VOLUME 1
ISSUE 3
JULY–SEPTEMBER
2026

Print ISSN: 3116-3769
Electronic ISSN: 3116-3777

INJELPS

International Journal of Education, Learning, and Pedagogical Sciences

A Quarterly Peer-Reviewed International Research Journal

EDUCATION LEARNING PEDAGOGY INNOVATION IMPACT

PUBLISHED BY

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International Journal of Education, Learning, and Pedagogical Sciences (INJELPS)
P - ISSN 3116-3769; E - ISSN 3116-3777
National Book Development Board (NBDB) Registration as Book Publisher (Print & Digital): 6312
PRC-CPD Accredited Provider: PTR-2025-749

Bridging virtual and physical learning environments: A mixed-method analysis of simulation tools and electronic trainers in developing students' troubleshooting skills

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Received: 21 June 2026 **Revised**: 22 July 2026; 26 July 2026; 27 July 2026; 28 July 2026; 29 July 2026

Accepted: 29 July 2026 **Available Online**: 30 July 2026

Volume 1 (2026), Issue 3, P-ISSN – 3116-3769; E-ISSN - 3116-3777

https://doi.org/10.63498/injelps99

Abstract
Aim: This study aimed to examine the effectiveness of three instructional modalities virtual simulation software, physical electronic trainer equipment, and their combined use in developing the troubleshooting skills of Grade 10 students in Electronics under the Technology and Livelihood Education (TLE) curriculum. The study sought to determine how these instructional approaches contribute to improving students' technical competence and learning experiences.
Methodology: A convergent mixed-methods research design was employed, consisting of quantitative and qualitative phases. The quantitative phase utilized a quasi-experimental pretest and posttest design involving three instructional groups, while the qualitative phase explored students' learning experiences through semi-structured interviews. Data were analyzed using appropriate statistical techniques and thematic analysis to provide a comprehensive understanding of the effectiveness of the instructional modalities.
Results: The quantitative findings revealed no significant differences among the three groups in their pretest scores, indicating comparable baseline competencies. Significant differences were observed in the post-test results, with students using physical electronic trainer equipment obtaining the highest performance. Although all groups demonstrated improved troubleshooting skills, no significant differences were found in their gain scores, suggesting that each instructional modality contributed to students' learning. Qualitative findings showed that virtual simulation enhanced conceptual understanding through safe and interactive exploration, while physical electronic trainers strengthened hands-on competence, troubleshooting ability, and real-world technical skills. The challenges encountered during learning further promoted students' critical thinking and problem-solving abilities.
Conclusion: The findings indicate that while virtual simulation software effectively develops conceptual understanding and supports flexible learning, physical electronic trainer equipment provides superior opportunities for developing authentic troubleshooting skills and technical competence. Integrating virtual and physical learning environments offers a balanced instructional approach that can enhance teaching practices, strengthen practical learning experiences, and support curriculum implementation in Technology and Livelihood Education.
Keywords: *electronic trainers; mixed-method research; simulation tools; technical-vocational education; troubleshooting skills*

INTRODUCTION

Amid the rapidly evolving educational landscape, integrating technology into teaching and learning has become essential in technical and vocational education. Simulation technologies provide safe, efficient, and cost-effective learning environments that enhance students' conceptual understanding and problem-solving skills (Makransky & Petersen, 2019; OECD, 2021). Nevertheless, physical electronic trainers remain indispensable in developing practical troubleshooting competencies through authentic hands-on experiences.

In the Philippines, competency-based instruction under the K to 12 Technology and Livelihood Education (TLE) curriculum emphasizes industry-relevant technical skills. However, many public schools, including Lambayong National High School, continue to experience shortages of laboratory equipment, instructional materials, and functional

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electronic trainers, limiting students' opportunities for meaningful laboratory practice. These constraints have encouraged teachers to integrate virtual simulation software into instruction, yet limited local evidence exists regarding its effectiveness compared with physical laboratory training or a combination of both approaches.

Addressing this gap, the present mixed-methods study examined the effectiveness of virtual simulation software, physical electronic trainer equipment, and their combined use in developing the troubleshooting skills of Grade 10 Electronics students at Lambayong National High School. The findings are expected to provide evidence-based recommendations for improving laboratory instruction, optimizing limited educational resources, and guiding teachers, school administrators, and curriculum developers in integrating technology with authentic hands-on learning.

Review of Related Literature and Studies

The integration of virtual simulation and physical electronic trainers has become increasingly important in technical and vocational education as institutions adopt technology-enhanced learning aligned with Education 4.0. Virtual simulations provide interactive and risk-free environments that enhance students' conceptual understanding, problem-solving, and analytical skills through visualization, inquiry-based learning, and immediate feedback (Schnieder et al., 2022). However, studies indicate that simulation alone cannot fully develop the psychomotor and practical competencies required in technical education, highlighting the continued importance of hands-on laboratory experiences (Matarirano et al., 2023)

Recent research recommends integrating virtual simulation with physical laboratory instruction to maximize learning outcomes. Evidence shows that blended learning approaches improve conceptual understanding, learner engagement, technical competence, and confidence more effectively than either approach alone (Flegr et al., 2023; Li & Liang, 2024). Similar findings have been reported in Asian countries and the Philippine TVET context, where virtual simulations enhance accessibility and theoretical learning, while physical laboratory activities remain essential for developing authentic troubleshooting and practical skills (Abdul Razak et al., 2022; Asgari et al., 2021; Jin et al., 2021; Makransky & Petersen, 2021; Wong & Sim, 2022).

The literature further demonstrates that virtual simulation enhances learners' troubleshooting, critical thinking, and decision-making skills through repeated practice and immediate feedback (Abdelmoneim et al., 2022; Antonio, 2023; Kaysi, 2025). Conversely, physical electronic trainers remain indispensable for developing psychomotor competence, independent learning, and authentic troubleshooting skills necessary in engineering and technical practice (Agustian et al., 2022; Herbert & O'Mahony, 2024; Nikolic et al., 2021). Comparative studies consistently conclude that combining virtual and physical learning environments produces the highest levels of knowledge acquisition, skill performance, and learner confidence (Foronda et al., 2022; Kyaw et al., 2023; Rowe et al., 2023).

Synthesis and Research Gap

Despite these benefits, successful implementation of technology-enhanced learning remains constrained by inadequate infrastructure, limited teacher preparedness, digital literacy issues, and the high cost of laboratory equipment (Bond et al., 2024; Herbert & O'Mahony, 2024; Lie et al., 2023; Radianti et al., 2020). Overall, the literature suggests that virtual simulation and physical electronic trainers are complementary instructional approaches that enhance both conceptual and practical learning. However, limited studies have examined their comparative and combined effectiveness in developing troubleshooting skills among Grade 10 learners in the Philippine TLE and TVL context, providing the rationale for the present study.

Theoretical Framework

This study is anchored on Constructivist Learning Theory (Piaget & Vygotsky) and Experiential Learning Theory (Kolb, 1984), which emphasize that meaningful learning occurs through active knowledge construction and experience. Experiential Learning Theory guided instructional intervention by integrating virtual simulation for conceptual exploration and safe experimentation with physical electronic trainers for authentic hands-on practice and troubleshooting. The theory also informed the interpretation of the quantitative findings, as the superior performance of the physical trainer and combined groups demonstrated the value of concrete experience in strengthening learning outcomes, while virtual simulation effectively supported conceptual understanding. Likewise, it guided the interpretation of the qualitative findings, where students described physical trainers as enhancing confidence and technical competence, whereas virtual simulations promoted conceptual understanding, cognitive engagement, and risk-free practice. Collectively, these findings support Kolb's experiential learning cycle, demonstrating that combining virtual and physical learning environments fosters both conceptual and practical competence aligned with Education 4.0 and Industry 5.0.

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Conceptual Framework

INPUT

- Use of Virtual Simulation Tools (software-based electronics learning)
- Use of Physical Electronics Trainers (hands-on laboratory learning

PROCESS

Quantitative Phase
- Implementation of lessons using virtual and physical trainers
- Assessment of students' troubleshooting performance

Qualitative Phase
- Focus group discussions/interviews with students
- Thematic analysis of experience and perceptions

Integration of Results
- Merging quantitative and qualitative findings for deeper insight

OUTPUT

- Comparative analysis of student performance
- Themes on challenges, perceptions, and experience
- Recommendations for blended electronics instruction
- Policy and instructional implementation for TLE/TVL Education under DepEd

Figure 1*. Conceptual Framework of the study*

The conceptual framework illustrates how three instructional modalities simulation software, physical electronic trainer equipment, and their combined influence students' troubleshooting skills in electronics. These instructional modalities serve as the independent variables, while students' troubleshooting performance, learning experiences, and perceptions are the dependent variables. Virtual simulation provides an interactive, risk-free environment that enhances conceptual understanding, analytical thinking, and troubleshooting practice, whereas physical electronic trainers develop hands-on skills, technical competence, and diagnostic abilities through authentic laboratory experiences. The study adopts an Input–Process–Output (IPO) framework. The inputs are the three instructional modalities. The process involves implementing each modality, administering pretests and post-tests, conducting semi-structured interviews, and analyzing quantitative and qualitative data. The outputs include students' troubleshooting performance, comparative learning outcomes, perceptions, identified challenges, and evidence-based recommendations for effectively integrating virtual simulation and physical electronic trainers to enhance electronics instruction and technical competence.

Statement of the Problem

The rapid advancement of technology has transformed teaching and learning in technical and vocational education through the integration of virtual simulation tools and digital instructional resources. These innovations provide safe, interactive, and cost-effective environments that enhance students' conceptual understanding and problem-solving abilities. However, despite these technological developments, practical hands-on experience using physical electronic trainers remains indispensable for developing authentic troubleshooting competencies and technical skills required in electronics education.

Within the Philippine Technology and Livelihood Education (TLE) and Technical-Vocational-Livelihood (TVL) curriculum, schools continue to encounter challenges in providing effective laboratory instruction because of limited equipment, financial constraints, and unequal access to laboratory facilities. Although virtual simulation has emerged as an alternative instructional strategy, questions remain regarding its effectiveness compared with physical electronic trainers and whether combining both instructional modalities produces better learning outcomes.

Previous studies have demonstrated the educational benefits of simulation technologies and laboratory instruction independently. However, limited research has comparatively examined virtual simulation, physical electronic trainers, and their combined use in developing the troubleshooting skills of Grade 10 learners in Electronics within the Philippine secondary education context. Furthermore, few studies have employed a mixed-methods approach to examine not only students' academic performance but also their learning experiences, challenges, and coping strategies.

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Given these educational concerns, the present study was conducted to determine the effectiveness of virtual simulation software, physical electronic trainer equipment, and their combined use in enhancing the troubleshooting skills of Grade 10 students. The findings are expected to provide evidence that may guide teachers, curriculum developers, school administrators, and policymakers in improving instructional practices and technology integration in electronics education

General Objective

To examine the effectiveness of virtual simulation software, physical electronic trainer equipment, and their combined use in enhancing the troubleshooting skills of Grade 10 students in Electronics under the Technology and Livelihood Education (TLE) and Technical-Vocational-Livelihood (TVL) curriculum of the Department of Education (DepEd).

Specific Objectives

The study specifically sought:

1. To determine the level of students' troubleshooting skills in the pretest and post-test using:
   a. virtual simulation software;
   b. physical electronic trainer equipment; and
   c. the combined use of virtual simulation software and physical electronic trainer equipment.
2. To determine whether there is a statistically significant difference in the pretest scores among students exposed to the three instructional modalities.
3. To determine whether there is a statistically significant difference in the post-test scores among students exposed to the three instructional modalities.
4. To determine whether there is a statistically significant difference in the mean gain scores among students exposed to the three instructional modalities.
5. To describe the learning experiences of students using virtual simulation software and physical electronic trainer equipment.
6. To identify the challenges encountered by students while learning through virtual simulation software and physical electronic trainer equipment.
7. To examine the strategies employed by students in overcoming the challenges encountered while using virtual simulation software and physical electronic trainer equipment.

Research questions:

The study sought to answer the following questions:

1. What is the level of students' troubleshooting skills in the pretest and post-test using:
   a. virtual simulation software;
   b. physical electronic trainer equipment; and
   c. the combined use of virtual simulation software and physical electronic trainer equipment?
2. Is there a statistically significant difference in the pretest scores among students exposed to the three instructional modalities?
3. Is there a statistically significant difference in the post-test scores among students exposed to the three instructional modalities?
4. Is there a statistically significant difference in the mean gain scores among students exposed to the three instructional modalities?
5. What are the learning experiences of students using virtual simulation software and physical electronic trainer equipment?
6. What challenges do students encounter while learning through virtual simulation software and physical electronic trainer equipment?
7. How do students overcome the challenges encountered while learning through virtual simulation software and physical electronic trainer equipment?

Hypotheses

- H_{01}: There is no statistically significant difference among the pretest scores of students exposed to virtual simulation software, physical electronic trainer equipment, and the combined use of both instructional modalities.

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- H_{02}: There is no statistically significant difference among the post-test scores of students exposed to virtual simulation software, physical electronic trainer equipment, and the combined use of both instructional modalities.
- H_{03}: There is no statistically significant difference among the mean gain scores of students exposed to virtual simulation software, physical electronic trainer equipment, and the combined use of both instructional modalities.

METHODOLOGY

Research Design

This study employed a convergent mixed-methods research design, integrating quantitative and qualitative data to examine the effectiveness of virtual simulation tools and physical electronic trainers in developing students' troubleshooting skills. The quantitative phase used a quasi-experimental pretest-posttest design with three groups: virtual simulation, physical electronic trainers, and a combination of both. All groups received the same classroom instruction, while laboratory activities varied by instructional modality. The qualitative phase explored students' experiences, perceptions, and challenges through interviews analyzed using thematic analysis. Integrating both datasets provided a comprehensive understanding of how each instructional modality influenced students' troubleshooting skills in Technology and Livelihood Education (TLE).

Population and Sampling

This study employed purposive sampling to select thirty (30) Grade 10 students enrolled in the Electronic Products Assembly and Servicing (EPAS) specialization at Lambayong National High School. Purposive sampling was used because only students enrolled in EPAS had access to the required virtual simulation software and physical electronic trainer equipment necessary for the intervention. Random sampling was not feasible since the study required participants with these specific characteristics. The participants came from one intact Grade 10 EPAS class. After participant selection, students were randomly assigned to three instructional groups ($n = 10$ per group) to minimize selection bias while ensuring comparable academic ability across groups based on their previous grading performance. The three groups received the following instructional interventions: (1) Virtual Simulation Software, (2) Physical Electronic Trainer, and (3) Combined Virtual Simulation Software and Physical Electronic Trainer. For the qualitative phase, five (5) students were purposively selected from the participants to participate in individual in-depth interviews. These students were chosen based on their ability to provide rich and relevant information regarding their learning experiences with the different instructional interventions.

Research Instruments

The study utilized two quantitative instruments. First, a researcher-developed Troubleshooting Skills Assessment Test measured students' troubleshooting competence in power supply systems across four dimensions: accuracy, efficiency, diagnostic methodology, and safety procedures. The instrument was validated by experts to ensure content validity, clarity, relevance, and alignment with the Electronics Products Assembly and Servicing (EPAS) curriculum. Its reliability was established using the Kuder–Richardson Formula 20 (KR-20). Second, a Performance Rubric/Rating Sheet, adapted from DepEd Order No. 8, s. 2015 and aligned with the EPAS Curriculum Guide, was used to assess students' practical troubleshooting performance during laboratory activities. The rubric provided standardized criteria to ensure objective, consistent, and reliable evaluation of students' technical competencies.

A semi-structured interview guide was developed to explore students' experiences with virtual simulation tools and physical electronic trainer equipment during electronics instruction. The guide focused on four areas: students' learning experiences, challenges encountered, coping strategies, and perceptions of the strengths, weaknesses, and influence of both instructional modalities on troubleshooting skills and learning outcomes. To ensure content validity, the instrument was reviewed by experts in electronics education and research. It was also pilot-tested with students outside the study to improve the clarity, relevance, and effectiveness of the interview questions.

Content Validity and Reliability

The research instruments underwent content validity and reliability testing prior to implementation. Six experts evaluated the instruments for relevance, clarity, and alignment with the study objectives. The Item Content Validity Index (I-CVI) values ranged from 0.83 to 1.00, while the Scale-Level Content Validity Index using Universal Agreement (S-CVI/UA) was 0.92, indicating excellent content validity. Following content validation, the instrument was pilot tested with students possessing characteristics like the study participants. Reliability analysis using the Kuder–Richardson

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Formula 20 (KR-20) yielded a coefficient of 0.89, indicating high internal consistency and confirming that the instrument was reliable for measuring students' troubleshooting competencies.

Data Collection Procedures

Prior to data collection, approval to conduct the study was obtained from the Department of Education (DepEd) Schools Division Office and the Office of the Principal of Lambayong National High School. Informed consent was secured from all participants and their parents or guardians after they were fully informed of the study's objectives, research procedures, voluntary nature of participation, confidentiality of responses, and their right to withdraw from the study at any time without any consequences. Before the implementation of the intervention, all participants completed a researcher-developed pretest to establish their baseline troubleshooting skills in Electronic Products Assembly and Servicing (EPAS). The thirty (30) participants were then randomly assigned to three instructional groups consisting of ten (10) students each. The intervention was implemented over four consecutive weeks with two instructional sessions per week, for a total of eight sessions, each lasting approximately 60 minutes. All groups were taught the same competencies, learning objectives, instructional content, and assessment activities by the same instructor to ensure consistency across treatments. The first group received instruction using Phet Interactive Simulations, where students performed troubleshooting tasks in a virtual environment by manipulating electronic circuits, identifying simulated faults, testing corrective procedures, and receiving immediate feedback without the risk of damaging actual electronic components. The second group received instruction using physical electronic trainer equipment, allowing students to perform troubleshooting activities with actual electronic trainer kits, measuring instruments, and laboratory tools while applying standard diagnostic procedures in authentic laboratory settings. The third group experienced a combined instructional modality, wherein students initially learned troubleshooting concepts and practiced fault diagnosis through virtual simulations before reinforcing their learning through hands-on activities using physical electronic trainer equipment. Upon completion of the intervention, all participants completed the same standardized posttest administered during the pretest to determine improvements in troubleshooting skills and compare the effectiveness of the three instructional modalities. Subsequently, five (5) participants were purposively selected for the qualitative phase based on their willingness to share rich and meaningful experiences regarding the instructional intervention. Individual semi-structured interviews were conducted by the researcher in a quiet room within Lambayong National High School immediately after the posttest administration. Each interview lasted approximately 30 to 45 minutes, was audio-recorded with participants' permission, transcribed verbatim, and analyzed thematically to identify common experiences, perceived benefits, challenges encountered, and coping strategies associated with learning through virtual simulation software, physical electronic trainer equipment, and the combined instructional modality.

Treatment of Data

Descriptive statistics (frequency, percentage, mean, and standard deviation) summarized the pretest and posttest results. Prior to inferential analysis, the assumptions of normality and homogeneity of variance were tested using the Shapiro–Wilk and Levene's tests, respectively. One-way ANOVA determined significant differences among the three instructional groups, while Tukey's HSD identified pairwise group differences. Effect size was measured using eta squared (η^2). All analyses were performed using IBM SPSS Statistics Version 29 at a 0.05 significance level. Qualitative data were analyzed using Braun and Clarke's (2006) thematic analysis, involving coding, theme generation, and validation through member checking and peer debriefing.

Ethical Considerations

This study was conducted in accordance with the ethical principles governing research involving human participants and complied with the ethical standards of the Department of Education (DepEd) and the institutional research ethics requirements of Sultan Kudarat State University. The research protocol underwent institutional ethics review prior to data collection. However, the University does not currently assign research ethics approval numbers for graduate student research; therefore, no ethics approval reference number is available for this study.

Administrative permission to conduct the study was obtained from the Schools Division Office and the school administration before the commencement of data collection. Because the participants were Grade 10 students, written informed consent was obtained from their parents or legal guardians, while written assent was secured from all student participants. Participation was entirely voluntary, and participants were informed of the study's purpose, procedures, potential benefits, and their right to decline participation or withdraw from the study at any time without penalty.

To protect participants' privacy, anonymity and confidentiality were maintained by assigning identification codes instead of recording participants' names. All research data were used solely for academic purposes and managed in compliance with the Data Privacy Act of 2012 (Republic Act No. 10173). Electronic records were stored in a password-

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protected computer, while printed documents were kept in a locked cabinet accessible only to the researcher. Research records will be retained for five (5) years following the completion of the study and will thereafter be securely destroyed through permanent deletion of electronic files and shredding of printed documents. Throughout the research process, the principle of non-maleficence was strictly observed to safeguard participants from physical, psychological, emotional, and social harm.

RESULTS and DISCUSSION

This section presents and discusses the results of the study based on the research questions. Findings are interpreted in relation to learning theory and relevant empirical studies to explain observed outcomes.

Quantitative Results

Skills of Students for Troubleshooting

Table 1
Pretest Level of Students' Troubleshooting Skills

Intervention	*Mean*	*SD*	Description
Virtual Simulation Tools	21.50	5.50	Average Mastery
Physical Electronic Trainer	21.20	7.7	Average Mastery
Both Virtual Simulation Tools and Physical Electronic Trainer	21.80	7.18	Average Mastery

Table 1 presents the students' pretest performance across the three instructional groups. The mean scores were comparable: virtual simulation tools (M = 21.50), physical electronic trainers (M = 21.20), and the combined modality (M = 21.80), indicating similar baseline troubleshooting skills prior to the intervention. Although the physical electronic trainer group showed slightly greater score variability (SD = 7.70) than the combined (SD = 7.18) and virtual simulation groups (SD = 5.50), the differences were minimal. These results indicate that the groups were comparable at baseline, supporting a valid comparison of the instructional modalities within the study sample. This finding is consistent with Hassan et al. (2021), who likewise reported comparable pre-intervention performance among learners. Accordingly, any post-intervention differences are more likely attributable to the instructional approaches rather than pre-existing group differences. However, these findings should be interpreted within the context of the Grade 10 students of Lambayong National High School and not generalized beyond similar educational settings.

Table 2
Post-test Level of Students' Troubleshooting Skills

Intervention	*Mean*	*SD*	Description
Virtual Simulation Tools	31.50	3.57	High Mastery
Physical Electronic Trainer	38.40	2.32	High Mastery
Both Virtual Simulation Tools and Physical Electronic Trainer	34.70	2.91	High Mastery

Table 2 presents the students' posttest performance after exposure to the three instructional modalities. The physical electronic trainer group obtained the highest mean score (M = 38.40, SD = 2.32), interpreted as Highly Proficient, indicating stronger troubleshooting performance than the other groups. The combined virtual simulation and physical electronic trainer group (M = 34.70, SD = 2.91) and the virtual simulation group (M = 31.50, SD = 3.57) both achieved a Proficient level. The relatively low standard deviations indicate consistent performance within each group. Overall, all three instructional modalities improved students' troubleshooting skills, with the physical electronic trainer yielding the highest posttest performance in this sample. These findings are consistent with Waldrop et al. (2022) and Zhou et al. (2021), who highlighted the value of hands-on laboratory experiences and the complementary role of virtual

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simulation in technical education. However, these results should be interpreted within the context of the Grade 10 students participating at Lambayong National High School.

Table 3
Comparison of the Pre-test Scores of the Three Groups of Students

Source of Variation	df	Sum of Squares	Mean Square	F	p-value
Between groups	2	1.80	0.90	0.02	0.98
Within groups	27	1269.70	47.03		
Total	**29**	**1271.50**			

α= 0.05 level of significance

These findings are consistent with Hassan et al. (2021), who reported that comparable pretest scores establish baseline equivalence, thereby strengthening the internal validity of intervention studies by reducing the influence of pre-existing group differences. Similarly, Gu et al. (2021) emphasized that baseline comparability is essential for evaluating the effectiveness of educational interventions, as it supports the interpretation that observed posttest differences are more likely attributable to the instructional modalities implemented within the study sample.

Table 4
Comparison of the Post-test Scores of the Three Groups of Students

Source of Variation	df.	Sum of Squares	Mean Square	F	p-value
Between groups	2	238.47	119.23	13.47	<0.0001
Within groups	27	239.00	8.85		
Total	**29**	**477.47**			

α= 0.05 level of significance

A one-way Analysis of Variance (ANOVA) was conducted to determine whether significant differences existed in the posttest scores of students exposed to virtual simulation tools, physical electronic trainer equipment, and a combination of both instructional modalities. The analysis yielded an F-value of 13.47 with a p-value less than .05, indicating a statistically significant difference among the group means. Thus, the null hypothesis of no significant difference was rejected, suggesting that at least one instructional modality produced significantly different posttest performance within the study sample. To identify which groups differed significantly, the Tukey–Kramer Multiple Comparison Test was subsequently performed as a post hoc analysis.

Table 5
Separation of Group Means Using Tukey-Cramer Multiple Comparison Test

Intervention	Mean
Virtual Simulation Tools	31.50^{b}
Physical Electronic Trainer	38.40^{a}
Both Virtual Simulation Tools and Physical Electronic Trainer	34.70^{b}

Notes: *Means of the same superscript are comparable.*
1 and 3 are comparable
2 has a highest post-test. The students performed well in the post-test compared to 1 and 3.

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Following the significant ANOVA results, the Tukey–Kramer Multiple Comparison Test identified significant differences among the instructional groups. The physical electronic trainer group obtained a significantly higher posttest mean (*M* = 38.40) than the virtual simulation group (*M* = 31.50) and the combined group (*M* = 34.70). However, no significant difference was found between the virtual simulation and combined groups, indicating comparable posttest performance. These findings suggest that, within the study sample, physical electronic trainers were the most effective instructional modality for developing students' troubleshooting skills. This result is consistent with Waldrop et al. (2022) and Zhou et al. (2021), who reported that hands-on laboratory experiences enhance technical competence and troubleshooting performance, while virtual simulations primarily strengthen conceptual understanding.

Table 6
Comparison of the Mean Gain Scores of the Three Instructional Groups

Source of Variation	*df*	*Sum of Squares*	*Mean Square*	*F*	*p-value*
Between groups	2	262.47	131.23	1.90	0.17
Within groups	27	1868.50	69.20		
Total	**29**	**2130.97**			

α= 0.05 level of significance

The one-way ANOVA revealed no significant difference in the mean gain scores among the three instructional groups (F = 1.90, p = .17), leading to the acceptance of the null hypothesis. This indicates that students exposed to virtual simulation tools, physical electronic trainers, and their combined use achieved statistically comparable improvements in troubleshooting skills. Although posttest mean scores differed, the magnitude of improvement from pretest to posttest was similar across the three groups. These findings are consistent with Chen et al. (2020) and Schnieder et al. (2022), who reported that both virtual and physical laboratory experiences can effectively enhance learning by supporting conceptual understanding, problem-solving, and practical skill development. However, these findings should be interpreted within the context of the participating Grade 10 students at Lambayong National High School.

The Qualitative Findings

Thematic analysis generated three overarching themes: (1) the complementary role of virtual simulation tools and physical electronic trainer equipment in enhancing learning, (2) enhanced practical competence through physical electronic trainer equipment, and (3) enhanced student learning engagement through active, cognitive, and inquiry-based participation. These themes reflect students' learning experiences and demonstrate how different instructional modalities contributed to the development of troubleshooting skills, technical competence, and learning engagement.

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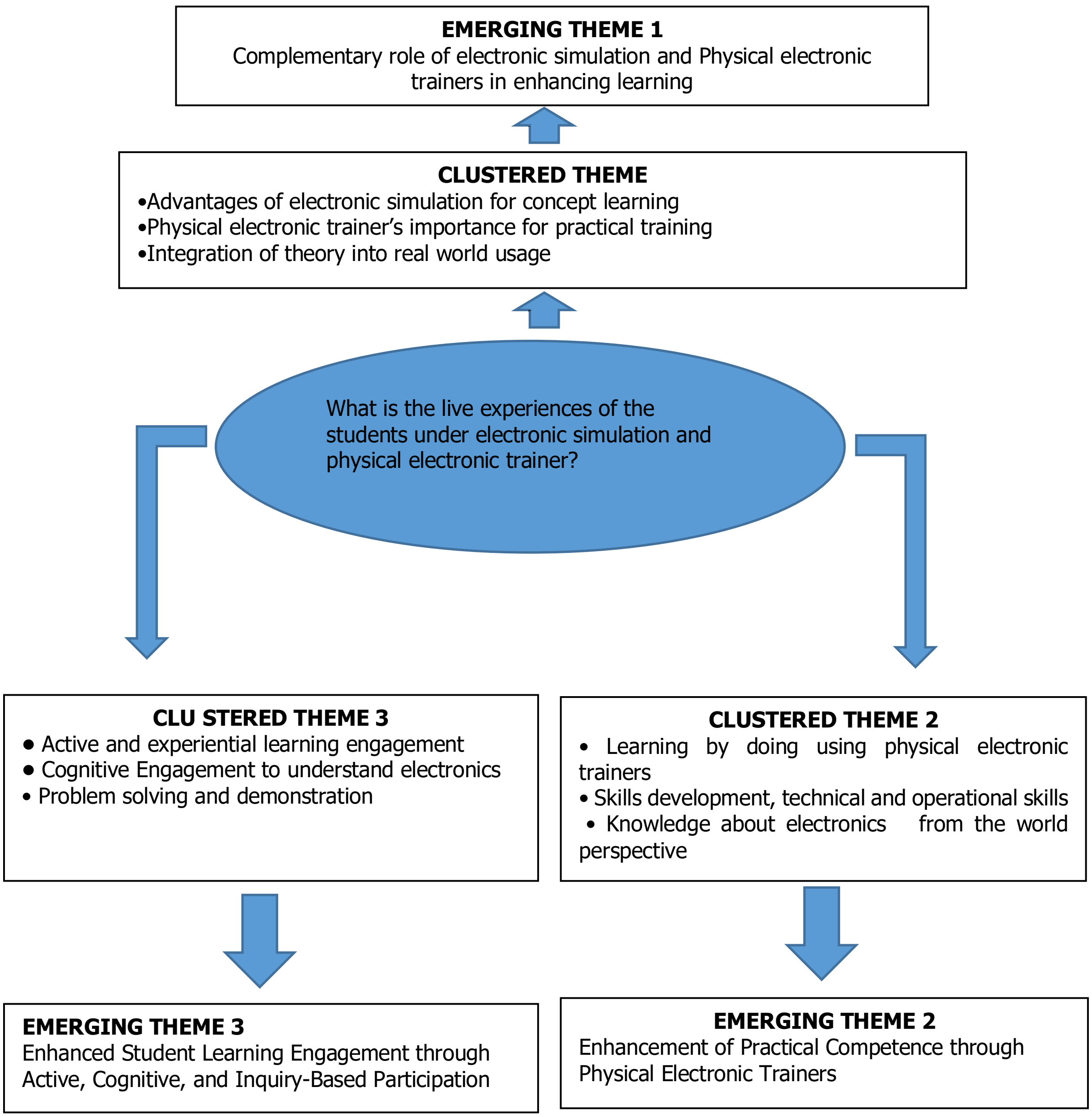

Figure 2
The Emerging Theme on the Students' Experiences in Electronic Simulation and Physical Electronic Simulation

Emerging Theme 1: Complementary Role of Electronic Simulation and Physical Electronic Trainers in Enhancing Learning

"Yeah, Sir: Simulation enabled me to comprehend concepts fast and the physical trainer aided me to develop practical skills and solving of problems." - P1

"Yeah, Po Sir: Electronic simulation enabled me to play with circuits safely without destroying any component but the physical electronic trainers enabled me to gain practical skills." – P2

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"Yes, Po Sir: Through Electronic simulation, I gained hands-on experience about components without any risk of destroying my parts. It helped me learn the behavior of components and their theory while Physical electronic trainer helped me learn to connect components practically." – P3

"I had a great experience in electronic simulation where I learned about circuits in a safer way, but Physical Electronic trainer helped me practice what I have learned in reality." – P4

"Yes Sir. In Electronic simulation, I experimented with the changing of components without any danger of destroying anything, but through Physical electronic trainer, I practiced the connection of components." – P5

The findings show that virtual simulation tools and physical electronic trainers play complementary roles in developing students' troubleshooting skills. Virtual simulations supported conceptual understanding by providing interactive, safe, and flexible learning environments with opportunities for repeated practice and immediate feedback, consistent with Constructivist Learning Theory (Foronda et al., 2020; Verkuyl et al., 2021). In contrast, physical electronic trainers strengthened hands-on experience, psychomotor skills, and authentic problem-solving, aligning with Experiential Learning Theory. Together, these instructional modalities combined theoretical knowledge with practical skills, supporting blended learning approaches in STEM and Technology and Livelihood Education (Ashraf et al., 2021; Rahman & Johari, 2022; Schnieder et al., 2022; Tenzin et al., 2024). These implications should be interpreted within the context of the participating Grade 10 students at Lambayong National High School.

Emerging Theme 2: Enhancement of Practical Competence through Physical Electronic Trainers

Theme 2 underscores the central role of physical electronic trainer equipment in promoting hands-on learning, skill development, and real-world understanding of electronics within the context of TLE. The clustered themes revealed consistent patterns related to hands-on engagement, technical skill acquisition, realism, and tool competency, all of which are essential components of skills-based education.

"Physical electronic trainer because it gave me the opportunity to have firsthand experience." -P1
"Physical trainer because I can connect the components practically." - P2
"Physical electronic trainer because it enabled me to understand electronics in real-life scenarios." -P3
"Physical electronic trainer because it improved my practical skills." -P4
"Physical electronic trainer because I learned how to use the right tools for assembling." -P5

The findings highlight the value of hands-on learning in developing students' practical competence in electronics. Physical electronic trainers enhanced circuit assembly, fault diagnosis, equipment handling, and troubleshooting skills through authentic laboratory experiences, consistent with Constructivist and Experiential Learning theories. These findings are consistent with Hardon et al. (2021), Li et al. (2021), and Li and Liang (2024), who reported that laboratory-based instruction strengthens technical and problem-solving skills more effectively than simulation alone. While virtual simulations reinforced conceptual understanding in a safe and flexible learning environment, physical trainers provided authentic experiences essential for technical competence. Within the context of this study, these findings suggest that combining both instructional approaches may support more comprehensive learning outcomes in Technology and Livelihood Education.

Emerging Theme 3: Enhanced Student Learning Engagement through Active, Cognitive, and Inquiry-Based Participation

Theme 3 highlights students' learning engagement through hands-on experiences, cognitive processing, problem-solving, inquiry, and active classroom participation. The findings indicate that both virtual simulation and physical electronic trainers promoted meaningful engagement by encouraging learners to think critically, ask questions, solve problems, and actively participate in learning activities. These instructional modalities fostered deeper understanding and supported the development of troubleshooting skills essential in Technology and Livelihood Education (TLE).

"My learning engagement can be described as hands-on and interactive." -P1

"My learning engagement can be described as being keen on observing how different parts function and solving problems." -P2

"My learning engagement can be described as being engaged, especially during demonstrations, and trying to implement what I learned from the simulations and physical electronic trainers." -P3

"My learning engagement can be described as interactive and engaged." -P4

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"My learning engagement can be described as participating in activities, posing questions where needed, and practicing building and testing circuits." -P5

The findings suggest that active participation, cognitive engagement, and problem-solving supported students' learning in electronics. Virtual simulations promoted conceptual understanding through experimentation, immediate feedback, and inquiry-based learning, while physical electronic trainers strengthened hands-on experience and practical troubleshooting through authentic circuit construction. Students actively applied concepts, asked questions, and solved problems, reflecting the Technology and Livelihood Education principle of integrating theory and practice. These findings are consistent with Al Mamun et al. (2020), Cairns and Areepattamannil (2022), Prince et al. (2020), Rahman and Johari (2022), and Van den Beam et al. (2022), who reported that combining virtual simulations with hands-on laboratory experiences supports both conceptual understanding and practical competence. These implications should be interpreted within the context of the participating Grade 10 students at Lambayong National High School.

Emerging Themes on the Challenges Encountered by the Students as they Engage in Electronic Simulation and Physical Electronic Trainer

The findings revealed that students encountered distinct yet complementary challenges across the two instructional modalities. Virtual simulations primarily involved cognitive and technological difficulties, such as understanding the software, circuit symbols, and circuit design, whereas physical electronic trainers posed challenges related to wiring, component placement, and circuit connections. Despite these differences, both instructional modalities supported the development of students' problem-solving, analytical thinking, and troubleshooting skills, contributing to meaningful learning in electronics. These findings should be interpreted within the context of the participating Grade 10 students at Lambayong National High School.

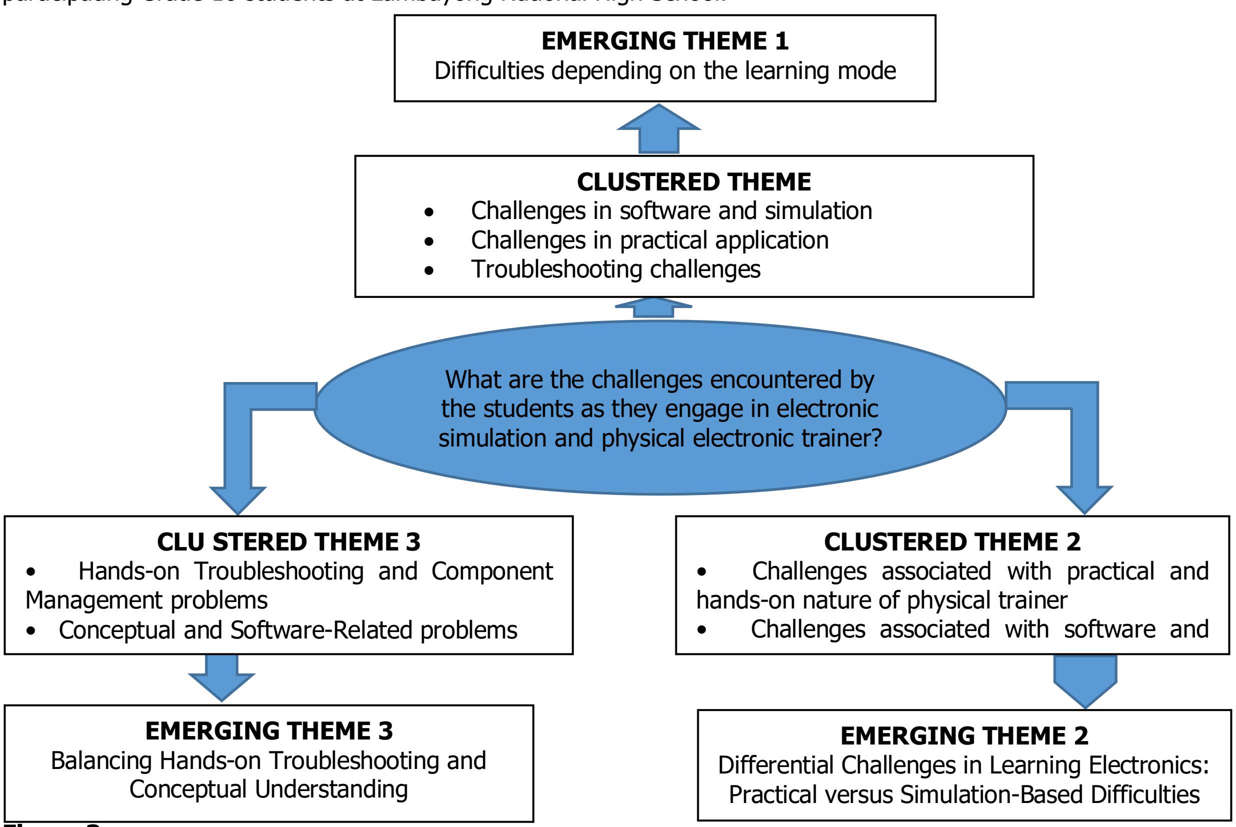

Figure 3
The Emerging Theme on Students' Challenges in Electronic Simulation and Physical Electronic Trainer

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Emerging Theme 1: Difficulties Depending on the Learning Mode

The findings indicate that students experienced distinct yet related challenges when using virtual simulation software and physical electronic trainers. Virtual simulations mainly involved cognitive and technical-interface difficulties, whereas physical trainers required procedural knowledge and troubleshooting of actual connections. Despite these differences, both instructional modalities provided valuable learning experiences that strengthened students' problem-solving and technical competencies.

"One challenge that I have faced when using electronic simulation was that some elements were confusing at first because it was challenging to choose the right components and set their values. The problem I faced when using physical electronic trainer was that it was difficult to make connections correctly." - P1

"One challenge that I have faced when using electronic simulation was that it was not easy to comprehend the circuit because it is all displayed on the screen. In physical electronic trainer, if the connection or component was misplaced, it would not be possible to make the circuit function, and it would need more time to identify the error and fix it." - P2

"One challenge that I have faced when using electronic simulation was understanding how to use the software elements and the symbols of the circuit. Sometimes it could take time to find out why the circuit was malfunctioning. In physical electronic trainer, sometimes I found it difficult to connect the wires accurately and place the components in the right location." - P3

"With electronic simulation, the issue lay in how one was able to configure the circuit within the software program. Errors were hard to spot since it was a virtual setting. When working on the physical electronic trainer, I ran into issues like bad connections, wiring errors, or inability to identify certain components." -P4

"The drawback with electronic simulation was its perceived lack of realism when compared with actual circuits. In contrast, working with the physical electronic trainer, there were times when troubleshooting the circuit proved difficult, especially if something went wrong." -P5

The findings revealed that students encountered different challenges across the two instructional modalities. Virtual simulations primarily involved cognitive and technological difficulties, such as understanding software, interpreting electronic symbols, and navigating the interface, whereas physical electronic trainers presented procedural challenges, including wiring, component placement, and circuit testing. Despite these difficulties, both approaches promoted the development of analytical thinking and troubleshooting skills. Consistent with Constructivist and Experiential Learning theories, the challenges served as valuable learning opportunities that enhanced conceptual understanding through simulations and practical competence through hands-on activities. These findings support the integration of virtual simulations and physical electronic trainers to address both cognitive and procedural aspects of electronics learning.

Emerging Theme 2: Differential Challenges in Learning Electronics: Practical versus Simulation-Based Difficulties

In Theme 2, there are two main areas where problems arise. First, there are problems associated with the actual application of the electronic trainer itself; second, there are problems concerning software applications and electronic circuit simulation. The problems vary widely according to their nature, frequency, and cause, but all fall under the category of difficulties in the field of TLE electronics education.

"I find the physical electronic trainer difficult because precise wiring and the proper placement of components are required. Any minor error in the connections will make the circuit non-functional." -P1

"Physical electronic trainers are harder for me since they involve more time when troubleshooting. It takes time to analyze the circuit and locate any errors made." -P2

"I find electronic simulations difficult since I tend to confuse myself with how to use the software. Component connections might become problematic in such cases." -P3

"Electronic simulation may be hard because there needs to be an understanding of the symbols used in the program and their functionalities." -P4

"Physical electronic trainers are harder since they demand patience and precision during the setup of the circuit components." -P5

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The findings indicate that learning barriers differed according to the instructional modality. Students using virtual simulations primarily encountered cognitive and interface-related challenges, including software navigation, symbol interpretation, and circuit assembly, whereas those using physical electronic trainers experienced procedural difficulties such as wiring errors, component placement, and circuit troubleshooting. Despite these challenges, both learning environments encouraged active engagement in problem-solving and troubleshooting tasks. Consistent with Constructivist and Experiential Learning theories, the findings suggest that virtual simulations and physical electronic trainers provide complementary learning opportunities by supporting conceptual understanding and practical skill development. Within the context of this study, these results suggest that balancing simulation-based and hands-on instruction may enhance both cognitive and procedural competencies in Technology and Livelihood Education.

Emerging theme 3: Balancing Hands-on Troubleshooting and Conceptual Understanding

Theme 3 was derived from two sets of problems, namely concrete and logistical problems, and abstract or software problems. This included issues that were encountered when conducting circuit troubleshooting, component selection, unexpected output results, and simulations. In other words, electronics education was characterized by multiple problems in TLE.

"The challenge that made the most difference in my learning process was finding the circuit problems as it called for a lot of patience and double-checking of all connections." P1

"Perhaps the biggest challenge for me was comprehending the way the circuit operates, particularly when there were differences between the anticipated and actual output results." P2

"The challenge that had the most influence on my learning process was choosing the right components and determining their proper values, as selecting an inappropriate component could result in improper operation of the circuit." P3

"One challenge that made the most impact in my learning process was learning to utilize electronic simulation software effectively, as I needed some time to get familiar with all its options." P4

"The challenge that had the largest impact on my learning process was correcting errors in connections within the circuit, as it allowed me to develop my analytical skills and focus." P5

The findings revealed that students encountered procedural, cognitive, and technical challenges depending on the instructional modality. Physical electronic trainers mainly involved troubleshooting, wiring, and component management, whereas virtual simulations presented challenges in software navigation, circuit interpretation, and symbol recognition (Kapilan et al., 2021; Maryanski & Petersen, 2021; Price et al., 2021; Zhao, 2021). Consistent with Constructivist and Experiential Learning theories, both modalities encouraged active engagement in troubleshooting tasks. Within the context of this study, the findings suggest that integrating virtual simulations with physical electronic trainers may provide complementary learning experiences that support conceptual understanding and practical skill development in Technology and Livelihood Education.

Emerging Theme on Students' Strategies, Skill Development, and Reflection in Electronic Simulation and Physical Electronic Trainer

The qualitative findings demonstrate that there are several ways in which students deal with their anxiety, build skills, and perform effectively in the electronics course. Students reduce their anxiety by preparing well, practicing, working together, and carefully executing procedures, which help them gain confidence in both simulation and real-life situations. Students build their skills through practical training in real-life electronic equipment and theoretical training using simulations. This helps them develop a better grasp of electronics concepts and application.

Finally, reflective learning is an important way in which students perform effectively in electronics. Students reflect on their mistakes, ask for feedback, practice continually, and plan well

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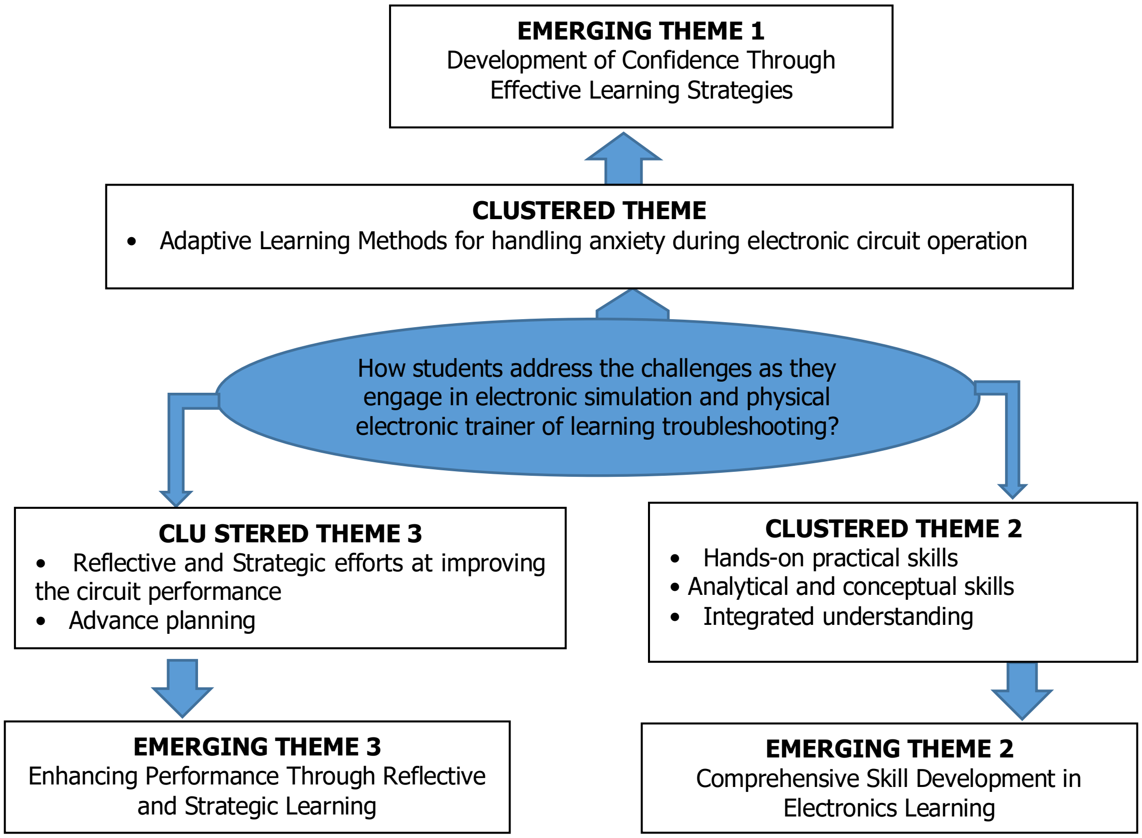

Figure 4
Emerging Theme on Students' Strategies, Skill Development, and Reflection in Electronic Simulation and Physical Electronic Trainer

Emerging Theme 1: Development of Confidence Through Effective Learning Strategies

Theme 1 involves techniques on how anxiety can be adapted while working with electronics circuits. This includes practice and preparation, teaming up, following of procedure, and overall testing. Such techniques effectively address issues related to anxiety, which may arise from confusion while using simulation interfaces, faulty wiring, wrong selection of parts, and difficult troubleshooting, among others.

"One thing that I found effective to minimize anxiety was to practice more and review the lesson prior to undertaking the task, giving me confidence to diagnose problems with the circuits." –P1

"I minimized my fear by asking for clarifications from my teacher and classmates whenever I encountered some challenges when conducting the simulations or while utilizing the electronic trainer." -P2

"My approach was to follow the instructions carefully, which enabled me to minimize the chances of making mistakes." -P3

"Anxiety was minimized by cross-checking connections between components and their values before powering up the circuit." -P4

"Fear was minimized by remaining patient and practicing more; the more I practiced, the more comfortable I got with electronic simulations and electronic trainers." -P5

The findings show that students employed adaptive strategies, including preparation, repeated practice, collaboration, and systematic troubleshooting, to address learning challenges in electronics. Participants reported that these strategies helped them manage difficulties encountered during virtual simulations and hands-on activities, consistent with Self-Efficacy Theory, Constructivist Learning Theory, and Experiential Learning Theory (Merensky et al., 2022; Trongtirakul et al., 2022; Van den Beem et al., 2022). Within the context of this study, the findings suggest

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that fostering collaborative learning, reflective practice, and structured troubleshooting activities may support students' conceptual understanding and practical skill development in Technology and Livelihood Education.

Emerging Theme 2: Comprehensive Skill Development in Electronics Learning

Theme 2 revolves around the following three areas of skill development: skills involving hands-on training, critical thinking or analysis, and integrated learning. It becomes clear how students used computer simulation and electronic training equipment to cope with software problems, symbol interpretation problems, wrong connections, and troubleshooting problems. All in all, one can state that different techniques prove effective in TLE in various contexts.

"The physical electronic trainer environment was the best for developing my skills as it enabled me to gain experience in component connections, troubleshoot circuits, and operate with actual components." -P1

"The electronic simulation environment was good for improving my skills as it enabled me to experiment with circuits and avoid damaging any components while learning from my mistakes." -P2

"The combination of simulation environment and physical trainer helped me develop my skills as simulation enhanced theoretical knowledge while the trainer helped me gain hands-on experience." -P3

"The hands-on laboratory environment using the physical trainer enabled me to develop practical skills and ability to solve problems with real-world circuits." -P4

"Simulation environment enabled me to develop analytical and planning skills as I could foresee the behavior of my future circuit." -P5

The findings indicate that hands-on practice, virtual simulations, and their integration enhanced students' electronics learning. Repeated use of physical electronic trainers improved wiring, troubleshooting, technical competence, and confidence through authentic laboratory experiences, consistent with Experiential Learning Theory (O'Brien, 2021; Wiggins et al., 2021). Meanwhile, virtual simulations strengthened conceptual understanding by allowing students to safely visualize circuit behavior and electronic symbols (Makransky & Petersen, 2021; Radianti et al., 2020). Within the context of this study, the findings suggest that integrating virtual simulations with physical electronic trainers may provide complementary learning experiences that support conceptual understanding, technical skills, and problem-solving abilities in Technology and Livelihood Education (Li & Liang, 2024; Tenzin et al., 2024).

Emerging Theme 3: Enhancing Performance Through Reflective and Strategic Learning

Theme 3 reveals three interrelated aspects: contemplation, planned actions to enhance circuit performance, improved foresight, and consistent implementation. This addresses issues like troubleshooting difficulties, erroneous wiring, improper component selection, and simulations. The strategies employed indicate the methods used by students to evaluate and improve their knowledge of TLE electronics.

"I considered the problems faced in terms of looking back at what had gone wrong in the past and taking note to avoid making similar mistakes in the future circuit."- P1

"Improvements in future performances were made through seeking feedback and criticism from my teacher or classmates and applying those ideas in the next circuit."- P2

"I reflected on problems by doing the circuit once more, which would help me become better acquainted with the circuit and be able to do it successfully in the future."- P3

"I considered the problems faced by analyzing a complicated circuit in order to break it down into manageable parts."- P4

"Improvements in future performances were made by formulating my plan beforehand to ensure I worked systematically in completing each task."- P5

The findings revealed that reflective learning, repeated practice, and systematic planning were effective strategies for improving students' electronics learning. Reflection and instructor feedback helped students identify errors and improve troubleshooting skills, consistent with Self-Regulated Learning (Panadero et al., 2022). Repeated practice strengthened confidence and technical competence through authentic learning experiences, supporting Experiential Learning Theory (Merensky et al., 2022; Wiggins et al., 2021). Meanwhile, planning and task segmentation reduced cognitive load and improved circuit management, aligning with Cognitive Load Theory (Martin et al., 2021; Sweller et al., 2022). Within the context of this study, these strategies suggest that reflective practice, repeated hands-on activities, and systematic planning may support the development of students' critical thinking, self-regulation, and technical competence in electronics.

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Comparative Analysis of Qualitative and Quantitative Results

The integration of the quantitative and qualitative findings demonstrates strong convergence, enhancing the credibility of the study. Quantitative results showed that the physical electronic trainer group achieved the highest posttest performance, while the combined and virtual simulation groups also demonstrated improvement. These findings were supported by the qualitative data, in which students described physical electronic trainers as valuable for developing hands-on troubleshooting skills and technical competence, whereas virtual simulations enhanced conceptual understanding, cognitive engagement, and safe experimentation. Although each modality presented distinct challenges, students addressed these through practice, collaboration, reflection, and systematic troubleshooting. Consistent with Constructivist Learning Theory and Experiential Learning Theory, the findings suggest that meaningful learning occurs through active knowledge construction and authentic experience. Within the context of this study, the convergence of both datasets indicates that integrating virtual simulations with physical electronic trainers may provide complementary learning experiences that support conceptual understanding, technical competence, and troubleshooting skills in Technology and Livelihood Education.

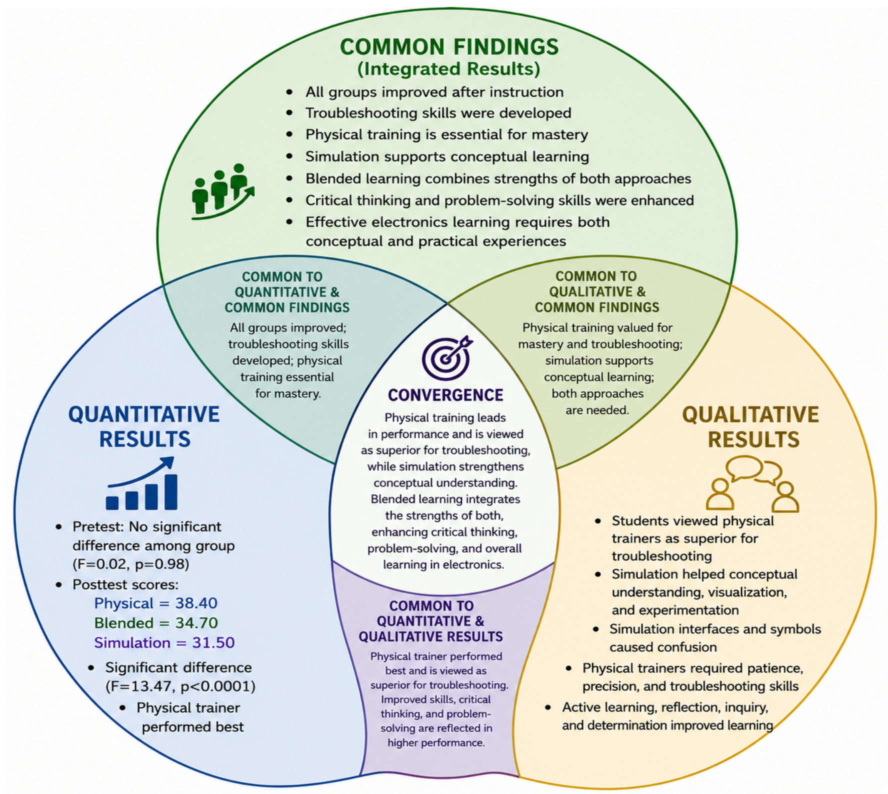

Figure 5

Venn Diagram that shows the convergence of Qualitative and Quantitative Results **Conclusions**

Based on the analysis and interpretation of the data, the following conclusions were drawn.

1. Virtual simulation tools and physical electronic trainers effectively improved students' troubleshooting skills. However, physical electronic trainers produced the highest posttest performance, emphasizing the importance of authentic hands-on experiences in developing technical competence and procedural skills.
2. Virtual simulations enhanced conceptual understanding and exploratory learning, while physical electronic trainers strengthened psychomotor skills and troubleshooting proficiency. Qualitative findings further showed that both modalities addressed different learning needs and promoted critical thinking, self-regulation, and problem-solving skills.
3. Guided by Constructivist and Experiential Learning theories, the study concludes that integrating virtual simulations with physical electronic trainers provides the most effective learning environment by combining

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conceptual understanding with authentic practical experiences, thereby enhancing electronics instruction in Technology and Livelihood Education (TLE).

Recommendations

Based on the conclusions of the study, the following recommendations are offered.

1. Schools should integrate virtual simulation tools and physical electronic trainers to provide balanced conceptual and hands-on learning experiences in electronics education.
2. Teachers should maximize the use of physical electronic trainers to strengthen students' troubleshooting skills while using virtual simulations to reinforce theoretical concepts before laboratory activities.
3. Professional development programs should be conducted to enhance teachers' competence in integrating simulation technologies into electronics instruction.
4. Schools should ensure the availability of adequate simulation software and functional electronic trainer equipment to support effective laboratory instruction.
5. Future researchers should replicate the study using larger samples, longer intervention periods, different educational settings, and additional variables such as motivation, self-efficacy, and learning engagement to further validate the findings.

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P - ISSN 3116-3769; E - ISSN 3116-3777
National Book Development Board (NBDB) Registration as Book Publisher (Print & Digital): 6312
PRC-CPD Accredited Provider: PTR-2025-749
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