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Mobile Simulation-Based Learning (MSBL): An Integrated Approach to Enhance Hands-On Instruction in Studying Basic Electronics

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Abstract

Technology integration in technical and vocational education has gained attention as educators seek innovative methods to enhance learning effectiveness. This study investigates the effectiveness of integrating Mobile Simulation-Based Learning (MSBL) with traditional hands-on laboratory instruction in enhancing students' learning performance in basic electronics. A quasi-experimental mixed-methods approach with a pretest-posttest control group design was employed, involving 40 higher education students. Learning performance was assessed using researcher-developed multiple-choice tests, while semi-structured interviews captured students' perceptions. Results indicated significant improvement in learning outcomes for both groups; however, the experimental group showed a notably greater increase in scores (mean gain = 9.10) compared to the control group (mean gain = 6.85). This suggests that MSBL uniquely facilitates deeper conceptual understanding and practical skill acquisition due to its accessibility, interactive nature, and seamless integration with physical laboratory experiences. Students reported increased flexibility, enhanced metacognitive awareness, and a smoother transition between theoretical and practical learning environments. Practically, this study underscores the scalability and effectiveness of MSBL compared to traditional digital tools, offering institutions a more adaptable and cost-effective approach to delivering technical education. The findings recommend systematic MSBL integration into TVET curricula and specialized instructor training for optimal implementation, ultimately improving students' competency and industry readiness.

1. Introduction

The rapid evolution of technology has significantly transformed educational practices, necessitating innovative approaches to meet the needs of today's digitally adept learners. Advances in educational technology have improved teaching environments, promoting the integration of digital tools into academic settings (Allataifeh & Aziz, 2024). As digital natives, students are more responsive to interactive, visually rich learning environments, making technology integration vital for improving outcomes (Arvind, 2024; Patteti, 2021). Given the rising demand for skilled technical professionals, Technical and Vocational Education and Training (TVET) institutions increasingly adopt technology-enhanced learning to optimize educational experiences.

TVET equips individuals with practical skills necessary for employment and lifelong learning (Yusvana, 2025). As industries evolve technologically, a workforce proficient in both theoretical and practical expertise is increasingly vital. Globally, TVET is recognized as essential for socio-economic development, particularly in developing countries facing skills mismatches and youth unemployment (Ogur, 2023). This global recognition underscores the urgency for TVET institutions to modernize instructional approaches. One notable national response can be observed in the Philippines, where the Technical Education and Skills Development Authority (TESDA) has actively promoted technology-enhanced learning through initiatives such as the TESDA Online Program (TOP). This program offers free, accessible online courses to support technical education and skills training (Orbeta, 2021). In response to Industry 4.0, TVET institutions face pressure to innovate instructional methods, ensuring learners are job-ready, adaptable, digitally literate, and prepared for ongoing upskilling (Wickramasinghe & Wickramasinghe, 2024; Ishar et al., 2020).

To effectively address these evolving demands, simulation-based learning (SBL) has emerged as a significant pedagogical innovation, immersing learners in virtual environments that closely replicate real-world scenarios (Sapuan & Chan, 2024). While traditional instructional methods, such as lectures and hands-on laboratory experiments, are foundational in technical education, debates persist regarding SBL's effectiveness compared to laboratory experiments. Some researchers propose replacing practical laboratories with simulations due to their structured conceptual learning benefits (Cabural, 2024). Conversely, others advocate for simulations as complementary, highlighting the indispensable role of hands-on laboratory work in skill development (Sarwono et al., 2022). This debate is particularly relevant in competency-based TVET programs like basic electronics, where mastery of circuit components and troubleshooting skills directly impacts students' industry readiness (Westcott & Westcott, 2023). Studies have indicated that interactive simulations, such as PhET (Najib et al., 2022) and Circuit Construction Kit (Perkins, 2020), enhance conceptual understanding, though traditional hands-on instruction remains critical for practical proficiency and real-world application.

To capitalize on the strengths of both methods, an integrated instructional approach has been proposed. Mobile learning, particularly mobile simulation-based learning (MSBL), supports this integration by providing flexible, accessible, and interactive learning experiences via mobile devices (Abdullah et al., 2024; Ghoulam et al., 2024). Given the widespread ownership of smartphones and tablets, learners now have unprecedented access to education anytime and anywhere overcoming classroom and laboratory constraints (Suryavanshi, 2024).

Despite existing research on simulation-based learning (SBL), the integration of MSBL with traditional laboratory instruction in basic electronics remains underexplored. This study aims to evaluate the effectiveness of combining MSBL with traditional laboratory instruction on students' learning performance in basic electronics. Specifically, it seeks to determine whether this combined instructional approach leads to a better learning outcome than hands-on laboratory instructions alone. Additionally, it investigates learners' perceptions to gain deeper insights into their experiences. Findings from this research will contribute to evidence-based practices in digitally enhanced TVET instruction, supporting educators in developing competent learners equipped with essential theoretical knowledge and practical skills.

2. Review of Related Literature

2.1 Hands-On Laboratory Instruction

Hands-on laboratory instruction remains a cornerstone of technical education, especially in TVET programs that prioritize competency-based learning. This instructional method provides students with direct, experiential interaction with tools, components, and equipment, reinforcing practical skills essential for workforce readiness (Tokatlidis et al., 2024). In electronics education, hands-on laboratory experiences are crucial for developing proficiency in circuit construction, troubleshooting, and measurement techniques, skills difficult to replicate fully in virtual environments. Tokatlidis et al. (2024) found that students engaged in physical electronics experiments exhibited higher confidence and accuracy in circuit assembly than those taught solely through theoretical instruction. Similarly, James et al. (2024) emphasized the role of hands-on laboratory work in enhancing psychomotor skills, problem-solving abilities, and teamwork which are critical competencies in technical fields.

Despite these advantages, traditional laboratory instruction faces challenges including limited equipment access, high maintenance costs, and safety concerns, particularly in resource-constrained institutions (Portillo et al., 2024). Moreover, structured and time-bound laboratory sessions may not adequately accommodate diverse learning paces (Halim et al., 2024). These constraints underscore the necessity for complementary instructional strategies to optimize learning outcomes.

2.2 Simulation-Based Learning in Technical Education

Simulation-Based Learning (SBL) has gained recognition in technical education for immersing learners in virtual environments replicating real-world systems. In electronics education, where abstract concepts such as current flow, resistance, and circuit behavior must translate into practical competencies, SBL offers effective scaffolding for experiential learning and conceptual mastery (Sapuan & Chan, 2024; Tokatlidis et al., 2024). Grounded in experiential learning theory (Kolb, 1984), SBL enables active experimentation and reflective observation, reinforcing theoretical comprehension through practical application.

Research consistently highlights the cognitive benefits of SBL. Alqahtani et al. (2020) reported that students using circuit simulations achieved higher conceptual clarity and troubleshooting accuracy compared to those receiving traditional lectures. Similarly, Abekiri et al. (2024) noted that SBL mitigates constraints such as limited laboratory equipment and safety concerns, expanding learning opportunities, particularly in resource-limited settings. Studies indicate that SBL effectively supports competency-based learning by allowing learners to practice, make mistakes, and refine their skills in a simulated setting before transitioning to real world application (Phacharoen & Akatimagool, 2019). A systematic review by Cabural (2024) corroborates these findings, demonstrating that SBL significantly enhances conceptual understanding and engagement compared to conventional methods.

Despite these advantages, debates persist about SBL's capacity to replace hands-on laboratories entirely. While simulations provide structured and controlled environments ideal for conceptual mastery (Mohammed et al., 2022), researchers argue that SBL alone may not sufficiently develop practical, hands-on skills crucial for technical fields (Sarwono et al., 2022). The consensus suggests a complementary role for SBL alongside hands-on instruction, particularly within skill-intensive disciplines like electronics.

2.3 Mobile Simulation - Based Learning

With the widespread adoption of mobile technologies in education, Mobile Simulation-Based Learning (MSBL) has emerged as a flexible and accessible instructional strategy. MSBL employs mobile applications to deliver interactive simulations, allowing students to engage in virtual experimentation beyond traditional classroom and laboratory constraints (Kathane & Dhole, 2024). Grounded in Constructivist theory, MSBL encourages active learning and self-directed exploration, facilitating deeper understanding and improved retention (Zhao & Lin, 2022).

Juera (2022) compared academic outcomes in electronics courses, revealing that students exposed to combined MSBL and hands-on laboratory approaches demonstrated significantly higher performance in circuit analysis and troubleshooting than their peers receiving conventional instruction. This finding aligns with a meta-analysis by Kaur (2022), which confirmed that MSBL consistently enhances student engagement and learning outcomes across various educational contexts due to its interactive and accessible nature.

However, implementing MSBL faces barriers, particularly in developing countries, including limited internet access and availability of mobile devices (Chikumba, 2024). Additionally, educators caution against potential over-reliance on digital simulations, emphasizing the necessity of balancing virtual simulations with physical laboratory practice to ensure comprehensive skill development (Tokatlidis et al., 2024).

In summary, by integrating theoretical frameworks such as Kolb's Experiential Learning Theory and Constructivism, this literature review provides a strong basis for understanding how combining MSBL with traditional hands-on instruction can optimize learning outcomes in technical education, specifically within the context of electronics education.

3. Methodology

3.1 Research Design

This study employed a quasi-experimental with a mixed methods approach utilizing a pretest-posttest nonequivalent control group design to assess the effectiveness of integrating mobile simulation-based learning (MSBL) with traditional hands-on laboratory instruction on students' performance in basic electronics (Nayeri et al., 2024). This design was selected due to practical considerations in educational settings where random assignment was not feasible.

To minimize threats to internal validity, pretest equivalence was established between groups to address selection bias. Both control and experimental groups were taught by the same instructor, mitigating potential teacher effects. Additionally, the relatively short duration of the intervention reduced risks of maturation and testing effects.

Quantitative data were collected through pretest and posttest assessments to measure learning performance. Complementing these measures, qualitative data were gathered via semi-structured interviews with the experimental group to explore students' perceptions, enhancing the validity and depth of findings.

The research design is shown in the table below:

Table 1 *Non-equivalent pretest-posttest control group design*

Group	Pretest	Intervention	Post-Test	
CG	O_1	-	O_2	
EG	O_3	X	O_4	SSI

Description:
CG : Control Group
EG : Experimental Group
O_1, O_3 : Pretest scores of the both groups
- : Traditional hands-on laboratory instruction only
X : Combined mobile simulation tool and hands-on laboratory instruction
O_2, O_4 : Posttest scores of the both groups
SSI : Semi-structured interview for the experimental group

3.2 Learning Environment

This study was conducted in two distinct learning environments, corresponding to the control and experimental groups:

1. Laboratory Environment (Control Group): Students in the control group engaged in learning activities within a traditional classroom and laboratory setting, utilizing real electronic components, including batteries, resistors, and other circuit elements. These students performed hands-on experiments using physical laboratory equipment without any digital simulation.
2. Combination Environment (Experimental Group): Students in the experimental group experienced a hybrid learning environment, integrating mobile simulation and hands-on laboratory activities. They first interacted with the mobile simulator to explore circuit concepts in a virtual setting. After completing the simulation, they replicated the circuit using real laboratory components to reinforce theoretical concepts with practical applications.

3.3 Research Setting

The study was conducted at Mindanao State University—Iligan Institute of Technology (MSU-IIT), within the College of Education, Department of Technology Teacher Education. MSU-IIT, a recognized center of excellence, provided an ideal environment for innovative educational research, particularly in foundational electronics courses.

3.4 Research Subject

The study participants comprised 40 second-year higher education students enrolled in the Fundamentals of Electronics Technology course. These students represented a heterogeneous group with diverse academic backgrounds, ensuring broad representation. The participants were pre-assigned to classes and laboratory schedules, with no possibility of reorganizing the classes or altering the existing group assignments. To prevent potential bias, the control and experimental groups were scheduled on separate days—Mondays for the control group (n=20) and Thursdays for the experimental group (n=20)—minimizing cross-group interaction. A purposive sampling method was used to select students already enrolled in the course and pre-assigned to specific laboratory sessions. This approach ensured the intervention could be implemented without disrupting institutional operations or student schedules.

The decision to include 40 participants was guided by practical limitations in higher education environments, such as fixed class sizes, lab availability, and instructor allocation. More importantly, this sample size aligns with similar quasi-experimental studies in the field of Technical and Vocational Education and Training (TVET). For instance, Hussain et al. (2023) conducted a study on inquiry-based blended learning in electronics education with 30 participants per group and reported statistically significant results using pre- and post-test comparisons. Similarly, Razak & Noordin (2022) highlighted how studies with smaller cohorts (n<50) still yield meaningful pedagogical insights, particularly when experimental controls and valid instruments are in place. Thus, based on both precedent in TVET literature and practical feasibility, the use of 40 students (20 per group) is consistent with accepted methodologies and sufficient to detect statistically significant differences in pre-post intervention studies under controlled conditions.

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3.5 Research Instrument

The research instrument employed in this study comprised 2 key sets: Pretest and Posttest Assessments and Semi-structured interview guide questions.

(a) Pretest and Posttest Assessments.

A researcher-developed, multiple-choice questionnaire was utilized for pretest and posttest assessments. The development process of the test questions begun with constructing a table of specifications (TOS) to ensure that the questions aligned with the learning objectives and covered a balance representation of cognitive levels. Instrument validity was enhanced through a rigorous item analysis employing Item Difficulty and Discrimination Index, based on the insights from De Guzman et.al's Assessment of Learning I, the questions were evaluated employing Item Analysis Difficulty and Discrimination Index. After the item analysis, 32 items were accepted, and 4 items were recommended for revision. The final set of questions consisted of 36 items, designed to effectively measure the students' baseline knowledge and skills during the pre-test and their progress after the intervention during the post-test. Cronbach's alpha reliability coefficient was calculated at $\alpha = 0.87$, indicating good internal consistency. Four subject matter experts validated the questionnaire for content alignment with learning objectives.

(b) Semi-Structured Interview Guide Questions.

The interview guide comprised five open-ended questions, validated by four expert validators for content accuracy and relevance. Semi-structured interviews involved 9 participants from the experimental group, achieving thematic saturation through iterative analysis.

3.6 Development and Validation of The Basic Electronic Worksheets

The development of the basic electronics worksheets followed a systematic and rigorous process to ensure educational relevance, effectiveness, and alignment with the course syllabus for IAE 102: Fundamentals of Electronics Technology. An initial assessment and thorough planning phase identified specific learning objectives and course requirements, guiding the creation of worksheets designed explicitly to measure learning performance. The worksheets directly addressed Course Learning Outcome #2 (CLO2), which focuses on developing students' proficiency in constructing and analyzing electronic circuits using passive and active components.

To maintain consistency and ensure equitable learning opportunities, both the experimental and control groups utilized identical worksheets for conducting hands-on experiments. Each worksheet consisted of the following sections: (a) Brief Introduction of the Component Used, (b) Schematic Diagram, (c) Blank Breadboard Layout, (d) Procedure, (e) Parts Lists, (f) Experiments with Learning Objectives, (g) What to Observe, and (h) Reflection Questions. A total of eight (8) activities were developed to scaffold learning effectively, each introducing fundamental electronic components and practical applications (see Table 2)..

Table 2 *Learning activity worksheets*

No.	Title
1	The Light Bulb
2	Resistors in Series
3	Resistors in Parallel
4	The Potentiometer
5	The Capacitor
6	The Diodes
7.1	Transistors as a Switch
7.2	Transistors as an Amplifier
8	Introduction to Integrated Circuit (555 timer)

After identifying the selected activities, four (4) expert-validators evaluated the worksheets using a validation tool adapted from Mercado (2020), which comprised three criteria: content quality, technical quality, and instructional quality. Each criterion contained nine indicators assessed on a 5-point Likert scale to describe and interpret the results.

Table 3 *Rating scale for the basic electronics learning activity worksheets adopted from Mercado (2020)*

Scale	Interval	Descriptive Rating	Interpretation
5	4.1-5.0	Strongly Agree	Highly Valid
4	3.01-4.0	Agree	Valid
3	2.0-3.0	Disagree	Slightly Valid
2	1.-01-2.0	Strongly Disagree	Not Valid
1	0.01-1.0	Not Applicable	Not Applicable

Validation results indicated strong agreement from validators across content, technical, and instructional criteria, confirming the worksheets' high validity for achieving intended learning outcomes.

3.7 Simulation Application Used in the Study

The CRUMB Circuit Simulator (mobile version), developed by Mike Bushell in 2022, was integrated exclusively for the experimental group as an additional learning tool alongside the developed basic electronics worksheets The simulator supported the study's goal of enhancing students' learning outcomes by providing an interactive, user-friendly platform for designing and simulating electronic circuits within a fully realized 3D environment, accessible anytime and anywhere via Android and iOS devices. Additionally, a Beginner's Guide to the CRUMB Circuit Simulator included within the worksheets provided step-by-step instructions on navigating the app, adding components, conducting simulations, and saving circuits, further supporting independent learning and ensuring clear alignment between practical activities and simulation tasks.

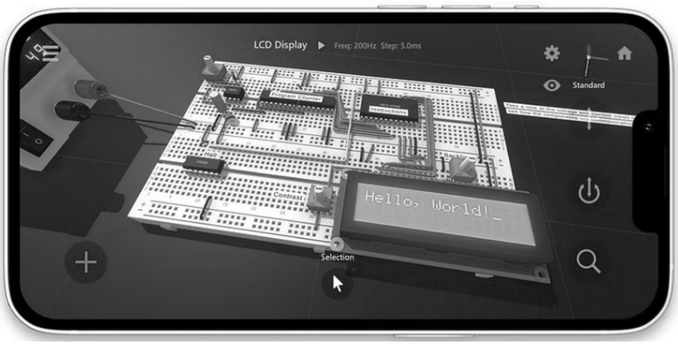

Fig. 1 *Mobile version of CRUMB circuit simulator interface from https://www.crumbsim.com/*

3.8 Data Gathering Procedure

The data gathering process spanned six weeks. In the first week, a pre-test was administered separately from regular class hours to both the control and experimental groups to establish baseline knowledge. Additionally, an orientation session exclusively for the experimental group introduced students to the mobile simulation application, emphasizing its functionalities and integration with worksheet activities.

From weeks 2 to 5, students engaged in eight structured learning worksheets, with two worksheets conducted each week during three-hour sessions. Both control and experimental groups utilized standardized learning activity worksheets featuring identical content and learning objectives, differing only in execution methods. To control for teacher variability, the same instructor facilitated all sessions. The control group used real laboratory equipment and components directly. In contrast, the experimental group first utilized the mobile simulation tool to design, explore, and test circuits, followed by replicating the tasks using actual laboratory equipment. This blended approach was intended to help students grasp theoretical concepts through simulation before applying them practically in real-world contexts (Chernikova et al., 2020).

Students were organized into permanent small groups throughout the study duration, promoting collaborative learning. Although group-based activities occurred during sessions, tasks were individually completed. Following each worksheet completion, the instructor conducted individual discussions and oral questioning sessions to assess comprehension, clarify misconceptions, and ensure mastery of concepts before progressing.

In the final week, a post-test assessed the knowledge and skills acquired by both groups. Additionally, qualitative feedback was gathered exclusively from the experimental group through semi-structured interviews. Nine (9) participants were purposefully selected based on their post-test performance, representing the top three

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(3), middle three (3), and lowest three (3) scorers, to ensure comprehensive insights. Interviews continued until data saturation was achieved, confirming the robustness of thematic analysis outcomes.

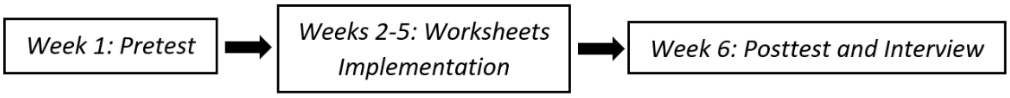

Fig. 2 *Flow of the 6-week study procedure*

3.9 Data Analysis

The data collected in this study were analysed using both quantitative and qualitative methods. An independent samples t-test was performed to compare pre-test scores between the experimental and control groups, ensuring initial equivalence. Paired samples t-tests were used to assess improvements within each group over time. Additionally, an independent samples t-test was conducted to compare post-test scores between the two groups, evaluating the overall effectiveness of the intervention.

Data obtained from the semi-structured interviews were analysed using Thematic Content Analysis. Interview responses were manually transcribed verbatim. Two independent researchers conducted initial coding separately to enhance the reliability and validity of the analysis. After coding, inter-rater reliability was calculated using Cohen’s kappa coefficient, yielding a value of 0.85, which indicates substantial agreement. Any discrepancies in coding were resolved through discussions between the researchers until consensus was achieved. Subsequently, recurring themes and patterns were systematically identified and organized for interpretation.

4. Results

4.1 Pretest Comparison Between Groups

To ensure comparability between groups before the intervention, baseline performance was assessed through a pretest. Assumptions of normality and homogeneity of variances were tested and satisfied. The descriptive statistics and results from the independent samples t-test, including effect size (Cohen’s d) and confidence intervals, are presented in table 4 below.

Table 4 *Comparison of pre-test scores between control group and experimental group, N=40*

Group	Mean±SD	t-vaue (df)	p-value	Cohen’s d	95% Confidence Interval of the Difference	
					Lower	Upper
Control Group	21.65±5.29	0.124(38)	0.902	0.04	-3.07	3.47
Experimental Group	21.45±4.91					

Note: Italicized values denote statistical significance at p < 0.05 level.

The analysis revealed no significant difference in pretest scores between the control (21.65 ± 5.29) and experimental groups (21.45 ± 4.91), $t(38) = 0.124$, $p = 0.902$, $d = 0.04$. This indicates homogeneous baseline performance, suggesting that any subsequent differences in post-test outcomes likely reflect the intervention's effectiveness rather than pre-existing group disparities (Gu et al., 2021).

4.2 Pretest-Post-Test Comparison Within Groups

To assessed changes within each group over time, a paired samples t-test was conducted to compare pretest and post-test scores for both the control and experimental groups. Table 5 below presents the results of the within-group comparison.

Table 5 *Comparison of pre-test and post-test scores within groups, N=40*

Group	Pretest Mean±SD	Posttest Mean±SD	Mean Difference	t-value (df)	p-value	Cohen's d	95% Confidence Interval of the Difference	
							Lower	Upper
Control Group	21.65±5.29	28.50±2.70	+6.85	6.195 (19)	*0.000*	1.38	4.54	9.16
Experimental Group	21.45±4.91	30.55±2.66	+9.10	7.304 (19)	*0.000*	1.63	6.49	11.71

Note: Italicized values denote statistical significance at p < 0.05 level.

Both groups demonstrated significant improvements. The control group increased from 21.65 ± 5.29 to 28.50 ± 2.70, reflecting a mean gain of +6.85, t (19) = 6.195, p < 0.001, d = 1.38. While statistically significant, the control group's gain suggests modest enhancement in fundamental electronics skills, potentially attributable to natural learning over time or exposure to standard instructional methods.

In contrast, the experimental group displayed greater improvement, with scores rising from 21.45 ± 4.91 to 30.55 ± 2.66, yielding a mean difference of +9.10, t (19) = 7.304, p < 0.001, d = 1.63. This substantial improvement reflects notable educational significance, implying that the intervention not only increased test scores but also meaningfully enhanced students' practical understanding and readiness for real-world electronics applications. These findings are visually summarized in Fig. 3, clearly illustrating the comparative pretest-posttest gains across both groups, highlighting the substantial advantage experienced by students in the experimental group.

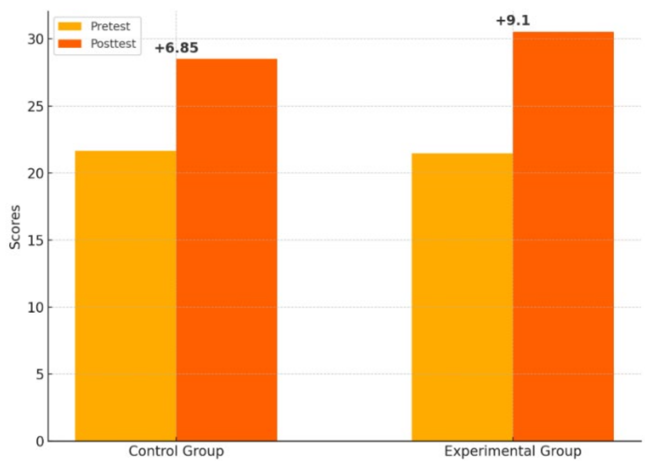

Fig. 3 *Comparison of pretest and posttest scores by group*

4.3 Post-Test Comparison Between Groups

An independent samples t-test was performed to assess the intervention's effectiveness between groups post-intervention, including effect size and confidence intervals, as detailed in Table 6 below.

Table 6 *Comparison of post-test scores between control group and experimental group, N=40*

Group	Mean±SD	t-value (df)	p-value	Cohens' d	95% Confidence Interval of the Difference	
					Lower	Upper
Control Group	28.50±2.70	2.414 (38)	*0.021*	0.76	0.33	3.76
Experimental Group	30.55±2.66					

Note: Italicized values denote statistical significance at p < 0.05 level.

Post-test scores differed significantly, favouring the experimental group (30.55 ± 2.66) compared to the control group (28.50 ± 2.70), t (38) = 2.414, p = 0.021, d = 0.76. This indicates not only statistical significance but practical relevance, suggesting that mobile simulation-based learning combined with traditional laboratory methods substantially improved students' electronics skills. The 2.05-point improvement for the experimental group represents a tangible increase in students' ability to apply electronics knowledge practically, enhancing their competency for real-world tasks in electronics troubleshooting, circuit construction, and technical problem-solving.

4.4 Students Perceptions on Combined Mobile Simulation Based Learning and Traditional Hands – On Laboratory Instruction

Participants' responses from the semi-structured interviews were analyzed, and themes were generated through thematic content analysis. A total of nine students participated in the interviews, and data saturation was achieved when no new information emerged from additional participants.

Three key themes emerged from the analysis: adaptive and self-paced learning opportunities, development of metacognitive awareness and reflective thinking, and seamless integration of digital and physical learning modalities.

Adaptive and Self-Paced Learning Opportunities

Students appreciated the flexibility and convenience of mobile simulations, which allowed them to learn at their own pace and reinforce concepts beyond scheduled laboratory sessions. One student described this benefit:

> *"…the simulator's accessibility on my phone made learning extremely convenient. It felt like having a portable lab available anytime, enabling repeated practice until I fully grasped the concepts."*

Another student reinforced the importance of adaptability:

> *"…I could revisit the simulation to clarify any confusion from hands-on sessions, testing different scenarios until I understood my mistakes. This significantly enhanced my control over my learning."*

Moreover, another student added:

> *"… I became more aware of how I learn best. Sometimes, I needed to spend more time in the simulation before moving to the lab, while other times, I felt ready to dive straight into hands-on work. Having the ability to adjust my learning process made a huge difference in my confidence and understanding."*

One student highlighted the advantage of personalized pacing:

> *"…being able to pause or slow down the simulation whenever I struggled with a topic was incredibly helpful. It let me learn thoroughly without feeling rushed or overwhelmed."*

Another student emphasized the value of repeated practice:

> "…the simulations provided a flexible review option. If I didn't fully grasp something during the class, I could practice repeatedly on my own until it clicked, which really reinforced my learning."

Development of Metacognitive Awareness and Reflective Thinking

The combination of mobile simulation-based learning (MSBL) with traditional laboratory activities fostered critical self-evaluation and reflection among students. Participants reported enhanced confidence and improved problem-solving skills. As one student explained:

> *"…initially, I felt anxious answering questions in class. Using simulations allowed me to experiment safely, make mistakes, and correct them privately. By the time I went into the lab, my confidence had greatly improved, and I felt prepared."*

Another student highlighted the development of reflective thinking:

> *"…using simulations helped me understand how I learn best. Sometimes, spending more time on simulations before lab work was beneficial; other times, I could proceed directly to hands-on tasks. This self-awareness significantly boosted my learning efficiency."*

Also, a student reflected:

> *"…I became more aware of how I learn best. Sometimes, I needed to spend more time in the simulation before moving to the lab, while other times, I felt ready to dive straight into hands-on work. Having the ability to adjust my learning process made a huge difference in my confidence and understanding."*

One student discussed how recognizing patterns improved their performance:

> *"…by working through the simulations, I started recognizing patterns in my mistakes, helping me pinpoint exactly where I needed improvement before lab sessions."*

Another student noted an increase in reflective thinking:

> "…the simulations prompted me to constantly reflect on why certain steps worked or failed, making me more conscious of my thinking process. This awareness translated into more efficient problem-solving during hands-on activities."

Seamless Integration of Digital and Physical Learning Modalities

Students reported enhanced engagement and understanding resulting from the effective integration of digital simulations with hands-on laboratory experiences. The interactive nature of simulations provided a strong foundational understanding, easing the transition to practical tasks. A student articulated:

> *"…the simulations offered a risk-free environment for experimentation, making mistakes less daunting since I could simply reset and retry. When performing hands-on activities, I felt well-prepared and less intimidated."*

Another student described the benefit of visual representation:

> *"…simulations allowed me to visualize the flow of current and component interactions clearly. This visualization significantly enhanced my comprehension during hands-on tasks, improving overall performance."*

One student described how simulations made theoretical concepts easier to grasp:

> *"…the simulation made abstract concepts tangible. When I transitioned to actual lab work, everything felt more intuitive, as if I had already practiced physically."*

Another student described the smooth transition between digital and physical experiences:

> "…switching between digital simulations and actual components was effortless. The simulation provided an accurate preview, so hands-on lab work felt like a natural continuation rather than something entirely new."

5. Discussion

This research aimed to assess the effectiveness of integrating Mobile Simulation-Based Learning (MSBL) with traditional hands-on laboratory instruction in enhancing students' learning performance in basic electronics. The study findings provide compelling evidence supporting the effectiveness of this blended instructional approach, structured around baseline comparability, within-group learning gains, post-test comparisons, and student perceptions.

The pretest analysis confirmed no significant differences between control and experimental groups, establishing comparable baseline knowledge. Ensuring group equivalence strengthens the validity of the results, confirming that observed improvements are attributable directly to the intervention (Damiao, 2022; Nayeri et al., 2024).

Both groups demonstrated significant learning gains; however, the experimental group's improvement was notably greater, highlighting the added value of MSBL. This aligns with previous research emphasizing technology-enhanced learning environments' potential to enhance student engagement, knowledge retention, and skill acquisition (Pedraja-Rejas et al., 2024; Abdullah et al., 2024). Specifically, mobile simulations support active learning by providing immersive experiences that reduce cognitive load through structured practice, as suggested by Cognitive Load Theory (Sweller, 1988; Ton et al., 2024). Consistent with Kolb's Experiential Learning Theory (Kolb, 1984), the interactive simulations allowed learners to actively experiment, reflect, and conceptualize, effectively linking theory with practice (Chen & Chan, 2024; Chinengundu, 2022).

The post-test comparisons further confirmed the superior performance of students exposed to MSBL. The immersive nature of simulations facilitated deeper conceptual understanding and practical skills, echoing findings from prior studies (Sayed et al., 2024; Levi-Keren et al., 2024; Portillo et al., 2024). Simulation-based learning effectively promotes active engagement and immediate feedback, essential elements underpinning Self-Regulated Learning Theory (Zimmerman, 2002). This reinforces that MSBL not only enhances cognitive performance but also develops learners' abilities to manage their learning strategies effectively.

MSBL significantly supported adaptive, self-paced learning, enhancing student engagement. Digital simulations allowed learners personalized pacing, enabling repetitive practice and concept mastery without external pressure (Kefalis et al., 2025; Hidayatullah et al., 2024). Such autonomy aligns with Zimmerman's (2002) Self-Regulated Learning Theory, fostering student motivation and efficacy through personalized learning pathways (Ali & Kuotian, 2024; Sisouvong & Pasanchay, 2024; Aznar-Díaz et al., 2022).

Moreover, integrating MSBL significantly enhanced students' metacognitive awareness. Simulations encouraged learners to reflect on mistakes, identify errors, and adjust their reasoning strategies. This aligns closely with principles from Self-Regulated Learning and metacognition theories, underscoring technology-enhanced learning environments' role in fostering reflective thinking and self-monitoring (Dobson et al., 2023; Miedijensky et al., 2025; Kefalis et al., 2025).

The seamless integration of digital simulations with physical laboratory experiences further bridged theoretical concepts and practical skills. Simulations provided dynamic visualizations and real-time feedback, essential for complex cognitive processing and spatial reasoning, reinforcing practical comprehension of abstract electronics concepts (Guarda & Díaz-Nafría, 2023; Hakim et al., 2024).

Practically, these findings hold significant implications for various stakeholders. Curriculum designers in TVET can leverage MSBL to create enriched learning environments that better bridge theory and practice. Instructors in electronics education should integrate mobile simulations to facilitate personalized learning experiences, fostering active engagement and reflective practices. Policymakers and technology developers can consider supporting and investing in simulation-based learning infrastructures, enhancing the effectiveness and appeal of technical education programs.

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Overall, this study demonstrates MSBL's potential as an innovative pedagogical tool, significantly enhancing learning outcomes in technical and vocational education contexts.

6. Conclusion

This study examined the integration of Mobile Simulation-Based Learning (MSBL) with traditional hands-on laboratory instruction in basic electronics and its impact on students' learning performance. Findings showed that this combined approach significantly enhanced students' comprehension of electronic concepts, their ability to apply theoretical knowledge practically, and confidence in performing hands-on tasks. Students exposed to both MSBL and traditional laboratory activities demonstrated higher learning gains than those who experienced hands-on instruction alone.

These results contribute to the growing evidence supporting digital learning tools in technical education. Specifically, MSBL improved students' problem-solving abilities, increased their metacognitive awareness, and bolstered their confidence when interacting with instructors. Students benefited notably from diagnosing and correcting their mistakes independently, fostering deeper conceptual understanding and practical knowledge transfer. Additionally, the visual representation of circuit operations within mobile simulations allowed learners a more intuitive grasp of electronic principles, supporting enhanced engagement and autonomy.

7. Recommendation

Based on the findings of this study, the following structured recommendations are proposed to enhance the integration and effectiveness of Mobile Simulation-Based Learning (MSBL) in Technical-Vocational Education and Training (TVET) settings:

Institutional & Curriculum Recommendations

Educational institutions should systematically integrate MSBL alongside traditional laboratory instruction. This blended approach facilitates deeper conceptual understanding and practical skill development. Additionally, institutions must select MSBL applications specifically aligned with industry standards and competencies, ensuring relevance and applicability of skills in real-world settings. For instance, simulation apps should replicate scenarios frequently encountered in industry practice.

Instructional Practice

Institutions should offer specialized instructor training through short-term certification modules or professional development courses focusing on the effective implementation of MSBL. Examples include TESDA-certified training sessions or online certification modules specifically tailored for instructors. Furthermore, institutions should develop instructional strategies and guided exercises within MSBL that clearly align with course objectives, emphasizing practical skills and industry-relevant tasks. Effective MSBL apps should include interactive feedback, scenario-based learning, and performance analytics to facilitate skill mastery, encouraging educators to integrate MSBL effectively into their teaching strategies by pairing simulations closely with hands-on laboratory tasks.

Student Learning Support

MSBL supports self-regulated learning by allowing students to progress at their own pace, revisit difficult concepts, and build independent problem-solving skills. Institutions should incorporate adaptive learning paths and interactive feedback mechanisms within simulations to enhance metacognitive awareness and learner autonomy. Additionally, adequate resources, such as robust internet connectivity, mobile device availability, and technical support systems, should be ensured. Institutions should consider cost-effective options like bulk licensing agreements or leveraging cloud-based platforms to manage expenses.

Future Research Directions

Future research could explore the long-term retention effects of MSBL by its applicability in other technical subjects beyond electronics.

Limitations

This study acknowledges several limitations, including the relatively small sample size and single-institution context, which may affect generalizability. Additionally, the short-term nature of the study precludes long-term outcome assessment. Potential technology access barriers and biases associated with non-randomized group assignments represent further limitations. Despite these constraints, the research design and methodological rigor provide valuable insights for educational practice in technical training contexts.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

All authors made substantial contributions to the conception and design of the study, data collection, analysis, and interpretation of results. They were actively involved in drafting, revising, and finalizing the manuscript. Each author approved the final version of the work and agrees to be accountable for all aspects of the research.

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