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LTspice vs. Multisim: Effects on Conceptual Understanding and Simulation Skills

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ABSTRACT

In electronics education, circuit simulation software is widely recognised as an instructional tool that supports conceptual understanding while reinforcing practical laboratory skills. This study examined the effects of circuit simulation software on both cognitive and psychomotor learning outcomes among diploma-level electronic engineering students. A total of 116 fourth-semester students participated, with Group A from UiTM Penang using Multisim and Group B from UiTM Johor using LTspice. Cognitive achievement was assessed using post-test scores to measure conceptual understanding of electronic circuits. Psychomotor performance was evaluated using simulation task scores based on a structured rubric across four components: software handling, circuit construction, output response, and output validation. Descriptive and inferential analyses indicated that students using LTspice achieved significantly higher post-test scores than Multisim users ($p < .001$, Cohen's $d = 0.65$), and outperformed them in software handling, circuit construction, and output validation, with moderate to very large effect sizes. No significant differences were observed in output response, and overall simulation task performance was comparable between the two groups. These findings suggest that the choice of simulation software significantly influences conceptual understanding, whereas overall psychomotor performance remains largely comparable across platforms. The results highlight the importance of selecting appropriate circuit simulation software in laboratory-based instruction, providing insights for curriculum design and teaching strategies aimed at enhancing both theoretical knowledge and targeted practical skills.

Keywords: Electronic Engineering Education, Circuit Simulation Software, Simulation-Based Laboratory, Conceptual Understanding, Psychomotor Performance

INTRODUCTION

Simulation-based laboratories play a vital role in electrical engineering education by allowing students to develop both conceptual understanding and practical skills in circuit design and analysis. They provide a flexible and cost-effective environment for students to design, test, and analyse circuits without the constraints of physical laboratory facilities. In higher education, circuit simulation software such as Multisim and LTspice is widely used to facilitate laboratory activities; however, different platforms may influence student learning outcomes. Despite widespread adoption of simulation software, there is limited empirical evidence available comparing the effects of different platforms on both cognitive achievement and psychomotor performance. It remains unclear whether the selection of software significantly impacts students' conceptual understanding and their ability to execute simulation tasks accurately.

SIMULATION-BASED LEARNING IN ELECTRONIC ENGINEERING

Circuit simulation tools have become a core component of modern electronics engineering education, particularly in courses that require circuit analysis and practical experimentation. The increasing reliance on digital learning environments has positioned circuit simulation software as an essential pedagogical tool that bridges theoretical knowledge with practical application (Li et al. 2020; Tokatlidis et al. 2024a; Shekh-Abed 2025; Sihab et al. 2025). Previous studies have consistently shown that simulation tools enhance students' understanding of circuit behaviour, enable safe experimentation, provide an efficient and accurate method of analysis, and facilitate engagement with complex concepts that are often challenging to understand using physical apparatus (Li et al. 2020; Tokatlidis et al. 2024a; Gonzales & Gonzales 2024). Simulations facilitate inquiry-based learning and enhance conceptual understanding by allowing students to manipulate parameters and observe outcomes instantly (Sihab et al. 2025). Furthermore, simulation platforms reduce reliance on physical lab equipment, minimise the risk of hardware damage, and allow repeated practice in a risk-free and flexible environment. These features create a more immersive learning experience, thereby supporting stronger conceptual understanding among engineering students (Tokatlidis et al. 2024b; Li & Liang 2024).

In addition to enhancing conceptual understanding, simulation-based environments support the development of troubleshooting, circuit modelling, and synthesis skills. Several studies demonstrate that students using simulation tools develop stronger analytical thinking and diagnostic skills compared with those using traditional laboratory methods (Li et al. 2020; Li & Liang, 2024). This advantage is attributed to the systematic feedback provided by simulation engines, allowing students to explore different scenarios, test circuit variations, and identify errors with minimal risk (Li et al. 2020). Consequently, circuit simulation is recognised as an effective instructional intervention for developing both foundational knowledge and higher-order thinking skills in electrical engineering education (Sihab et al. 2025).

PEDAGOGICAL USE OF MULTISIM

Multisim, a commercial circuit simulation software developed by National Instruments, is widely used in both industrial and educational settings for designing, simulating, and analysing analogue and digital circuits. In higher education engineering programmes, it is valued for its intuitive graphical interface, comprehensive component library, and integrated virtual instruments, which facilitate circuit construction, testing, and troubleshooting. These features enable students to design, simulate, and refine electronic circuits in real time, making Multisim an effective platform for both instructional and practical applications. Furthermore, these capabilities reinforce students' understanding of circuit behaviour and troubleshooting while providing a clear interface, simple operation, and real-time visualisations that particularly benefit novice learners with limited prior exposure to circuit analysis (Cret & Darabant 2025; Li et al. 2020). Research indicates that Multisim's interface reduces cognitive load by simplifying circuit construction, providing a laboratory-like experience, and enabling an intuitive and efficient experimental setup (Hossain et al. 2017). Collectively, these features support the principle that learning is enhanced in environments that minimise extraneous cognitive load (Omar et al. 2023) while also improving students' motivation and achievement (Rosli & Ishak, 2024).

Empirical studies indicate that Multisim enhances students' understanding of operational amplifier characteristics, transient responses, and frequency-domain analysis. Students also tend to report positive perceptions of usability, describing the software as beginner-friendly and supportive of self-paced learning. Sihab et al. (2025) reported that Multisim enhances higher-order thinking, conceptual understanding, and practical skills through its interactive circuit simulations and visual learning tools. The platform promotes engagement, supports experiential learning, and improves students' self-efficacy by enabling safe, low-risk experimentation and immediate feedback. Consequently, Multisim is particularly well suited for introductory or intermediate circuit analysis courses, where students are still gaining familiarity with electronic components, measurement instruments, and laboratory procedures (Hossain et al. 2017).

Despite its powerful capabilities, Multisim has several limitations, including restricted accessibility, installation requirements, and licensing costs. These constraints pose challenges to academic institutions with limited financial resources. Additionally, the advanced features contribute to a steep learning curve that may require additional instructional support for beginners who are unfamiliar with the platform (Cret & Darabant 2025). However, it remains highly valued for its pedagogical strengths and its ability to support students' conceptual understanding and practical skill development in electronic circuit analysis (Li et al. 2020; Halim et al. 2024).

PEDAGOGICAL USE OF LTSPICE

LTspice, a SPICE-based simulator developed by Analog Devices, is known for its analytical accuracy and ability to efficiently handle complex circuit models. In contrast to Multisim, LTspice requires students to manage circuit parameters and work with SPICE-based commands, which can pose an initial learning challenge for those unfamiliar with text-driven simulation environments. Structured activities and guided reflection, however, can help learners overcome these difficulties and effectively use the software for circuit analysis and design (Shekh-Abed 2025). The literature recognises LTspice for enhancing motivation, fostering skills development, and encouraging deeper engagement with circuit principles (Tokatlidis et al. 2024b). The precision required in modelling requires students to understand circuit parameters, node assignments, and simulation structures at a fundamental level (Shekh-Abed 2025).

LTspice is often regarded as an effective tool for advanced learners and complex circuit simulations, particularly in power electronics, mixed-signal systems, and measurement courses. This is because its SPICE-based, text-driven approach enables in-depth engagement with the mathematical behaviour of circuits rather than relying solely on graphical interpretation. A recent study found that LTspice-based adaptive learning significantly improved students' problem-solving performance compared with traditional methods (Hamris & Amri 2025). Moreover, LTspice's free-of-charge availability and unrestricted access make it an ideal option for academic institutions.

Despite its strengths, students accustomed to highly visual learning interfaces may find LTspice less user-friendly due to its limited drag-and-drop capabilities and less intuitive graphical plotting tools. Research shows that students with limited digital skills or insufficient prior experience often find text-based simulators such as LTspice more difficult to navigate because basic tasks such as adjusting source values or selecting waveform types require higher procedural knowledge (Hossain et al. 2017). This added complexity can affect motivation and reduce achievement, particularly among novice learners. Nevertheless, LTspice is valued for its accuracy, speed, and ability to model industry-relevant circuit behaviours.

COMPARATIVE STUDY ON CIRCUIT SIMULATION TOOLS

Comparative studies have examined differences among circuit simulators, typically contrasting graphical tools such as Multisim or Proteus with SPICE-based environments such as LTspice or PSpice. Prior research shows that the design of simulator interfaces can substantially influence learning outcomes (Li et al. 2020; Li & Liang 2024). Graphical interfaces tend to reduce cognitive load and enhance student engagement for novice learners, whereas command-driven simulators promote analytical thinking and deeper conceptual understanding (Sihab et al. 2025; Omar et al. 2023; Hossain et al. 2017). For instance, students using GUI-based tools often exhibit faster circuit construction and higher task completion rates (Li & Liang, 2024; Hossain et al. 2017), whereas those using SPICE-based simulators demonstrate stronger problem-solving skills and more precise circuit modelling (Tokatlidis et al. 2024a; Hamris & Amri 2025).

However, prior findings remain substantially inconsistent. Hossain et al. (2017) reported that GUI-based simulators enhance cognitive performance and engagement among novice learners, whereas Tokatlidis et al. (2024a) found that physical laboratories yield higher learning gains than virtual simulations. Additionally, many earlier studies have emphasised students' perceptions, engagement, and learning experiences (Hamris & Amri 2025; Shekh-Abed 2025; Gonzales & Gonzales 2024; Tokatlidis et al. 2024b) or have assessed performance solely through laboratory activities without linking it to cognitive achievement (Tokatlidis et al. 2024a; Li et al. 2020).

Several studies have compared different learning environments, such as physical laboratories and TINA (Tokatlidis et al. 2024a), cognitive and perceptual outcomes using LTspice (Hamris & Amri, 2025), comparisons involving LTspice, Multisim, and hardware implementation (Hossain et al. 2017), and comparative analyses of circuit simulation software (Cret & Darabant 2025). Although these studies contribute to the theoretical foundation and highlight the importance of virtual laboratories in electrical engineering education, existing literature does not yet provide a comprehensive understanding of how widely used circuit simulation tools differ in their support for student learning outcomes.

More critically, there is a lack of recent studies that directly compare Multisim and LTspice using quasi-experimental or post-test designs to evaluate both cognitive and psychomotor domains, supported by structured performance rubrics. This gap underscores the need for research that examines multiple learning outcome variables, including cognitive achievement, simulation task performance, and specific components of simulation skill proficiency. Evaluating different simulation platforms is essential for understanding their impact on student learning. Awareness of these differences helps educators select appropriate circuit simulation tools that support learning and align with the intended course outcomes.

THEORETICAL FOUNDATIONS OF SIMULATION-BASED LEARNING

Learning through simulation in electrical engineering can be explained through a combination of foundational theories. Cognitive Load Theory (Sweller 1988; Paas et al. 2003) emphasises that learning is more effective when tasks and interfaces are designed to reduce unnecessary extraneous load while optimising meaningful processing in working memory. In the context of circuit simulation, graphical interfaces such as Multisim tend to reduce extraneous cognitive load, whereas text-based platforms such as LTspice require a higher level of analytical processing.

Prior studies in electrical engineering education indicate that the design of laboratory tasks and the type of simulation software influence students' ability to develop conceptual knowledge and psychomotor skills (Tokatlidis et al. 2024; Hamris & Amri 2025; Li & Liang 2024; Halim et al. 2024). However, empirical studies linking cognitive load theory to performance differences between platforms such as Multisim and LTspice remain limited.

Therefore, this theoretical framework not only guides the analysis of student performance but also explains why certain simulation software may be more effective in supporting cognitive achievement and psychomotor skills development in electronics education.

IDENTIFIED RESEARCH GAP

Although circuit simulation software is important in current electronics education, empirical comparisons between Multisim and LTspice, particularly in Malaysian diploma-level electrical and electronics engineering programmes, remain underexplored. While previous studies have demonstrated the educational value of both LTspice and Multisim in supporting circuit analysis, laboratory activities, and practical learning (Ptak 2018), direct investigations comparing their relative effectiveness remain limited. Existing studies examining how simulation tools influence both cognitive and psychomotor outcomes are inconsistent, and the theoretical foundation is fragmented (Li & Liang 2024; Tokatlidis et al. 2024a). Furthermore, most prior research focuses solely on either conceptual understanding achievement or practical performance in isolation (Gonzales & Gonzales 2024; Tokatlidis et al. 2024b); however, the integration of multiple outcome variables within a comprehensive analytical framework remains limited.

Studies employing post-test designs to assess the causal effects of circuit simulation software on student performance have not yet been thoroughly investigated, resulting in limited evidence to support pedagogical decision-making, particularly in the selection and integration of circuit simulation software. Addressing these gaps is important for strengthening curriculum design, improving instructional planning and strategies, and informing evidence-based decisions regarding the use of circuit simulation software in simulation-based laboratories for electronics engineering education.

Hence, this study aims to investigate the effects of two commonly used circuit simulation software, Multisim and LTspice, on (1) students' conceptual understanding of electronic circuit principles, (2) simulation task performance, and (3) component-level simulation skills, including software handling, circuit construction, output response, and output validation.

METHODOLOGY

To achieve the research objectives, this study's methodological framework is organised into three main components: (1) research design (participants and software platforms), (2) research procedure (variables, instruments, and data collection), and (3) data analysis, as illustrated in Figure 1.

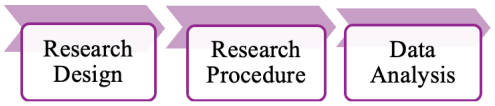


FIGURE 1. Overview of the Research Methodological Framework

RESEARCH DESIGN

For research design, this study employed a quasi-experimental design using a two-group post-test comparative format. Both groups underwent the same instructional procedures, including a written test assessment to evaluate theoretical understanding and an individual simulation-based laboratory task to assess practical skills, as illustrated in Figure 2. The groups were differentiated based on the simulation software used, with one group utilising Multisim and the other LTspice. This design enabled a comparison of the effects of both simulation software platforms on students' cognitive achievement, conceptual understanding, and simulation task performance, while maintaining practical feasibility in a classroom setting.

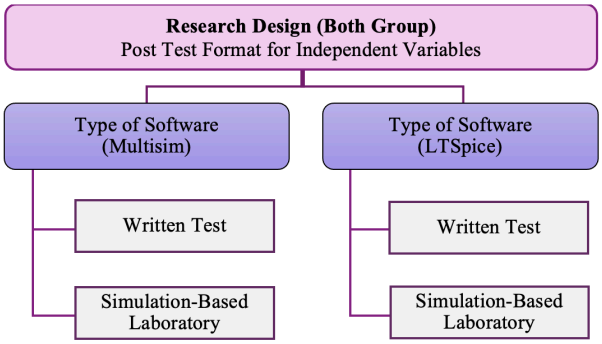


FIGURE 2. Overview of Research Design in Post-Test Format

A total of 116 fourth-semester Diploma in Electrical (Electronics) Engineering students participated in this study. The participants were divided into two groups: Group A, comprising 58 students from the UiTM Penang Campus, and Group B, comprising 58 students from the UiTM Johor Campus. Group A used Multisim software, while Group B used LTspice software. Table 1 presents the distribution of the study participants by campus and software platform.

TABLE 1. Distribution of Participants by Campus and Software Platforms

Group	Campus	Number of Participants	Software Platform
A	UiTM Penang	58	Multisim
B	UiTM Johor	58	LTspice

Both groups were enrolled in the same course and followed an identical syllabus, course learning outcomes, assessment structure, and examination requirements prescribed by the university. To ensure consistency across campuses, identical laboratory activities, instructional materials, and assessment instruments were implemented for both groups. The topics covered, instructional duration, laboratory modules, and assessment procedures were also standardised. Furthermore, both campuses adhered to a common course outline and assessment scheme coordinated by the course resource person, ensuring consistency in course delivery and evaluation. Consequently, the primary difference between the two groups was the simulation software used (LTspice or Multisim). These measures helped minimise potential campus-related variations and increase confidence that any observed differences in student performance were attributable to the simulation software rather than variations in curriculum, assessment, or instructional practices.

RESEARCH PROCEDURE

This section outlines the research procedures employed in this study, including research variables, research instruments, study procedures, and data collection procedures, as illustrated in Figure 3. These procedures were systematically implemented to ensure methodological consistency across the study groups and to support the achievement of the research objectives.

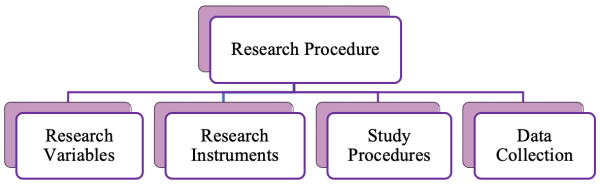


FIGURE 3. Outline of Research Procedures

RESEARCH VARIABLES

1. Independent Variable

   The independent variable in this study was the type of simulation software, namely Multisim and LTspice. This variable was used to examine the effects of circuit simulation software on students' learning outcomes in electronics education.

2. Dependent Variables

   The dependent variables consisted of two distinct measures, namely cognitive and psychomotor outcomes. All students had comparable prior exposure to basic electronic circuit fundamentals. The simulation-based laboratory method employed identical laboratory modules, and learning outcomes were assessed using a structured rubric, ensuring consistency across groups. Specifically, cognitive achievement was measured using post-test scores, which evaluated the students' conceptual understanding and problem-solving abilities in circuit principles. In parallel, psychomotor performance was assessed through simulation task performance using a structured rubric to capture students' hands-on ability in completing the required procedural circuit simulation tasks. No additional variables, such as student perceptions or external control factors, were included. By combining cognitive and psychomotor measures, the study provided a comprehensive assessment of both students' conceptual understanding and circuit simulation skills.

RESEARCH INSTRUMENTS ON DEPENDENT VARIABLES

Based on the identified dependent variables, this study employed two corresponding research instruments: (1) a post-test to assess cognitive achievement, and (2) a structured simulation task rubric to evaluate psychomotor performance.

1. Post-Test: Written Cognitive Test

   The post-test was conducted at the end of the semester after completion of all simulation laboratory modules. It was developed to measure the students' conceptual understanding and problem-solving skills in circuit analysis, in line with the cognitive outcome variables of the study. The test comprised a combination of theoretical questions requiring explanations of underlying concepts and principles and calculation-based questions involving circuit problem-solving, such as determining voltages, currents, gains, impedances, and frequency responses. The content and structure of the written test were reviewed by subject-matter experts to ensure alignment of the test questions with Bloom's taxonomy and the learning objectives for diploma-level electronics engineering students. Each student's post-test score was recorded and used as the primary indicator of cognitive achievement after all simulation laboratory modules were completed.

2. Simulation Task: Psychomotor Performance Rubric

   Psychomotor performance was assessed using a structured simulation task rubric, which evaluated students' practical skills in performing circuit simulations using the assigned software platforms. The rubric measured four attributes within the psychomotor domain: (1) software handling, reflecting proficiency in operating the simulation software; (2) circuit construction, assessing accurate assembly of circuits as instructed; (3) output response, evaluating competence in selecting appropriate analyses, generating accurate simulation outputs and troubleshooting any discrepancies; and (4) output validation, measuring skills in verifying and interpreting simulation results. Each attribute was scored on a four-point scale, giving a total possible score of 10. This allowed for both aggregate scoring to support inferential analysis and component-level descriptive comparisons to identify specific areas of strength or difficulty in simulation skills.

STUDY PROCEDURES

To obtain students' cognitive post-test scores and psychomotor simulation performance, students participated in both lecture and laboratory sessions designed to develop theoretical knowledge and practical skills. As summarised in Table 2, both groups attended 14 weeks of lectures and completed four laboratory modules (Modules 1 to 4) using their assigned simulation software.

The first two modules (Module 1 and 2) constituted the familiarisation phase, during which students were introduced to the simulation software with full guidance from lecturers, covering software operation, circuit construction, and basic analysis. The final two modules (Module 3 and Module 4) constituted the consolidation phase, during which students completed tasks independently with minimal lecturer assistance. All laboratory activities were conducted under lecturer supervision in a face-to-face mode, and student progress was systematically recorded during each session to monitor skill development.

For the purposes of this study, the topics analysed included amplifier frequency response and operational amplifier applications. Simulation task performance was evaluated using scores obtained during the consolidation phase (Module 3 and Module 4), while cognitive performance was assessed using a post-test format at the end of the semester, immediately after the completion of all lectures and laboratory modules.

TABLE 2. Overview of the Research Procedures

Topic	Teaching and Learning Activities	Assessment Types				
		Written Test	Simulation-Based Laboratory			
			Module 1	Module 2	Module 3	Module 4
Multistage Amplifier	8-Week Duration (24 Lecture Hours, 4 Laboratory Hours)	O	O	O		

continue...

Amplifier Frequency Response	4-Week Duration (24 Lecture Hours, 2 Laboratory Hours)	X	X	
Operational Amplifier Applications	2-Week Duration (6 Lecture Hours, 2 Laboratory Hours)	X		X

Note. X = assessments included in this study. O = assessments not included in this study.

DATA COLLECTION

Data were collected from two sources: post-test scores and rubric-based scores for circuit simulation task performance. These data allowed for a comparison of students' cognitive and psychomotor learning outcomes across different simulation software platforms.

Academic records for the respective groups were obtained from lecturers. All data were anonymised, coded, and analysed in aggregate to maintain student confidentiality and comply with institutional ethical guidelines. No individual identifiers were included in the analysis.

DATA ANALYSIS

Statistical analysis comprised descriptive measures, including mean, standard deviation, minimum, and maximum values, which were computed for both groups to summarise overall performance.

In the main analysis, post-test scores and simulation task scores were compared between the Multisim and LTspice groups using independent-samples *t*-tests, with Cohen's *d* calculated to determine effect size. Prior to analysis, assumptions of normality and homogeneity of variance were assessed. In addition, Pearson correlation and box plots were used for exploratory data analysis.

Next, the descriptive and inferential analyses were conducted to gain further insight into students' component-level simulation skills. The simulation task scores were further disaggregated by rubric components to investigate students' performance in software handling, circuit construction, output response, and output validation. Means and standard deviations for each component were calculated and compared descriptively between groups. This allowed for a detailed assessment of performance components based on psychomotor attributes, enabling differences in performance to be identified according to the simulation software used. These approaches provided a comprehensive view of skill development through students' simulation task scores.

Statistical significance was set at $p < 0.05$ for all analyses, and results were interpreted in terms of both statistical and practical significance. For multiple comparisons, a Bonferroni-adjusted significance level ($\alpha = 0.0125$) was applied.

RESULTS AND DISCUSSION

PRELIMINARY ANALYSIS

Prior to analysis, the assumptions of normality and homogeneity of variances were assessed. Shapiro-Wilk tests indicated that post-test scores were approximately normally distributed ($W = 0.983$, $p = .136$), whereas simulation task scores deviated significantly from normality ($W = 0.957$, $p < .001$). However, independent-samples *t*-tests were considered appropriate because they are generally robust to moderate violations of normality when group sizes are approximately equal ($n = 58$ per group). Levene's tests indicated equal variances for simulation task scores ($F = 0.058$, $p = .810$) but unequal variances for post-test scores ($F = 6.264$, $p = .014$). Accordingly, independent-samples *t*-tests were conducted, with Welch's *t*-test applied when the assumption of equal variances was violated.

DESCRIPTIVE STATISTICS

Descriptive statistics for post-test and simulation task scores are summarised in Table 3. The LTspice group achieved higher post-test scores ($M = 79.31$, $SD = 14.66$) with lower variability (CV = 0.185) compared to the Multisim group ($M = 67.72$, $SD = 20.18$; CV = 0.298), indicating lower relative variability in conceptual understanding among LTspice students. In contrast, simulation task scores were comparable across groups (LTspice: $M = 86.45$, $SD = 8.96$; Multisim: $M = 87.37$, $SD = 8.84$), suggesting consistent simulation task execution regardless of the software used.

TABLE 3. Descriptive Statistics for Post-Test and Simulation Task Scores by Software Group

Measure	Group	N	Mean	*SD*	*SE*	CV
Post-Test Score	LTspice	58	79.31	14.66	1.93	0.185
	Multisim	58	67.72	20.18	2.65	0.298
Simulation Task Score	LTspice	58	86.45	8.96	1.18	0.104
	Multisim	58	87.37	8.84	1.16	0.101

Note. SD = Standard Deviation; *SE* = Standard Error; CV = Coefficient of Variation.

These descriptive trends show that while conceptual understanding differed between the software groups, simulation task performance was largely comparable. The difference in mean post-test scores indicates that the LTspice group performed higher than the Multisim group, representing an approximately 17.1% increase in cognitive achievement. This suggests that students using LTspice demonstrated better conceptual understanding in the post-test compared to those using Multisim. This pattern may be explained by differences in software interfaces and their impact on cognitive load. Graphical platforms such as Multisim can reduce extraneous cognitive demands and support more accessible conceptual understanding, whereas the LTspice group requires more in-depth analytical processing. The challenges associated with the LTspice group appear to enhance students' cognitive engagement and achievement. At the same time, simulation tasks primarily assess procedural fluency, allowing students to complete steps accurately regardless of the platform used, which may explain the comparable psychomotor performance across groups (Tokatlidis et al. 2024b). Furthermore, the use of structured laboratory procedures (Mulla & Deshmukh, 2023) and performance rubrics provides sufficient scaffolding to support task completion, ensuring that both software groups achieve similar outcomes in practical circuit simulation exercises (Li & Liang, 2024). Collectively, these findings indicate that software selection may have a greater influence on conceptual understanding gains than on procedural performance.

COGNITIVE AND SIMULATION PERFORMANCE ACROSS SOFTWARE

Table 4 shows the results of independent-samples *t*-tests examining whether students' performance differed significantly between the LTspice and Multisim groups.

As indicated by Levene's test, post-test scores violated the assumption of equal variances across groups; therefore, a Welch's *t*-test was conducted. This analysis revealed that students in the LTspice group scored significantly higher than those in the Multisim group, $t(104) = 3.82$, $p < .001$, and Cohen's $d = 0.65$, indicating a medium-to-large effect size.

By contrast, as the simulation task scores satisfied the assumption of equal variances, a standard independent-samples *t*-test was conducted. No significant difference was observed between LTspice and Multisim groups: $t(114) = -0.53$, $p = .598$, and Cohen's $d = 0.10$, indicating no meaningful difference in performance across the two software platforms.

These findings indicate that the software selection has a significant effect on students' conceptual understanding (post-test scores). Students using LTspice achieved higher post-test scores than those using Multisim, suggesting that LTspice may better support the development of cognitive learning outcomes, including conceptual and analytical skills. The findings are consistent with meta-analysis conducted by Li and Liang (2024), which reported that virtual-laboratory implementation in engineering programmes significantly enhances students' cognitive outcomes, psychomotor skills, and motivation. This is further supported by Sihab et al. (2025), who found that Multisim-based simulation learning also showed similar improvements in higher-order thinking, engagement, practical ability, and learning satisfaction. Moreover, virtual laboratories enable students to visualise abstract concepts and conduct experiments at their own pace, contributing to a more positive learning experience (Rosli & Ishak, 2024).

In contrast, the results show no significant difference between LTspice and Multisim in simulation task performance, indicating that both simulation tools similarly support the fundamentals of circuit construction and analysis. Overall, practical performance appears to be largely unaffected by the choice of software or platform (Li & Liang, 2024). Both formats also provide a strong cognitive foundation, engaging students in critical thinking, analysis, and synthesis of knowledge.

TABLE 4. Descriptive Statistics for Post-Test and Simulation Task Scores by Software Group

Measure	Test Type	Group Means (*SD*)	*t*	*df*	*p*	Cohen's *d*
Post-Test Score	Welch's *t*-test	LTspice: 79.31 (14.66)	3.82	104	< .001	0.65
		Multisim: 67.72 (20.18)				
Simulation Task Score	Independent *t*-test	LTspice: 86.45 (8.96)	-0.53	114	.598	0.10
		Multisim: 87.37 (8.84)				

Note. SD = Standard deviation. Cohen's *d* interpreted as Small = 0.2, Medium = 0.5, Large = 0.8. Significance based on $\alpha = .05$.

These results suggest that software selection influences cognitive skills more strongly than psychomotor performance. LTspice may encourage deeper analytical engagement by requiring students to interpret parameters and circuit behaviour, thereby fostering higher-order analytical and conceptual thinking. This finding aligns with prior studies demonstrating the positive impact of laboratory activities on cognitive development (Halim et al. 2024; Tokatlidis et al. 2024a; Tokatlidis et al. 2024b).

The findings have important implications for simulation-based laboratory instruction. The selection of simulation platforms should be made strategically, not merely on the basis of ease of use, but on their capacity to support conceptual understanding, circuit analysis, and circuit behaviour interpretation. Although the choice of simulation software may not significantly influence students' psychomotor performance in completing structured simulation exercises, it can have a greater impact on cognitive learning outcomes. Collectively, these findings suggest that software selection has a greater influence on conceptual gains than on psychomotor performance.

RELATIONSHIPS BETWEEN POST-TEST SCORES AND SIMULATION TASK SCORES

Pearson correlation analysis examined the relationship between students' conceptual understanding, as measured by the post-test scores, and simulation task performance, as measured by the simulation task scores. The analysis in Table 5 revealed a weak positive correlation between post-test and simulation task scores, $r = .144$, $p = .124$, 95% CI [-0.040, 0.318].

The positive weak correlation, which was not statistically significant, suggests that students' performance in simulation task execution did not strongly correspond with their conceptual understanding. This indicates that students' proficiency in simulation task execution does not necessarily reflect stronger conceptual understanding or overall cognitive development. The findings highlight a potential distinction between psychomotor skills in using simulation software and conceptual understanding of electronics principles. This pattern suggests that simulation-based task execution tends to develop psychomotor skills rather than conceptual understanding (Mulla & Deshmukh, 2023). Students may therefore focus primarily on completing laboratory procedures rather than interpreting the underlying electronic principles of circuits. Overall, this misalignment between cognitive and psychomotor outcomes suggests that accurate completion of laboratory tasks does not necessarily reflect a deeper conceptual understanding.

These findings highlight the importance of pedagogical scaffolding that explicitly integrates reflective activities and structured guidance, helping students connect simulation procedures with conceptual understanding while ensuring alignment of cognitive learning outcomes with practical skill development.

TABLE 5. Pearson Correlation Between Post-Test Scores and Simulation Task Scores

Variable 1	Variable 2	*r*	*p*	95% CI Lower	95% CI Upper
Post Test Scores	Simulation Task Scores	0.144	.124	-0.040	0.318

Note. r = Pearson correlation coefficient. CI = confidence interval.

BOX PLOTS

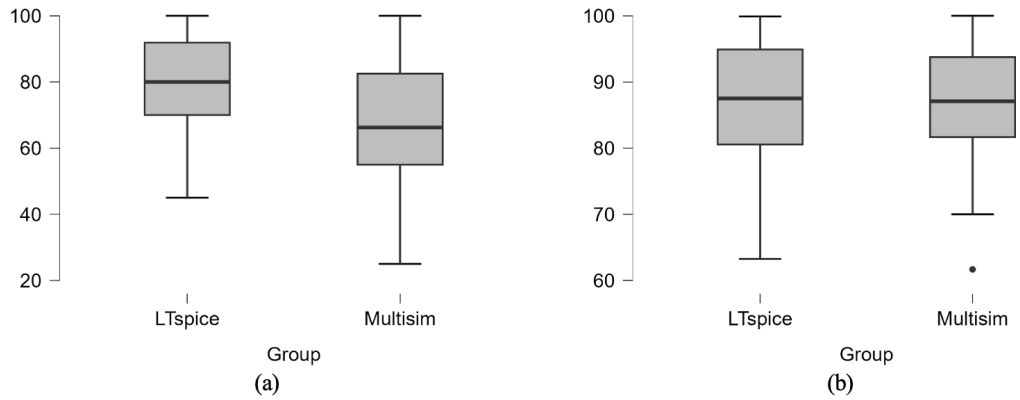
Figure 4 shows box plots of post-test scores and simulation task scores for LTspice and Multisim groups. Students using LTspice demonstrated higher and more consistent cognitive post-test performance, whereas the Multisim group showed greater variability in cognitive outcomes. In contrast, simulation task scores were comparable across both groups, indicating that practical performance was largely unaffected by the choice of software platform. These patterns align with the descriptive and inferential analyses, suggesting that software selection exerted a stronger influence on conceptual learning than on procedural execution.

The higher cognitive post-test scores among LTspice students suggest that its text-based interface may have encouraged more analytical engagement with circuit behaviour. Although Multisim's graphical environment is designed to reduce extraneous cognitive load, this advantage did not translate into stronger conceptual gains. At first glance, this appears inconsistent with a straightforward interpretation of Cognitive Load Theory, which posits that reducing unnecessary cognitive demands should enhance learning processes. In this context, however, the additional effort required to construct and refine LTspice circuit simulations may have prompted students to engage more deliberately with circuit parameters, node definitions, and circuit analysis, thereby supporting deeper conceptual understanding (Gonzales & Gonzales, 2024).

This interpretation is further supported by differences in the design affordances of the two platforms. Consistent with the study conducted by Vasetska (2024), LTspice is widely recognised for its high-fidelity modelling, computational efficiency, and emphasis on analytical precision, which require users to engage explicitly with underlying circuit principles. In contrast, Multisim is commonly favoured in educational settings for its user-friendly interface, extensive component library, and effective graphical visualisation, which facilitate ease of use and support task completion. While these features are beneficial for enhancing procedural competence, they may have inadvertently reduced students' engagement in sustained analytical reasoning during circuit simulation tasks. These findings suggest that, although ease of use in simulation software facilitates task completion, it may limit opportunities for developing higher-order thinking skills and deeper conceptual understanding.

Notably, the absence of significant differences in simulation task performance reflects the structured and guided nature of the laboratory exercises. Clear task instructions and a well-defined performance rubric facilitated effective step-by-step task completion, regardless of the circuit simulation platform used. This distinction between procedural accuracy and conceptual understanding suggests that students may have followed prescribed procedures without fully engaging with the underlying circuit principles.

These findings are consistent with Rosli and Ishak (2024), who reported that virtual laboratories support conceptual understanding by enabling students to connect abstract concepts with prior knowledge, emphasising critical information, and facilitating repeated experimentation. Taken together, the present results suggest that although both LTspice and Multisim effectively support students' procedural performance, differences in software design may have contributed more substantially to conceptual understanding learning outcomes than to practical task performance. In summary, the findings suggest that software selection has greater implications for cognitive gains than for simulation task performance, whereas the development of fundamental procedural competencies appears to be relatively independent of the simulation platform.



Note. The box represents the interquartile range (IQR), horizontal line represents the median, the whiskers extend to 1.5 × IQR, and circles indicate outliers. LTspice: $n = 58$; Multisim: $n = 58$.

FIGURE 4. Box plots of (a) post-test scores and (b) simulation task scores for the LTspice and Multisim groups.

COMPONENT-LEVEL CIRCUIT SIMULATION SKILLS

1. Descriptive Statistics

To further investigate students' performance in circuit simulation skills, the study analysed results at the component level, focusing on specific skill attributes within simulation tasks. This analysis provides a more detailed understanding of strengths and weaknesses in software handling, circuit construction, output response, and output validation.

Descriptive statistics for simulation skill components are presented in Table 6. Overall, both groups demonstrated competent simulation skills. The LTspice group showed slightly higher performance across all components, with the largest differences observed in software handling ($M = 3.98$, $SD = 0.09$) and output validation ($M = 3.18$, $SD = 0.65$) compared to the other group. Smaller differences were observed in circuit construction ($M = 3.56$, $SD = 0.48$) and output response ($M = 3.04$, $SD = 0.52$).

TABLE 6. Descriptive Statistics for Simulation Skill Components

Skill Component/ Psychomotor Attribute	Group	N	Mean	*SD*
Software Handling	LTspice	58	3.98	0.09
	Multisim	58	3.30	0.47
Circuit Construction	LTspice	58	3.56	0.48
	Multisim	58	3.33	0.50
Output Response	LTspice	58	3.04	0.52
	Multisim	58	2.88	0.45
Output Validation	LTspice	58	3.18	0.65
	Multisim	58	2.72	0.77

Note. Scores for each component were recorded on a 1 to 4 performance scale, with higher values indicating better performance.

2. Inferential Analysis

Independent sample *t*-tests were conducted for each simulation task component, and a Bonferroni correction was applied ($\alpha = 0.05 / 4 = 0.0125$) to control for Type I error.

The results presented in Table 7 indicate that LTspice participants outperformed Multisim participants in several key components of the simulation task. In terms of software handling, LTspice users scored significantly higher, $t(114) = 10.88$, $p < .001$, with a very large effect size (Cohen's $d = 2.02$). Similarly, for circuit construction, the LTspice group achieved significantly better results, $t(114) = 2.92$, $p = .004$, Cohen's $d = 0.54$, indicating a moderate effect. In contrast, no significant difference was observed in the output response, $t(114) = 1.77$, $p = .079$, Cohen's $d = 0.33$, suggesting comparable performance between both groups. However, for output validation, LTspice participants again outperformed Multisim users, $t(114) = 3.41$, $p < .001$, with a moderate effect size (Cohen's $d = 0.63$).

TABLE 7. Independent Samples *t*-Tests for Simulation Skill Components

Component	*t*	*df*	*p*	Cohen's *d*
Software Handling	10.88	114	< .001	2.02
Circuit Construction	2.92	114	.004	0.54
Output Response	1.77	114	.079	0.33
Output Validation	3.41	114	< .001	0.63

Note. Bonferroni correction was applied, with adjusted significance threshold set at $p = .0125$. Significant results are interpreted in relation to this threshold.

The results indicate that LTspice students outperformed Multisim students in software handling, circuit construction, and output validation, with effect sizes ranging from moderate to very large. Performance in output response, however, was comparable between the two groups. These findings suggest that LTspice's text-based interface may better support procedural and analytical engagement, thereby contributing to higher cognitive post-test scores.

This pattern aligns with Tokatlidis et al. (2024), who found that virtual laboratory environments enhance conceptual knowledge and inquiry skills more effectively than psychomotor abilities. The comparable performance in output generation suggests that both LTspice and Multisim adequately support practical skill development, consistent with previous studies indicating that psychomotor competencies can be developed across different laboratory formats, whereas cognitive gains are more strongly influenced by the design and features of simulation tools (Li & Liang, 2024). Noga and Palczynska (2018) similarly reported that Multisim provides a comprehensive and creative approach to learning, enhancing knowledge transfer and strengthening students' conceptual understanding and practical skills. In line with Vasetska (2024), the selection of simulation software should consider users' needs, circuit complexity, and prior experience, as different platforms offer distinct instructional advantages. LTspice offers a powerful and freely available platform that supports analytical engagement, whereas Multisim is particularly suited for structured learning environments.

Overall, these results highlight the distinction between procedural execution and conceptual understanding. Both simulation tools support practical learning, but LTspice appears to provide additional cognitive benefits, possibly because its text-based interface encourages greater analytical reasoning. This underscores the importance of selecting simulation software not only for task completion but also for its potential to foster higher-order cognitive skills, including analytical reasoning, conceptual understanding, and error prediction in circuit design and analysis.

SYNTHESIS OF FINDINGS

The analysis of cognitive and psychomotor outcomes revealed a clear distinction between conceptual understanding and procedural simulation skills, highlighting differences in learning domain performance. LTspice participants consistently outperformed Multisim participants in software handling, circuit construction, and output validation, with effect sizes ranging from moderate to very large, indicating enhanced proficiency in these simulation skills. In contrast, both groups demonstrated comparable performance in generating and interpreting outputs, suggesting that basic task completion is achievable across software platforms. When considered alongside the post-test results, LTspice students also exhibited higher levels of conceptual understanding of circuit principles, suggesting that LTspice's text-based simulation interface may promote deeper analytical thinking by requiring students to explicitly define circuit components and their connections during simulation. This pattern highlights that software selection can significantly influence cognitive gains, whereas procedural fluency in simulation tasks remains largely consistent between LTspice and Multisim. From an instructional perspective, educators may further enhance students' learning experiences by incorporating a combination of simulation tools and physical laboratory sessions into the curriculum. This approach enables students to benefit from the complementary strengths of each learning environment while enhancing both their conceptual understanding and practical skill development (Cret & Darabant, 2025; Rosli & Ishak, 2024).

Collectively, these findings underscore that simulation software selection not only affects practical skills but also shapes a deeper understanding of circuit design principles (Gonzales & Gonzales, 2024) and supports higher-order cognitive outcomes (Sihab et al. 2025). The observed advantage of LTspice in conceptual understanding suggests that instructional strategies should consider not only the functional capabilities of circuit simulation software but also the cognitive demands imposed by the learning environment. Accordingly, integrating structured laboratory tasks, performance rubrics, and pedagogical scaffolding into simulation-based learning may support the development of both conceptual knowledge and psychomotor competence in electronics education.

CONCLUSION

This study compared students' conceptual understanding and simulation task performance using two different simulation software platforms, LTspice and Multisim. The findings indicate that software selection in circuit simulation-based experiments significantly influences learning outcomes in electronics courses. Students who used LTspice demonstrated higher levels of conceptual understanding than those who used Multisim. However, overall simulation task performance did not differ significantly between the two groups.

With respect to psychomotor abilities, LTspice supported better student performance in software handling, circuit construction, and output validation, while both groups achieved comparable performance in output response. Overall, however, these findings suggest that

strong circuit simulation skills do not necessarily translate into deeper conceptual understanding. In contrast, the study indicates that the selection of appropriate simulation software not only supports the development of specific psychomotor skills but also plays an important role in strengthening students' conceptual learning in electronics education.

These findings have important implications for educators and curriculum designers. Selecting appropriate simulation software may enhance the effectiveness of laboratory instruction while supporting the balanced development of both cognitive and psychomotor skills, thereby preparing students for future engineering careers and fostering both conceptual understanding and psychomotor competence.

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DECLARATION OF COMPETING INTEREST

None.

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