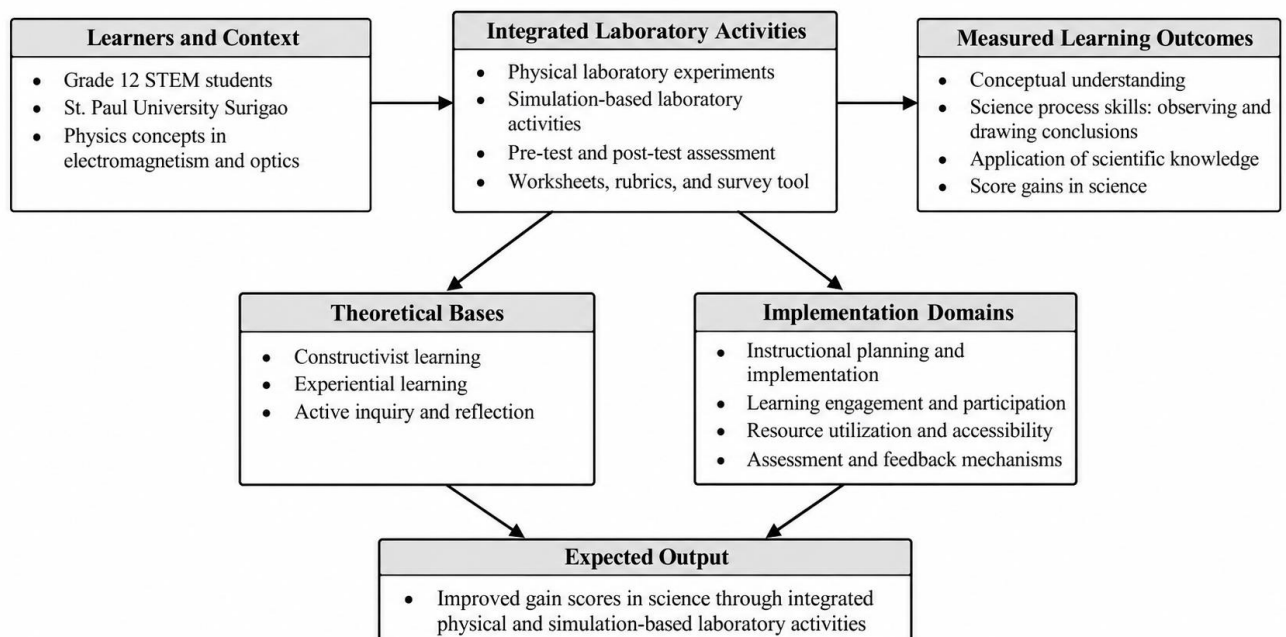


Figure 1. Conceptual framework for integrated physical and simulation-based laboratory activities.

Figure 1 presents the conceptual framework for the integration of physical and simulation-based laboratory activities in science instruction. It shows how the study connects the learners' context, instructional intervention, theoretical bases, implementation domains, measured learning outcomes, and expected output.

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The framework begins with the learners and context, which include Grade 12 STEM students of St. Paul University Surigao and the Physics concepts in electromagnetism and optics. These represent the participants and subject areas where the integrated laboratory activities were applied.

At the center of the framework are the integrated laboratory activities. These include physical laboratory experiments, simulation-based laboratory activities, pre-test and post-test assessment, worksheets, rubrics, and survey tools. This component represents the main instructional approach used in the study. It combines hands-on experimentation with digital simulations to strengthen students' understanding of abstract Physics concepts.

The framework then identifies the measured learning outcomes, which include conceptual understanding, science process skills, application of scientific knowledge, and score gains in science. These outcomes show how the effectiveness of the integrated laboratory approach was evaluated.

The lower part of the figure shows the theoretical bases of the study. These include constructivist learning, experiential learning, active inquiry, and reflection. These theories support the idea that students learn more effectively when they actively explore, manipulate materials, observe results, and reflect on their learning experiences.

The figure also includes the implementation domains, namely instructional planning and implementation, learning engagement and participation, resource utilization and accessibility, and assessment and feedback mechanisms. These domains show the key conditions needed for the successful use of integrated laboratory instruction.

Finally, the framework leads to the expected output, which is improved gain scores in science through the integration of physical and simulation-based laboratory activities. Overall, Figure 1 explains that the study examines how combining real laboratory work and simulation-based activities can improve students' conceptual understanding, science process skills, application of scientific knowledge, and overall science performance.

3. Methodology

The study employed a one-group pretest-posttest design with descriptive-correlational components. This design allowed the researcher to measure students' conceptual understanding before and after the implementation of integrated laboratory activities and to examine relationships among conceptual understanding, science process skills, and application of scientific knowledge.

The participants were 184 Grade 12 STEM students of St. Paul University Surigao during Academic Year 2025–2026. Total enumeration sampling was used because the entire population of eligible Grade 12 STEM learners was included. Data were gathered using validated pretest and posttest assessments, laboratory worksheets, performance-based rubrics, survey questionnaires, and lesson plans. The intervention integrated hands-on laboratory activities

with simulation-based activities in selected physics topics, particularly electromagnetism and optics.

Descriptive statistics, including mean and standard deviation, were used to describe students' performance and the extent of implementation. The Wilcoxon signed-rank test was used to determine significant differences between pretest and posttest scores. Spearman's rank correlation coefficient was used to determine relationships among conceptual understanding, science process skills, and application of scientific knowledge.

4. Results and Discussion

Table 1. Students' Conceptual Understanding Before the Intervention

Conceptual understanding indicator	M	SD	Interpretation
Lenz's Law: induced electric field, magnetic field, and current	2.29	1.25	Moderate
Conditions for total internal reflection	1.99	0.99	Moderate
Dispersion in relation to Snell's Law	2.91	1.22	Moderate
Image formation using reflection, refraction, and paraxial approximation	3.10	1.13	High
Mirror and lens properties in relation to object and image distance and size	2.98	1.02	Moderate

Table 1 shows that students' pretest scores were generally within the moderate level, except for image formation, which was rated high. This suggests that students entered the intervention with partial understanding of electromagnetism and optics concepts. The lowest mean was recorded for total internal reflection, showing that abstract optical concepts remained difficult before the integrated laboratory intervention.

Table 2. Students' Conceptual Understanding After the Intervention

Conceptual understanding indicator	M	SD	Interpretation
Lenz's Law: induced electric field, magnetic field, and current	5.41	0.90	Very High
Conditions for total internal reflection	5.55	0.85	Very High
Dispersion in relation to Snell's Law	5.73	0.57	Very High
Image formation using reflection, refraction, and paraxial approximation	5.32	0.83	Very High
Mirror and lens properties in relation to object and image distance and size	5.65	0.73	Very High

Table 2 shows a clear improvement after the implementation of physical and simulation-based laboratory activities. All indicators were interpreted as very high. The highest posttest mean was recorded for dispersion in relation to Snell's Law, while the lowest posttest mean was still within

the very high level. This indicates that the combined laboratory approach helped students visualize abstract physics concepts, connect theory with observable phenomena, and improve conceptual mastery.

Table 3. Students' Science Process Skills

Science process skill	M	SD	Interpretation
Observing	13.40	0.80	Very High
Drawing conclusions	13.30	0.84	Very High

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Table 3 indicates that students demonstrated very high science process skills in observing and drawing conclusions. The results suggest that the integrated laboratory approach helped students identify relevant details, record observations, and interpret evidence from laboratory activities. The close mean scores also show that the students were able to move from data gathering to evidence-based reasoning.

Table 4. Application of Scientific Knowledge

Indicator	M	SD	Interpretation
Application of scientific knowledge	17.40	2.02	Very High

Table 4 shows that students achieved a very high level in the application of scientific knowledge based on laboratory worksheet scores. This means that students were able to apply learned physics concepts to practical laboratory tasks. The result supports the value of laboratory worksheets as tools for connecting conceptual understanding with problem-solving and real laboratory performance.

Table 5. Extent of Integration of Physical and Simulation-Based Laboratory Activities

Domain	M	SD	Interpretation
Instructional planning and implementation	3.75	0.31	Very Satisfactory / Exceeds Expectations
Learning engagement and participation	3.90	0.14	Very Satisfactory / Exceeds Expectations
Resource utilization and accessibility	3.85	0.14	Very Satisfactory / Exceeds Expectations
Assessment and feedback mechanisms	3.90	0.14	Very Satisfactory / Exceeds Expectations

Table 5 shows that the integration of physical and simulation-based laboratory activities was rated very satisfactory in all domains. The highest mean scores were recorded for learning engagement and participation and assessment and feedback mechanisms. This means that the intervention was not limited to the use of laboratory tools but was supported by active participation, collaboration, aligned assessment, and feedback. Instructional planning and implementation received the lowest mean, although it was still very satisfactory, indicating that further strengthening of planning consistency may improve implementation.

Table 6. Significant Difference Between Pretest and Posttest Scores

Conceptual understanding indicator	W	p-value	Interpretation
Lenz's Law	47.5	< .001	Significant
Total internal reflection	12	< .001	Significant
Dispersion and Snell's Law	10	< .001	Significant
Image formation	95	< .001	Significant
Mirror and lens properties	72.5	< .001	Significant

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Table 6 shows that all conceptual understanding indicators had p-values lower than 0.05. The null hypothesis was rejected for each indicator, confirming a significant difference between students' pretest and posttest scores. These results indicate that the integration of physical and simulation-based laboratory activities significantly improved students' conceptual understanding in science.

Table 7. Correlation Among Conceptual Understanding, Science Process Skills, and Application of Scientific Knowledge

Variable pair	rho	p-value	Interpretation
Conceptual understanding and observing	0.005	0.945	Not significant
Conceptual understanding and drawing conclusions	-0.11	0.137	Not significant
Conceptual understanding and application of scientific knowledge	0.071	0.336	Not significant
Observing and application of scientific knowledge	-0.04	0.588	Not significant
Drawing conclusions and application of scientific knowledge	-0.01	0.898	Not significant

Table 7 shows that no significant relationships were found among conceptual understanding, science process skills, and application of scientific knowledge. Although students performed highly in all areas, the correlation results suggest that these learning outcomes may develop through different but complementary learning processes. Conceptual understanding may depend on comprehension and visualization of scientific principles, while science process skills and application may require repeated practice, interpretation, and transfer of knowledge to laboratory tasks.

5. Conclusion

The study concludes that the integration of physical and simulation-based laboratory activities is an effective instructional approach for improving students' science learning outcomes. The significant improvement from pretest to posttest demonstrates that combining hands-on experiments with simulation-based learning strengthens students' conceptual understanding, especially in abstract physics topics such as electromagnetism and optics. Students also demonstrated very high science process skills and very high application of scientific knowledge, indicating that integrated laboratory instruction supports both inquiry and practical application. However, the absence of significant correlations among conceptual understanding, science process skills, and application of scientific knowledge suggests that these outcomes should be developed intentionally through distinct but aligned instructional tasks. Overall, integrated laboratory instruction provides a meaningful, interactive, and resource-responsive approach to science teaching.

6. Recommendations

Based on the findings, science teachers should continue integrating physical and simulation-based laboratory activities as a regular instructional strategy, especially in topics that require visualization of abstract concepts. Lesson plans should deliberately connect physical experiments, simulations, worksheets, rubrics, and feedback mechanisms to ensure alignment among objectives, activities, and assessment. Schools should provide adequate laboratory materials, simulation tools, internet access, and teacher training to sustain implementation. Teachers should also design learning activities that explicitly connect conceptual understanding with observing, drawing conclusions, and applying scientific knowledge. Future researchers may conduct comparative or longitudinal studies to determine whether integrated laboratory instruction has lasting effects on retention, problem-solving, and higher-order science process skills.

Declaration of Interests

The authors declare no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Funding

No external funding was reported for this study.

Ethical Statement

The study followed appropriate ethical procedures for educational research. Participation was limited to academic activities relevant to the study, and data were handled with confidentiality.

Data Availability

The data supporting the findings of this study may be made available by the corresponding author upon reasonable request, subject to institutional policies.

AI Usage Statement

AI-assisted tools were used only for language editing, formatting, and manuscript organization. The authors remain responsible for the academic content, data interpretation, and final version of the manuscript.

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