Examining the Educational Effectiveness, Technology Acceptance, and Perceived Social Utility Value of PhET Simulations in Vocational Electrical Education

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Abstract:
The integration of interactive simulations in technical-vocational education and training (TVET) offers a promising strategy for addressing resource limitations and improving students' understanding of abstract electrical concepts. This study examined the educational effectiveness, technology acceptance, and perceived social utility value of Physics Education Technology (PhET) simulations in teaching Electronic Product Assembly and Servicing (EPAS) through an embedded mixed-methods design. The quantitative component employed a quasi-experimental pretest-posttest control group design involving 50 first-year Bachelor of Science in Industrial Technology students at North Eastern Mindanao State University, with 25 students assigned to the experimental group and 25 to the control group. Data were collected using a validated 30-item achievement test and a Technology Acceptance Model (TAM) questionnaire, while qualitative data were gathered through semi-structured interviews with 15 purposively selected students from the experimental group. Results revealed no significant difference in pretest scores, confirming baseline equivalence; however, the experimental group demonstrated significantly higher posttest performance than the control group (M = 18.74 vs. 16.94, p = .007). Although perceived usefulness and perceived ease of use were rated as neutral, students reported positive attitudes toward using PhET (M = 4.06) and high personal innovativeness (M = 3.64). Among the TAM constructs, Actual Use was the only significant predictor of academic performance (r = .542, p = .038). Qualitative findings further revealed that students perceived learning through PhET as socially valuable by preparing them for future work, enabling them to help others through technical skills, strengthening the purpose of vocational learning, fostering professional responsibility, and promoting equitable access to technical education. Overall, the findings suggest that PhET simulations function not only as effective instructional tools for improving academic performance but also as meaningful learning technologies that cultivate students' appreciation of the broader professional and societal value of vocational education.

Keywords: PhET Simulations; Technical and Vocational Education and Training (TVET); Technology Acceptance Model; Perceived Social Utility Value; Vocational Education

1. Introduction

In the era of rapid technological advancement and the Fourth Industrial Revolution, technical-vocational education and training (TVET) plays a pivotal role in preparing a skilled workforce capable of meeting industry demands (Edralin & Pastrana, 2023; Budhrani et al., 2018). This is particularly evident in fields like electrical, where hands-on competencies in assembly, troubleshooting, and servicing are essential for economic participation (Bermundo, 2025). In the Philippines, the K-12 curriculum emphasizes TVET tracks such as Electronic Product Assembly and Servicing (EPAS) to equip students with National Certificate II (NC II) level skills (Orbeta, 2021). However, traditional teaching methods often struggle to address systemic challenges in instruction, including insufficient laboratory resources, high costs of electronic components, and the inherent difficulty of visualizing abstract concepts such as current flow and voltage distribution (Azarias et al., 2020; Villacorta & Arnado, 2023). These constraints often lead to diminished student engagement and incomplete competency mastery, particularly in resource-limited educational settings (Suryavanshi, 2024).

Interactive simulations have emerged as a transformative solution to these challenges by offering cost-effective, safe, and repeatable virtual environments (Banda & Nzabahimana, 2021; Yanto et al., 2026). The Physics Education Technology (PhET) project provides research-based interactive simulations that foster conceptual understanding by making invisible processes visible (Diab et al., 2024; Fuada et al., 2023). Extensive literature has demonstrated the effectiveness of PhET in improving student achievement in electricity and circuits, as these tools allow for intuitive exploration that traditional labs cannot always replicate (Fitriani, 2024; Villaruel, 2025). Recent studies further support the integration of these simulations in secondary and tertiary education, highlighting significant gains in conceptual mastery and the transfer of skills to real-world applications (de Medeiros Jr. et al., 2024; Furqon, 2024).

Despite the documented benefits of PhET simulations in pure science contexts, their adoption and pedagogical value within TVET electrical programs remain underexplored. Specifically, there is a lack of empirical evidence regarding student acceptability through the lens of the Technology Acceptance Model (TAM). Understanding factors such as perceived usefulness and ease of use is critical for the sustainable integration of digital tools in vocational curricula. However, technology acceptance alone may not sufficiently explain how students perceive the broader educational, professional, and societal significance of digital learning innovations, thereby necessitating complementary perspectives that examine the value students attribute to learning beyond technology adoption.

Despite the growing application of the Technology Acceptance Model (TAM) in educational technology research, recent scholarship suggests that technology acceptance alone does not fully explain why students remain engaged with learning technologies or perceive them as meaningful beyond classroom requirements. Drawing from Situated Expectancy-Value Theory, utility value refers to learners' beliefs that academic tasks are useful for achieving future goals, career aspirations, and meaningful life outcomes. More recent perspectives extend this concept to **Perceived Social Utilitarian Value**, emphasizing that students assign greater value to learning when they recognize its contribution not only to their individual academic success but also to their future professions, communities, and society. Empirical evidence consistently demonstrates that students who perceive stronger utility value exhibit higher engagement, persistence, academic achievement, and stronger commitment to future careers (Wang, 2022; Harackiewicz & Priniski, 2023; Shang et al., 2022; Breetzke et al., 2024). Likewise, longitudinal investigations have shown that utility value develops through meaningful learning experiences and predicts students' motivation and academic performance over time (Sutter et al., 2024). Within vocational education, these findings suggest that educational technologies should not merely facilitate learning but also enable students to recognize the broader practical and societal significance of the competencies they develop.

Recent international investigations further demonstrate that learners who perceive greater social utility value are more likely to develop stronger professional commitment, career aspirations, and sustained engagement with educational technologies. For instance, Li et al. (2025) reported that social utility value significantly influenced professional commitment and career choice among university students, while Mok et al. (2021) found that utility value strengthened students' long-term career motivation by linking classroom learning with future professional and societal goals. Similarly, Chan and Zhou (2023) showed that students' perceptions of value significantly predicted their willingness to adopt emerging educational technologies. Within the Philippine context, related studies have likewise emphasized that students value vocational education because of its perceived contribution to career readiness, lifelong learning, employability, and social participation (Mokher et al., 2025; Generalao et al., 2025; Abing, 2025; Estilo, 2025; Sibug et al., 2026). Collectively, these studies suggest that meaningful educational technologies are evaluated not only by their instructional effectiveness or technological acceptability but also by the extent to which students perceive them as instruments for future professional success and societal contribution. Nevertheless, despite the growing evidence supporting utility value in educational settings, limited research has examined the **Perceived Social Utilitarian Value of PhET simulations** within technical-vocational education, particularly in Electrical Technology programs. Addressing this gap may provide a more holistic understanding of how simulation-based learning influences students beyond academic performance and technology acceptance.

For the aforementioned reasons, this study integrated selected PhET simulations—specifically the Circuit Construction Kit: DC, Ohm's Law, and Battery-Resistor Circuit—as supplementary instructional tools in teaching

Electronic Product Assembly and Servicing (EPAS) to first-year Bachelor of Science in Industrial Technology students majoring in Electrical Technology. Employing an embedded mixed-methods approach, the quantitative component evaluated the educational effectiveness and technology acceptance of PhET simulations, while the qualitative component explored students' perceptions of the social utility of simulation-based learning in relation to their future professional and societal roles. Specifically, the study sought to: (1) compare the academic performance of students receiving PhET-integrated instruction with those taught using traditional lecture-demonstration methods; (2) determine the level of technology acceptance of PhET simulations based on the Technology Acceptance Model (TAM) constructs of perceived usefulness, perceived ease of use, personal innovativeness, attitude toward using, and actual use; (3) examine the significant differences in academic performance between the experimental and control groups; (4) investigate the relationship between TAM constructs and students' academic performance; and (5) explore students' perceived social utility value of PhET simulations and how these perceptions shape their views of vocational learning, future professional practice, and societal contribution. Based on existing evidence supporting interactive simulations, the following null hypotheses were tested at α = 0.05:

H_{01}: There is no significant difference in pretest and posttest performance between the experimental group and the control group.

H_{02}: There is no significant correlation between TAM constructs and posttest performance in the experimental group.

This study seeks to provide empirical evidence on the effectiveness and acceptability of PhET simulations as an accessible digital tool for enhancing vocational electronics education globally.

2. Materials and Methods

2.1 Research Design

This study employed an embedded mixed-methods research design, wherein the quantitative component served as the primary method while a qualitative component was embedded to provide a deeper understanding of the quantitative findings. The quantitative phase utilized a quasi-experimental pretest-posttest control group design to evaluate the educational effectiveness of integrating Physics Education Technology (PhET) simulations in teaching Electronic Product Assembly and Servicing (EPAS) among first-year Bachelor of Science in Industrial Technology students majoring in Electrical Technology. Following the intervention, a qualitative inquiry was conducted through semi-structured interviews with selected participants from the experimental group to explore their perceived social utility value of learning through PhET simulations, particularly in relation to vocational learning, future professional practice, and societal contribution. Integrating the two strands enabled the study to examine not only the effectiveness and technology acceptance of PhET simulations but also the broader meanings students attached to their learning experiences. The research was conducted at North Eastern Mindanao State University (NEMSU), Cantilan Campus, Surigao del Sur, Philippines, during the Academic Year 2025–2026.

2.2 Participants

The participants consisted of 50 first-year Bachelor of Science in Industrial Technology students majoring in Electrical Technology enrolled in the Electronic Product Assembly and Servicing (EPAS) course. Using simple random sampling, the students were divided into two intact groups: an experimental group (n = 25) that received instruction incorporating PhET simulations and a control group (n = 25) that received traditional lecture-demonstration methods. Both groups completed a pretest to assess baseline equivalence. For the qualitative component, 15 students were purposively selected from the experimental group following the completion of the intervention. Purposive sampling was employed to obtain rich and information-intensive accounts of students' learning experiences with PhET simulations. To ensure that participants possessed adequate experience to meaningfully reflect on the intervention, the following inclusion criteria were established: (1) the student must belong to the experimental group; (2) must have completed the three-week PhET-integrated instruction; (3) must have completed both the pretest and posttest as well as the Technology Acceptance Model (TAM) questionnaire; (4) must have attended at least 90% of the intervention sessions; and (5) must have voluntarily agreed to participate in the interview through informed consent. Recruitment continued until sufficient depth and thematic richness were achieved across participants' responses.

Informed consent was obtained from all participants, and the study followed ethical guidelines under the supervision of the Research Ethics Committee of North Eastern Mindanao State University. Given its non-invasive educational nature, no formal ethical clearance code was required.

2.3 Research Instruments

Four main instruments were utilized:

1. Achievement Test: A researcher-developed 30-item multiple-choice and problem-solving test covering EPAS topics such as circuit assembly, component identification, troubleshooting, and servicing. The instrument was validated by three electrical education experts (Content Validity Index = 0.92) and pilot-tested for reliability (KR-20 = 0.85).
2. PhET Simulations: Interactive simulations sourced from the University of Colorado Boulder library, including Circuit Construction Kit: DC, Ohm's Law, Resistance in a Wire, Battery-Resistor Circuit, and Capacitor Lab: Basics. These open-access simulations were used unmodified and accessed via laboratory computers in online or offline modes.
3. Technology Acceptance Model (TAM) Questionnaire: Adapted from established TAM frameworks and extended to include Personal Innovativeness. It consisted of 27 items on a 5-point Likert scale (1 = Strongly Disagree to 5 = Strongly Agree) measuring Perceived Usefulness (9 items), Perceived Ease of Use (6 items), Personal Innovativeness (4 items), Attitude Toward Using (6 items), and Actual Use (2 items). The instrument achieved an overall Cronbach's alpha of 0.89, indicating high internal consistency.
4. Semi-Structured Interview Guide: A researcher-developed semi-structured interview guide was designed to explore students' perceived social utility value of learning through PhET simulations. The interview consisted of open-ended questions focusing on students' perceptions of the practical relevance of simulation-based learning, preparation for future professional practice, potential contributions to society, and the broader significance of technical-vocational education. The interview guide underwent expert validation by three specialists in educational research and qualitative methodology prior to implementation.

2.4 Data Gathering Procedure

The intervention lasted three weeks, covering major EPAS modules on electronic components, circuit building, and servicing. Both groups received identical lesson objectives and instructional time (10 hours per week). The control group received traditional lecture-discussion instruction using physical components and textbook exercises. The experimental group was taught using the same content but with PhET simulations integrated into lessons. Approximately 40–50% of class time involved simulation-based exploration, guided inquiry, and group discussion. Both groups took a pretest one week before and a posttest immediately after the intervention. The TAM questionnaire was administered to the experimental group at the end of the study.

Following the quantitative data collection, the qualitative phase was conducted to provide explanatory insights into the statistical findings. Fifteen participants from the experimental group who satisfied the inclusion criteria were invited to participate in individual semi-structured interviews. Each interview lasted approximately 20–30 minutes and was conducted in a quiet setting within the university. With participants' permission, the interviews were audio-recorded and subsequently transcribed verbatim for analysis. The interview protocol focused on exploring students' perceived social utility value of learning through PhET simulations, including their perceptions of its relevance to future employment, vocational competence, practical application, and potential contributions to their communities.

2.5 Data Analysis

Data were analyzed using SPSS Statistics. Descriptive statistics (weighted mean and standard deviation) were used to summarize TAM constructs, interpreted as follows: 4.50–5.00 (Strongly Agree), 3.50–4.49 (Agree), 2.50–3.49 (Neutral), 1.50–2.49 (Disagree), 1.00–1.49 (Strongly Disagree).

An independent samples t-test (α = 0.05) compared pretest and posttest scores between groups, and gain scores were calculated as Posttest – Pretest. Pearson product-moment correlation examined relationships between TAM constructs and posttest performance.

Qualitative data were analyzed using reflexive thematic analysis following the procedures proposed by Braun and Clarke (2006). Interview transcripts were read repeatedly to achieve data familiarization before initial codes were generated. Similar codes were subsequently organized into broader categories and refined into overarching themes that captured participants' shared perceptions regarding the social utility value of learning through PhET simulations. To enhance the credibility and trustworthiness of the findings, the coding process was independently reviewed by two qualitative research experts, and representative participant excerpts were included to support the interpretation of each emergent theme.

All instruments, raw data, and lesson materials are available from the corresponding author upon reasonable request. PhET simulations are freely accessible at https://phet.colorado.edu.

3. Results

This quasi-experimental study involved 50 first-year Bachelor of Science in Industrial Technology students majoring in Electrical Technology (N=50). Participants were equally divided into an experimental group (n=25), utilizing PhET-integrated instruction, and a control group (n=25), following traditional instructional methods.

3.1 Comparative Analysis of Performance Outcomes

The pretest mean scores (Table 1) for the experimental group (M = 13.68, SD = 2.94) and the control group (M = 13.06, SD = 1.79) indicated similar baseline knowledge. Following the intervention, the experimental group achieved a higher posttest mean score (M = 18.74, SD = 3.10) compared to the control group (M = 16.94, SD = 3.46). Correspondingly, the mean gain score for the experimental group was 5.06, while the control group was 3.88.

Table 1. Mean Pretest and Posttest Scores for Experimental and Control Groups

	Group	**N**	**Mean**	**Std. Deviation**
Pretest	Experimental	25	13.68	2.94466
	Control	25	13.06	1.78897
Posttest	Experimental	25	18.74	3.09582
	Control	25	16.94	3.46062
Gain	Experimental	25	5.06	3.58802
	Control	25	3.88	3.18568

As shown in Table 2, the independent samples t-test revealed that the difference in pretest scores was not statistically significant (t = 1.272, p = 0.206), confirming group equivalence at the outset. However, the posttest difference was statistically significant (t = 2.741, p = 0.007), indicating that the experimental group significantly outperformed the control group after the integration of PhET simulations.

Table 2. Significant Difference in Pretest and Posttest Performance Between the Experimental and Control Groups

	Group	Mean	SD	t-ratio	p-value	Decision	Interpretation
Pretest	Experimental	13.6800	2.945	1.272	0.206	Failed to reject H_{01}	Not significant
	Control	13.0600	1.789				
Posttest	Experimental	18.7400	3.096	2.741	0.007	Reject H_{01}	Significant
	Control	16.9400	3.461				

3.2 Analysis of Student Acceptability through the Technology Acceptance Model (TAM)

The experimental group's evaluation of PhET simulations across TAM constructs is summarized in Table 3. **Attitude Toward Using** received the highest rating (AWM = 4.06, SD = 0.78), interpreted as "Agree." **Personal Innovativeness** also fell within the "Agree" range (AWM = 3.64, SD = 0.76).

Conversely, **Perceived Usefulness** (AWM = 3.43, SD = 0.67) and **Perceived Ease of Use** (AWM = 3.49, SD = 0.90) were both interpreted as "Neutral." The lowest mean was recorded for **Actual Use** (AWM = 2.14 SD = 1.24), which was interpreted as "Disagree," indicating infrequent independent utilization of the simulations outside of the structured laboratory sessions.

Table 3. Level of Acceptability of the PhET Simulations based on the following TAM constructs.

Perceived Usefulness	**Weighted Mean**	**Standard Deviation**	**Verbal Description**
PhET simulations enable me to accomplish electronics assembly and servicing tasks more quickly.	3.28	0.57	Agree
PhET simulations have improved the quality of my work in electronic product assembly and servicing.	3.56	0.73	Agree
PhET simulations make it easier for me to understand and perform electronic product assembly and servicing.	2.64	0.78	Neutral
PhET simulations have improved my productivity in learning electronic product assembly and servicing.	3.84	0.65	Agree
PhET simulations give me greater control over the processes involved in electronic product assembly.	3.58	0.61	Agree
The use of PhET simulations increases the effectiveness of performing electronic assembly and servicing tasks.	3.34	0.59	Neutral
Using PhET simulations gives me access to a lot of helpful information about electronics concepts.	3.94	0.71	Agree
PhET simulations provide thorough and accurate information for my learning in electronic product assembly and servicing.	3.36	0.69	Neutral
The advantages of using PhET simulations in learning electronic product assembly outweigh the disadvantages.	3.32	0.65	Neutral
AWM	3.43	0.67	Neutral
Perceived Ease of Use	**Weighted Mean**	**Standard Deviation**	**Verbal Description**
My interaction with PhET simulations in learning electronics has been clear and understandable.	2.8	1.01	Neutral
Overall, PhET simulations are easy to use for learning electronic product assembly and servicing.	3.5	0.86	Agree
Learning to operate PhET simulations was easy for me in the context of electronics.	4.24	0.74	Agree
The use of PhET simulations for learning electronics does not confuse me.	3.14	1.03	Neutral
PhET simulations are easy to navigate when studying electronic circuits and assembly.	3.44	0.97	Neutral
Using Phet simulation enable me to have more accurate information.	3.84	0.77	Agree
AWM	3.49	0.90	Neutral
Personal Innovativeness	**Weighted Mean**	**Standard Deviation**	**Verbal Description**
If I hear about a new technology or simulation tool, I would look for ways to experiment with it in electronics.	3.38	0.67	Neutral
Among my classmates, I am usually the first to explore new simulation tools for learning electronics.	3.06	0.89	Neutral
I like to experiment with new information technologies and simulation tools for electronics learning.	4.28	0.81	Agree

In general, I do not hesitate to try out new simulation tools for learning electronic product assembly.	3.82	0.69	Agree
AWM	3.64	0.76	Agree
Attitude Towards Using	**Weighted Mean**	**Standard Deviation**	**Verbal Description**
I think positively about using PhET simulations for learning electronic product assembly and servicing.	4.06	0.74	Agree
PhET simulations are a positive tool for learning electronic product assembly and servicing.	3.96	0.67	Agree
Using PhET simulations for learning electronic product assembly and servicing is a wise idea.	3.96	0.70	Agree
PhET simulations are worth using in the learning process of electronic product assembly and servicing.	3.88	0.72	Agree
I plan on using Phet simulation for innovation processes on a regular basis in the future	4.44	0.79	Agree
Using Phet simulation within the innovation process is pleasant	4.06	1.04	Agree
AWM	4.06	0.78	Agree
Actual Use	**Weighted Mean**	**Standard Deviation**	**Verbal Description**
I use Phet simulation for innovation frequently	1.78	0.93	Disagree
I use Phet simulation for innovation regularly, at least once a week.	2.5	1.54	Neutral
AWM	2.14	1.24	Disagree

Legend: 4.50-5.00 -Strongly Agree 3.50-4.49 -Agree 2.50-3.49 -Neutral 1.50-2.49 -Disagree 1.00-1.49 -Strongly Disagree

3.3 Correlational Analysis of TAM Constructs and Posttest Performance

The Pearson correlation analysis (Table 4) examined the relationship between TAM constructs and student performance. The results revealed that **Actual Use** (r = 0.542, p = 0.038) was the only construct with a significant positive relationship with posttest performance. Other constructs, including Perceived Usefulness, Perceived Ease of Use, Personal Innovativeness, and Attitude Toward Using, demonstrated non-significant relationships with the students' learning outcomes

Table 4. The Relationship Between TAM Constructs and Student Posttest Performance in the Experimental Group.

Posttest and:	r-value	p-value	Decision	Intepretation
Perceive Usefulness	0.137	0.398	Failed to reject H_{02}	Not Significant
Perceive Ease of Use	0.029	0.853	Failed to reject H_{02}	Not Significant
Personal Innovativeness	0.145	0.314	Failed to reject H_{02}	Not Significant
Attitude Toward Using	0.227	0.073	Failed to reject H_{02}	Not Significant
Actual Use	0.542	0.038	Reject H_{02}	Significant

3.4 Perceived Social Utility Value of Learning Through PhET Simulations

To complement the quantitative findings, qualitative interviews were conducted with fifteen (15) students from the experimental group to gain deeper insights into how they perceived the social utility value of learning through PhET simulations. Through reflexive thematic analysis, five interrelated themes emerged that illustrate how students viewed the relevance of simulation-based learning beyond academic performance, particularly in relation to their future careers, practical application of technical skills, and broader societal contribution.

3.4.1. Theme 1. Preparing for Future Work

The majority of the participants (13 out of 15) perceived that learning through PhET simulations extended beyond improving classroom performance. They described the simulations as practical learning tools that allowed them to practice electrical concepts similar to tasks they expect to perform in future workplaces. Participants believed that repeated exposure to virtual circuit construction and troubleshooting strengthened their confidence in handling actual electrical work, making them feel more prepared for employment after graduation. Rather than viewing the simulations as merely classroom activities, students regarded them as meaningful experiences that developed competencies applicable to industry settings.

"I feel more prepared for actual work because the simulations let me practice solving electrical problems before working with real equipment. It gave me an idea of what I might encounter in the field." (Participant 07)

The participants viewed PhET simulations as an important step toward becoming competent future electrical technicians.

3.4.2. Theme 2. Helping Others Through Technical Skills

A substantial number of participants (12 out of 15) perceived that the knowledge and skills gained through PhET simulations could be applied beyond their personal academic and career goals. They believed that the concepts learned from simulation-based activities would enable them to assist family members, friends, and community members in addressing simple electrical concerns. Participants emphasized that understanding electrical systems is not only beneficial for future employment but also equips them with practical skills that can improve everyday life and promote electrical safety within their communities. This perception strengthened their appreciation of vocational education as a means of contributing positively to others rather than solely achieving personal success.

"Learning through PhET made me realize that these skills are not just for getting a job. Even at home, I can help fix simple electrical problems or explain how to avoid unsafe wiring.." (Participant 11)

The participants viewed technical competence as an opportunity to become helpful members of their communities.

3.4.3. Theme 3. Seeing Purpose in Vocational Learning

Most participants (**11 out of 15**) shared that learning through PhET simulations changed how they viewed their vocational education. Rather than considering EPAS as another technical subject to complete, they began to recognize its relevance in preparing them for real-life responsibilities and meaningful contributions to society. The simulations helped students appreciate that the knowledge and skills acquired in class have practical value beyond examinations, reinforcing the importance of vocational education as a pathway toward becoming competent and responsible individuals.

"Before, I just wanted to pass the subject. After using PhET, I realized that what we're learning can really be useful in real situations. It made me take the course more seriously because I know it has a purpose." (Participant 04)

For many students, vocational learning became more meaningful when they recognized its value beyond the classroom.

3.4.4. Theme 4. Developing Professional Responsibility

The majority of the participants (10 out of 15) expressed that learning through PhET simulations helped them recognize the importance of performing electrical tasks responsibly. They emphasized that simulations encouraged them to understand proper procedures, identify potential mistakes, and appreciate the consequences of unsafe electrical practices before working with actual equipment. This experience fostered a stronger sense of accountability, as participants viewed technical competence as a responsibility that protects not only themselves but also the people who may rely on their work in the future.

"The simulations taught me that even small mistakes in electrical work can have serious consequences. It reminded me that if I become a technician, I have to be careful because other people's safety will depend on the quality of my work." (Participant 09)

Students associated technical competence with responsibility, not merely technical skill.

3.4.5. Theme 5. Promoting Equitable Technical Education

Most participants (13 out of 15) perceived that PhET simulations created more equitable opportunities for learning, particularly in situations where access to laboratory equipment and electrical components was limited. They appreciated that every student could actively participate, repeatedly practice electrical procedures, and explore circuit concepts without being constrained by the availability of physical resources. Participants believed that simulation-based learning helped minimize disparities in practical learning experiences, making technical education more inclusive and beneficial for all learners regardless of resource limitations.

"Not everyone gets enough time to use the actual equipment during laboratory activities. With PhET, everyone had the chance to practice and learn at their own pace, so no one was left behind." (Participant 02)

Students recognized simulation-based learning as a means of making technical education more accessible and equitable.

4. Discussion

The findings of this study provide empirical evidence regarding the transformative potential of PhET simulations in technical-vocational electrical education. The significant improvement in posttest scores among the experimental group ($p = 0.007$) suggests that simulation-based interventions effectively bridge the gap between theoretical knowledge and practical application.

4.1 Pedagogical Efficacy and Conceptual Mastery

The superior performance of the experimental group aligns with the cognitive load theory, which posits that interactive visualizations reduce the extraneous cognitive burden associated with abstract concepts (Sweller 1988). In the context of EPAS, electricity is inherently "invisible"; simulations like the Circuit Construction Kit provide a mental model that allows students to "see" electron flow and voltage drops. This result is consistent with a vast body of literature demonstrating PhET's efficacy in physics and engineering across diverse geographical contexts (Finkelstein et al. 2005; Wieman et al. 2008; Moore et al. 2014). Recent studies in Southeast Asian TVET settings similarly report that digital twins and virtual labs compensate for the lack of physical high-precision equipment (Sari et al. 2021; Nguyen & Khoo 2022). Furthermore, the gain scores ($G = 5.06$) suggest that the interactive nature of the tool facilitates "active learning," a pedagogical shift widely supported by contemporary educational researchers (Prince 2004; Freeman et al. 2014; Hake 1998).

4.2 The TAM Paradox: Attitude vs. Actual Use

A critical finding in this study is the discrepancy between student **Attitude** (AWM = 4.06) and **Actual Use** (AWM = 2.14). While the high attitude and innovativeness scores indicate a readiness for digital adoption—consistent with findings in modern educational technology assessments (Venkatesh et al. 2003; Teo 2011)—the low actual usage suggests significant barriers to implementation. This "neutral" perception of ease of use and usefulness may stem from a lack of prior exposure to sophisticated simulation software.

Similar "TAM paradoxes" have been documented in resource-constrained environments where students value technology in theory but struggle with "technostress" or limited digital fluency in practice (Abdullah & Ward 2016; Al-Adwan et al. 2013; Granić & Marangunić 2019). The "Neutral" rating for Perceived Usefulness contradicts several studies in well-resourced institutions where students immediately recognize simulations as time-saving tools (Roca et al. 2006; Lee et al. 2005). This suggests that for TVET students in the Philippines, the value of the simulation is highly dependent on teacher-led guidance rather than autonomous exploration.

4.3 Behavioral Engagement as the Primary Predictor

The correlational analysis ($r = 0.542$) highlights that **Actual Use** is the only significant predictor of performance. This finding is profound: it implies that merely liking the software (Attitude) or believing it is easy to use (Ease of Use) does not translate to higher grades in electrical. Learning gains are a product of *behavioral engagement*. This aligns with the "learning-by-doing" principle (Dewey 1938) and more recent "Time-on-Task" theories which argue that academic achievement is directly proportional to the time spent interacting with the learning material (Carini et al. 2006; Kuh 2003).

The non-significant relationship between Perceived Usefulness and performance in this study contradicts the original TAM model (Davis 1989) but supports modified frameworks which suggest that in mandatory or highly structured learning environments, "Perceived Usefulness" is often overshadowed by the necessity of "Actual Use" for task completion (Hu et al. 2003; Legris et al. 2003).

4.4 Implications for Resource-Constrained TVET

The efficacy of PhET in this study offers a viable solution to the "equipment gap" in Philippine TVET. As noted in the Introduction, insufficient laboratory resources often hinder competency mastery. The results support the argument that simulations can serve as "low-cost, high-impact" pedagogical scaffolds (Zhu et al. 2021; Perkins et al. 2006). However, the low independent usage underscores the need for "mobile-first" strategies, as many students in rural regions access the internet primarily via smartphones rather than PCs (Al-Emran et al. 2018; Briz-Ponce et al. 2017).

4.5 Perceived Social Utility Value of Learning Through PhET

The qualitative findings broaden the interpretation of the quantitative results by demonstrating that students perceived the value of PhET simulations beyond improved academic performance and technology acceptance. Across the five emergent themes, participants viewed simulation-based learning as preparation for future employment, an opportunity to assist others through technical competence, a means of recognizing the purpose of vocational education, a foundation for developing professional responsibility, and a strategy for promoting equitable access to technical learning. These perceptions closely align with Situated Expectancy-Value Theory, which posits that learners become more engaged when they recognize the future utility and broader significance of what they learn (Wang, 2022; Harackiewicz & Priniski, 2023). Likewise, Sutter et al. (2024) emphasized that utility value develops when students connect classroom activities to meaningful real-world applications, while Shang et al. (2022) demonstrated that utility value strengthens engagement and skill development. The themes on preparing for future work and helping others through technical skills further support the findings of Li et al. (2025) and Mok et al. (2021), who reported that social utility value enhances professional commitment and long-term career motivation.

Moreover, participants' recognition of vocational learning as purposeful, socially responsible, and accessible resonates with Philippine studies highlighting the practical, professional, and societal value of technical-vocational education (Mokher et al., 2025; Generalao et al., 2025; Abing, 2025; Estilo, 2025). The emergence of equitable technical education as a distinct theme also reinforces the argument that digital learning technologies can reduce barriers to practical instruction in resource-constrained settings while extending learning opportunities to a wider range of students. Collectively, these findings suggest that the educational contribution of PhET simulations extends beyond improving learning outcomes; they also cultivate students' appreciation of the broader social relevance and utility of vocational education.

4.6 Limitations and Strengths

A primary strength of this study is the use of a quasi-experimental design with a clear control group, providing a high level of internal validity. However, the study is limited by its short duration and geographic specificity. The "Neutral" perceptions might shift toward "Positive" in a longitudinal study as students gain higher digital self-efficacy (Compeau & Higgins 1995; Bandura 1997). Additionally, the reliance on self-reported data for TAM constructs may introduce social desirability bias, where students report a positive "Attitude" to please the instructor (Podsakoff et al. 2003).

5. Conclusion

This study evaluated the efficacy and acceptability of PhET interactive simulations in teaching Electronic Product Assembly and Servicing (EPAS) among Industrial Technology students. The findings confirm that simulation-integrated instruction significantly enhances academic performance ($p = 0.007$), validating the tool as a robust pedagogical scaffold for mastering abstract electronic concepts in resource-constrained environments.

The principal contribution of this research lies in its nuanced application of the Technology Acceptance Model (TAM), revealing a critical "implementation gap" in vocational digital adoption. While students demonstrated high levels of personal innovativeness and a strong positive attitude toward the simulations, these psychological predispositions did not directly translate into academic gains. Instead, the study identifies **Actual Use** as the sole significant predictor of performance ($r = 0.542$), suggesting that learning outcomes are driven by sustained behavioral engagement rather than perceived ease or usefulness alone.

Beyond technology acceptance, the qualitative findings further revealed that students perceived learning through PhET simulations as socially meaningful. Participants recognized the simulations as valuable tools for preparing them for future employment, assisting others through technical skills, appreciating the purpose of vocational education, developing professional responsibility, and promoting equitable access to technical learning. These findings suggest that the value of PhET extends beyond improving academic achievement, as it also fosters students' awareness of the broader professional and societal significance of technical-vocational education.

These findings challenge the assumption that providing access to digital tools alone is sufficient for competency mastery. Instead, they underscore the importance of instructional designs that promote sustained engagement while helping students recognize the broader professional and societal value of their learning experiences. By integrating educational effectiveness, technology acceptance, and perceived social utility value within a single investigation, this study provides a more comprehensive understanding of how simulation-based instruction can strengthen technical competence, foster professional responsibility, and support equitable vocational education. Ultimately, the findings offer valuable evidence for educators, curriculum developers, and policymakers seeking to implement accessible, meaningful, and socially responsive digital innovations in technical-vocational education.

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AI Statement

The author acknowledges the use of specific artificial intelligence (AI) technologies to support the preparation of this manuscript, in strict adherence to ethical research and publication guidelines. **Consensus AI** and **Elicit** were utilized to assist in identifying and retrieving relevant scholarly studies to support the theoretical framework in the Introduction and the comparative analysis in the Discussion section.

Furthermore, **Gemini** and **Grammarly** were employed exclusively for language refinement, paraphrasing, and grammatical correction to ensure linguistic clarity and academic flow. The author confirms that no AI tools were used for data generation, statistical analysis, or the scientific interpretation of the results. All data processing and the final conclusions are the original work of the author, who has critically reviewed all AI-assisted outputs and accepts full responsibility for the integrity and content of this work.

The authors declare that the generative artificial intelligence (AI) tool [name of the tool] was used exclusively for language editing and/or grammatical improvement. The use of AI did not influence the scientific content, study design, data analysis, data interpretation, results, or conclusions of the manuscript. Full responsibility for the content remains with the authors.

Ethical considerations

This study was conducted in strict accordance with the institutional ethical guidelines for research involving human subjects and received formal approval from the University Research and Innovation Office at North Eastern Mindanao State University – Cantilan Campus.

Prior to data collection, informed consent was obtained from all participants. Individuals were explicitly briefed on the voluntary nature of their involvement and their right to withdraw from the study at any stage without prejudice or penalty. To safeguard participant confidentiality, all data were anonymized at the point of collection. Digital records were stored in an encrypted environment with access restricted exclusively to the primary research team, ensuring compliance with data privacy standards.

Conflict of Interest

The author declares no conflict of interest.

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