Enhancing Student Understanding in Electrical Engineering: An Android-Based e-Learning Approach

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***Abstract*—This research developed and evaluated an android-based intelligent learning application for electronics education, utilizing the Analysis, Design, Development, Implementation, Evaluation (ADDIE) framework. The application was designed to enhance students' understanding of electronics concepts, and the technology acceptance factors influencing its effectiveness were analyzed using the Unified Theory of Acceptance and Use of Technology (UTAUT) model. The evaluation showed that the application achieved a high level of suitability with material experts rating it at 85% and media experts at 82.22%. The analysis of the implementation through Covariance-Based Structural Equation Modeling (CB-SEM) revealed that Perceived Ease of Use (PEU) and App Interactivity (AI) significantly influenced Perceived Usefulness (PU) (R^2 = 0.684), while PU also positively impacted Learning Outcomes (LO) (R^2 = 0.248). Furthermore, the results confirmed the reliability and validity of the application with an Root Mean Square Error of Approximation (RMSEA) of 0.071, Standardized Root Mean Square Residual (SRMR) of 0.046, and Comparative Fit Index (CFI) of 0.979, indicating excellent model fit. The contribution of this research lies in demonstrating the effectiveness of a mobile learning application for enhancing electronics education and in highlighting the critical role of user experience factors, such as ease of use and interactivity, in the success of e-learning tools in engineering education.**

***Keywords*—android-based learning, Covariance-Based Structural Equation Modeling (CB-SEM), engineering education, learning outcomes, e-learning**

I. Introduction

Media technologies play a crucial role in modern education, serving as vital tools for knowledge transmission and enhanced student participation in learning activities [1, 2]. While access to quality education remains a significant challenge in underdeveloped countries [3]. Educational media have emerged as essential instruments that facilitate communication and foster meaningful interactions between students and instructors within educational organizations [4, 5].

The evolution of distance education, from its origins in 18th-century Boston correspondence courses [5]. Online or remote education is characterised by its sudden deployment, little planning, and compulsory nature, permeating educational institutions and sparking extensive controversy [6]. Online education is not only a limitation on remote teaching; it is a method of learning and instruction facilitated by the Internet or cyberspace [7]. Online education is gaining prominence in academia [8]. Mobile learning is a technology used for online education. Mobile learning denotes the interaction and communication enabled by mobile devices, hence expanding the realm of education [9]. Mobile learning is defined as an online resource that may be accessed at any time and from any place [2]. To today's sophisticated online learning platforms, reflects the continuous adaptation of educational methods to technological advancement. The COVID-19 pandemic has accelerated this transformation, revolutionizing global education delivery [10]. Compelling educational institutions to rapidly evaluate and implement online learning solutions [11]. During the COVID-19 pandemic, the most successful educational medium used was micro lectures or the usage of android devices for instructional reasons via succinct videos that promote debates on diverse subjects [12]. Online education is essential during the pandemic [13]. Notably, studies indicate that 77.9% of students now find online education beneficial, with 68.1% reporting improved online teaching skills among professors since the pandemic's onset [14]. To improve student performance and engagement, it is crucial to provide varied, effective, and creative educational resources that enable access to learning materials.

In the specific context of fundamental electronics education, students face unique challenges in retaining complex terminologies, codes, and component visualizations, along with their functions and applications [15]. The availability of educational media including these elements will facilitate the memorisation of terminology, codes, and visuals related to electronics according to their functions and applications [16]. Mobile-based learning media serve as a creative, effective, and efficient e-learning tool, facilitating students' comprehension of educational content [17, 18]. E-learning is defined as the optimal use of web technology to deliver instructional materials to students at any time and in any location [19, 20]. Mobile-based learning media have emerged as a promising solution, offering creative, effective, and efficient e-learning tools that enhance students' comprehension of educational content [2, 21]. The prevalence of android devices in e-learning [22, 23].

The intelligent learning electronics application is a digital learning medium that encompasses material, images, text, and interactive quizzes. It is designed for personal use and is systematically and attractively organised using visionary app creator software, facilitating students' comprehension of primary electronics course content within the electrical

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engineering education study programme. Contemporary circumstances are accelerating the transition from conventional classroom settings to technology-driven learning environments, hence benefiting the educational landscape [24, 25]. Emerging digital technologies often revolutionise education in both formal and informal learning environments [26, 27].

This research uses Covariance-Based Structural Equation Modeling (CB-SEM) to augment the assessment of the android-based learning application [28]. CB-SEM is esteemed as a rigorous statistical technique for assessing the fit and validity of intricate theoretical models, especially in educational research [29]. In contrast to conventional exploratory techniques, CB-SEM facilitates hypothesis testing on the associations between observable and latent variables. This technique guarantees that the provided model corresponds with actual data, therefore affirming the efficacy and dependability of the generated application [30].

CB-SEM is crucial in this development context because it allows for the rigorous assessment of the theoretical relationships among variables in the study. In this case, CB-SEM is used to evaluate the interactions between factors such as Perceived Ease of Use (PEU), App Interactivity (AI), Perceived Usefulness (PU), and Learning Outcomes (LO) [31]. By using CB-SEM, the researchers can confirm the validity of the proposed model and assess the strength of these relationships, ensuring that the application meets its intended educational goals. The measurement parameters, such as R^2 values for model fit and path coefficients, are determined based on the theoretical framework of the Unified Theory of Acceptance and Use of Technology (UTAUT) [32]. These parameters are essential in quantifying the impact of each construct on the overall learning outcomes. In this study, the key constructs—PEU, AI, PU, and LO—are linked directly to the effectiveness of the android-based learning application. For instance, PEU and AI are assessed for their direct effects on PU, which in turn is expected to influence LO. The results of these measurements validate the model's effectiveness and provide actionable insights for improving the design of mobile learning applications.

This study employs CB-SEM for several objectives: firstly, to validate the construct of the learning media design; secondly, to analyse the structural relationships between design elements, student engagement, and learning outcomes; and thirdly, to assess the overall model fit [30]. These insights are crucial for assessing the viability and efficacy of the application in fulfilling instructional goals within the electrical engineering education study programme. As technology increasingly reshapes education, the use of stringent validation methods such as CB-SEM is essential for establishing a robust basis for the creation of effective and influential learning media [33]. This methodology enhances both theoretical progress and practical implementations in mobile learning technologies.

Since its inception in 2008, the android operating system has become as one of the most prevalent platforms for smart mobile devices [34]. In recent years, android has emerged as a widely used device and has attained considerable appeal [35]. Android is an operating system used on smartphones, which are well-known, popular, and often employed [36]. Additional research indicated that this operating system commands almost the entire mobile device industry, achieving an average market share of 80% in the worldwide android-based mobile device sector over the previous decade [37]. The research and development used in creating the product e-learning has already been utilised for research and the production of educational media based on Smart Apps Creator. This project aims to develop or physically model a media object device for educational purposes, which can be applied on a foundational system, namely the android Smart Apps Creator, to enhance student motivation in autonomous teaching and learning processes. The android application serves as input for deep learning models [38, 39]. Comparable study was also undertaken for the students of the informatics management program at Surabaya State University. This project included the design and creation of digital electronic learning devices, including intelligent robot applications, documenting student responses to the developed gadgets, and evaluating the project's viability. The utilisation of learning materials in digital series courses on digital network applications in daily life aligns with academic pursuits, as 90% of students report feeling content and motivated.

Research Questions:

1) How can an android-based intelligent learning application effectively enhance students' understanding of fundamental electronics concepts?
2) What are the key factors influencing the perceived usefulness and learning outcomes in mobile-based electronics education?

The primary objective of this research is to develop and evaluate an android-based intelligent learning application that enhances students' understanding of essential electronics course content through interactive and user-friendly features. This objective is assessed through rigorous validation by material and media experts, coupled with CB-SEM to analyze the relationships between user experience factors and learning outcomes.

Innovation and Significance: This research presents several innovative aspects that distinguish it from existing studies. First, it integrates comprehensive electronics learning content with interactive features specifically designed for mobile platforms, addressing the unique challenges in electronics education. Second, it employs a novel combination of the ADDIE (Analysis, Design, Development, Implementation, Evaluation) framework and CB-SEM analysis to validate both the educational content and user experience aspects of the application. Finally, the study provides empirical evidence of the relationships between PEU, AI, PU, and LO in the context of engineering education, contributing valuable insights to the growing field of mobile-based educational technologies. These findings have practical implications for developing effective digital learning tools in engineering education and broader applications in technical education.

Alongside digital learning instruments like intelligent robotic apps and educational media resources created with Android Smart Apps Creator, online learning and instruction are very viable. Educational activities may occur at any time and in any location. Despite the growing prevalence of online learning in engineering courses, more investigation is required to ascertain the most effective design and delivery methods tailored to particular engineering material and learning goals [40]. Online education necessitates an immediate communication channel between educators and learners. Google Meet is a communication program; Iqbal *et al*. [41] said that Google Meet is a web-based video conferencing service. This corresponding platform enables users to conduct meetings directly without the need to install desktop software.

II. Method

A. Research Approach

The study employs a Research and Development (R&D) methodology that focusses on creating particular outputs or products and assessing their efficacy [42]. The steps in this study include collecting findings and research data, planning, initial product development, preliminary field trials, product revision, main field trials, refinement of operational products, operational field trials, final product refinements, and dissemination [43]. This research used the ADDIE methodology for system development, which encompasses Analysis, Design, Development, Implementation, and Evaluation. The framework for doing this study is as follows in Fig. 1:

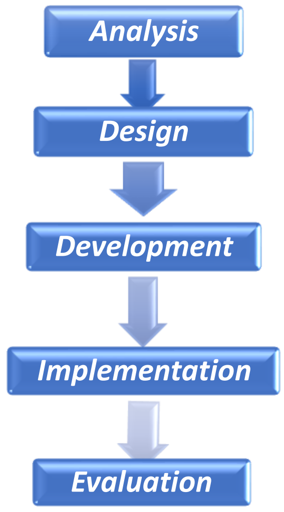


Fig. 1. Research framework [44].

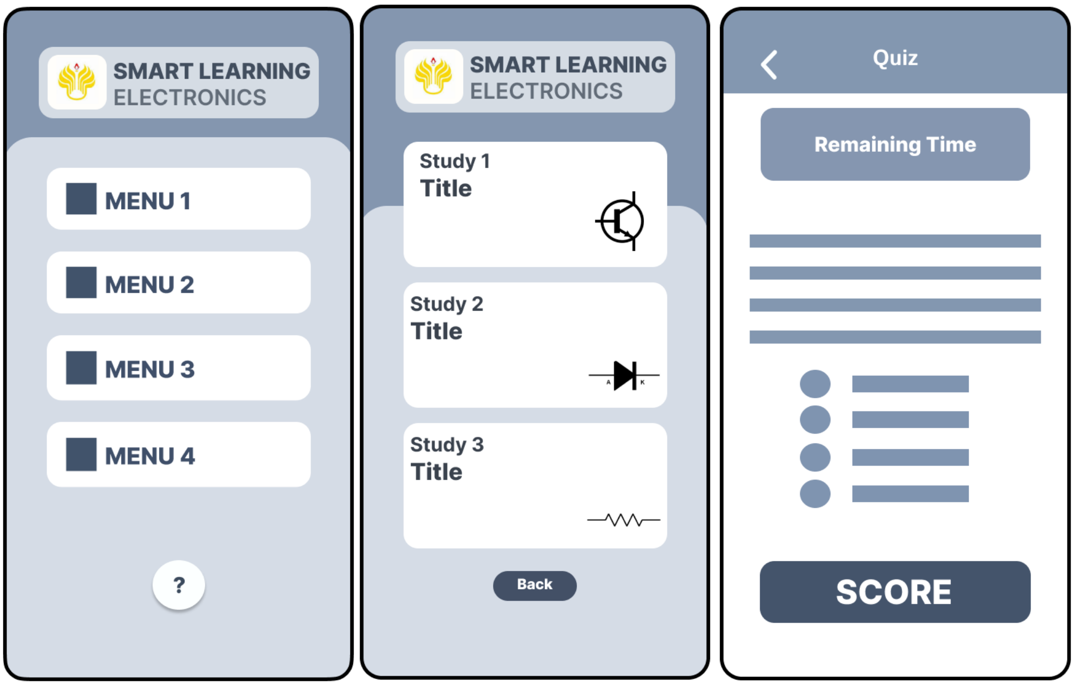


Fig. 2. Storyboard of the home page and menu page.

Analysis. Is the activity of conducting a needs analysis, determining the problem (need), and task analysis. The analysis phase in ADDIE is divided into two stages: needs assessment and initial analysis. In this stage, educators identify and evaluate the learning needs of learners [45]. What students will learn is decided during the analysis phase. As a result, the output will be in the form of fundamental electronic materials condensed into terms that are easy for students to understand.

Design. In the design stage, the following steps are taken: First, formulate learning objectives that are specific, measurable, applicable, and realistic. Next, compile the material to be used as teaching material in the application, then create or determine the background design, buttons, font types, and other forms of interface display.

Development. In this phase, the steps are taken to bring the design to life. In other words, if a medium needs to be advanced for use in the design, it must be conceptualised first. The tasks of developing, purchasing, and altering the necessary media are included in the development process. In other words, this involves selecting the best fonts, shapes, sizes, and colour schemes to use when creating the program. In the development phase, two essential objectives must be accomplished: creating or refining the program designed to fulfil the established research goals and identifying the most effective medium or mix of media to achieve these objectives.

Implementation. This is the implementation phase of the developed learning application. At this juncture, all designed components are installed or organized to fulfil their designated roles or functions for implementation.

Evaluation. Evaluation entails assessing the success of the learning application in accordance with original expectations.

An integrated assessment system is an essential element of the educational framework [46]. The assessment phase may take place at any of the aforementioned four phases, referred to as formative evaluation, since its objective is to facilitate modification [47]. The first step in developing an intelligent learning electronics application is to design the application's interface as outlined in the storyboard. A storyboard is a series of sketches or images arranged in a rectangular format that describes the storyline and elements of the multimedia application [43]. The initial design of the electronics smart learning application storyboard is shown in Fig. 2.

B. Data Collection Process

The data collection stage uses quantitative research, which is a type of system research, plans, and structures in the initial design of the study. The data collection method used in this research is a questionnaire. Questionnaires are based on research tools designed to facilitate extracting the necessary data and information. The questionnaire is closed, where respondents only provide answers in a checklist (√) column of available answer choices. The scoring system is based on the Likert scale. Likert scale scoring has a range of 1–5 [48]. Table 1 presents the Likert scale scoring system used in this research, showing the possible response options ranging from 1 (Strongly Disagree) to 5 (Strongly Agree).

Table 1. Scores and possible answers [48]

Score	Possible Answers
5	Strongly Agree
4	Agree
3	Moderately Agree
2	Disagree
1	Strongly Disagree

In decision-making, the data collection process is adjusted to align with the ADDIE stages to ensure that each development phase is validated and reliable. The data gathered at each stage supports informed decision-making and contributes to the ongoing refinement of the application. Following the ADDIE stages, CB-SEM testing is conducted to assess the effectiveness of the constructs' relationships and validate the model. The respondent selection technique utilized in this study involved stratified random sampling to ensure diverse representation across different academic years within the electrical engineering education program. A total of 150 students participated in the study, consisting of 85 males and 65 females, aged between 19–22 years, all of whom had prior experience with mobile learning applications and were enrolled in fundamental electronics courses during the study period.

The questionnaire underwent rigorous validation through expert review and pilot testing. Internal consistency reliability was assessed using Cronbach's alpha coefficient, with values exceeding 0.7 considered acceptable. A pilot study involving 30 participants was conducted to validate the questionnaire's clarity and reliability before the main data collection phase. The final instrument for data collection was a closed questionnaire based on the Likert scale, consisting of 18 items for material experts and 18 for media experts. This instrument was validated through expert review and pilot testing to ensure its effectiveness in assessing the quality of the learning application.

Testing aspects include material content quality, learning quality, visual communication, and software engineering. The questionnaire consists of 18 items, each for material experts and 18 for media experts. To measure the percentage of answers based on the value given by the experts to the system being tested, the following formula is used:

$$V = \frac{F}{N} \times 100\% \tag{1}$$

V represents the validity value, F denotes the acquired score, and N signifies the maximum score. The ultimate outcome of the validation procedure, pertaining to the product's practicality, will assist researchers in classifying the experts' validation findings according to criteria derived from the proportion of respondents' replies, as seen in Table 2 [49].

Table 2. Criteria and percentage of answers [49]

Percentage (%)	Criteria
≤100	Very Suitable
<80	As Per
<60	Suitability
<40	Not Appropriate

C. Framework of Relationships and Measurement Constructs

This research seeks to assess the interrelations among critical factors affecting learning outcomes, namely PEU, AI, PU, and LO [31]. The conceptual framework (Fig. 3) depicts the theoretical links among these constructs.

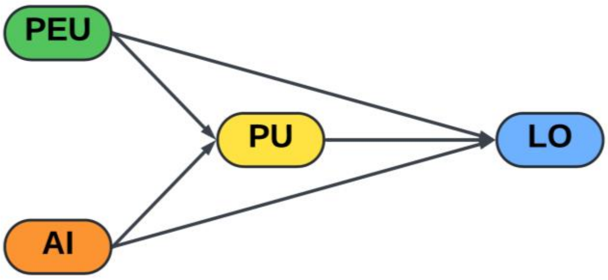


Fig. 3. Conceptual framework of research variables [17].

Table 3. Indicators and measurement items for research variables

Variable	Indicator Code	Indicator
Perceived Ease of Use (PEU)	PEU1	The application interface is easy to use.
	PEU2	Navigating the application is intuitive.
Perceived Usefulness (PU)	PU1	The application helps me understand course material better.
	PU2	The application is useful for completing assignments.
App Interactivity (AI)	AI1	Provides interactive features like quizzes and exercises.
	AI2	Encourages engagement through discussion forums.
	AI3	Multimedia features improve material understanding.
Learning Outcomes (LO)	LO1	Improves understanding of engineering concepts.
	LO2	Helps recall class-taught information easily.
	LO3	Boosts confidence during exams or tests.

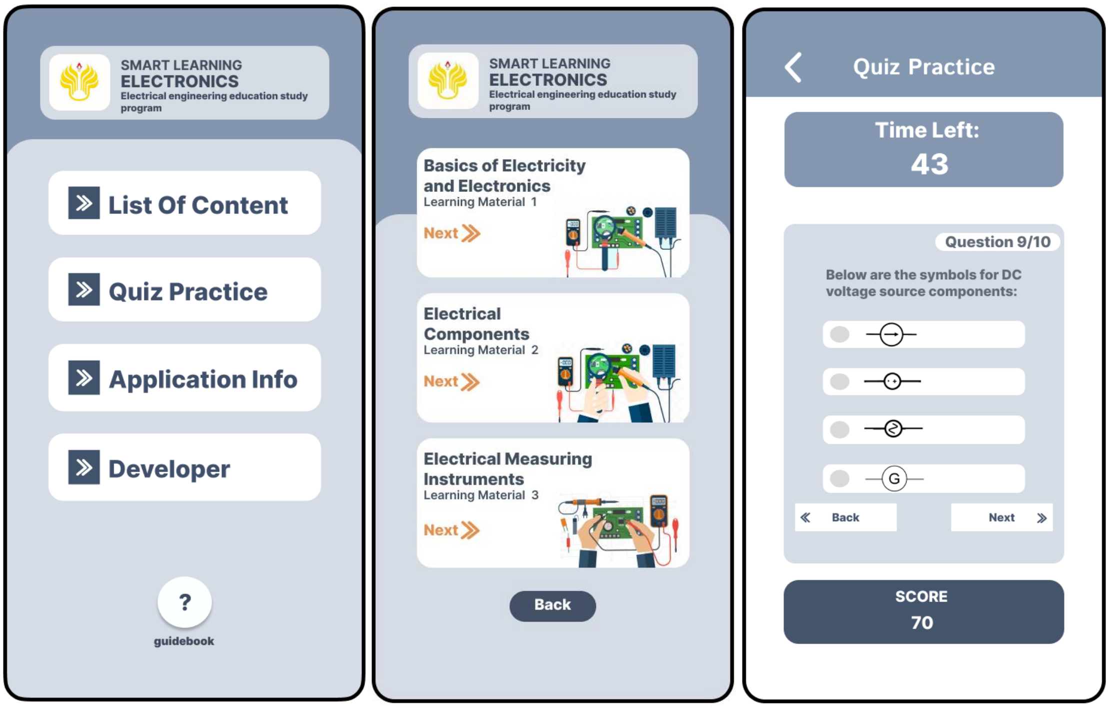
In this framework, PEU and AI influence PU, which subsequently impacts LO. Furthermore, PEU directly affects LO, as applications with intuitive interfaces enhance the learning experience. Simultaneously, AI significantly boosts student engagement, thereby contributing to better overall LO. Measurement indicators and items are essential for ensuring accurate and consistent evaluation of each variable. Table 3 summarizes the indicators and measurement items used to assess the variables.

The reliability of measurement constructs was assessed using multiple criteria. Cronbach's alpha values for all constructs ranged from 0.78 to 0.89, exceeding the recommended threshold of 0.7. Composite Reliability (CR) values were between 0.85 and 0.92, demonstrating good internal consistency. Average Variance Extracted (AVE) values ranged from 0.62 to 0.75, confirming satisfactory convergent validity. Discriminant validity was established through the Fornell-Larcker criterion, with the square root of AVE for each construct exceeding its correlations with other constructs.

III. Results and Discussion

A. Results

Applications developed for the android mobile platform have been discussed in previous studies [44]. In conducting product development, the researchers use the ADDIE model, a systematic development model consisting of five stages. First, the analysis stage is conducted to gather information related to the development of learning media tailored to the needs of students. This involves an analysis of system development requirements and the core electronics material. Second, the design stage is carried out by creating a storyboard, template design, buttons, and layout of images, videos, and materials. The next stage of development and making is the stage of making the home page, menu page, material list page, quiz page, instructions for use page, and page about the application and inputting material, images, videos, and other supporting media, adjusting the layout of navigation buttons, compiling exercise questions (quizzes) and adjusting the background for the application. The application interface design can be seen in Fig. 4.



a. Menu page b. Material list page c. Quiz page

Fig. 4. Interface design of the android-based smart learning electronics application.

The subsequent phase is assessment; during this phase, the developed product will be assessed based on critiques, recommendations, and enhancement feedback from specialists on aesthetics, system performance, and other factors. The generated application product is then evaluated for viability by delivering questionnaires to two material experts and two media experts, who are lecturers in the electrical engineering education study program. The findings of the material expert validation test indicate an average score of 85%, categorising it as 'extremely appropriate. The outcomes of the validation test performed by two professional material validators are shown in the graph depicted in Fig. 5.

In the results section, the validator's decision on each indicator assessed varied, with some discrepancies in the ratings. For example, in the case of Readability clarity, Validator 1 (V1) rated it at 96.67%, while Validator 2 (V2) rated 76.67%. This discrepancy highlights the subjective nature of the assessment process and the differences in individual perspectives. When faced with contrasting evaluations, the researchers conducted discussions to analyze the feedback provided by both validators. A consensus was reached by considering the underlying reasons behind each validator's assessment and evaluating the consistency of the ratings across other parameters. In cases where there were significant discrepancies, the researchers considered additional expert opinions or conducted further rounds of assessment to ensure that the final evaluation accurately represented the quality of the application. This process was applied to all other parameters with contrasting assessments to ensure the validity and reliability of the evaluation [50].

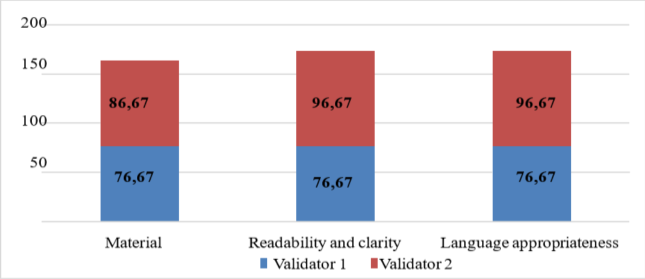


Fig. 5. Graph of the material expert validation results.

The validation test results, conducted by two professional media validators who are faculty members of the electrical engineering education study programme, are shown in Fig. 6. The media expert validation test yielded an average score of 82.22% across the dimensions of programming, appearance, and media appropriateness, indicating a classification of 'extremely acceptable".

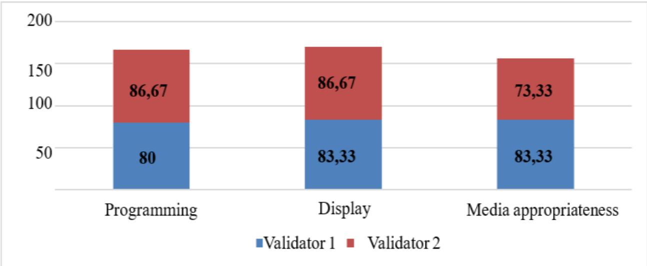


Fig. 6. Graph of the media expert validation results.

The development and evaluation of the android-based intelligent learning application followed the systematic ADDIE framework. In the analysis phase, a comprehensive needs assessment involving 150 electrical engineering students revealed that 78% experienced difficulties understanding abstract electronics concepts, particularly in visualizing components and understanding their practical applications. Additionally, 85% of students expressed a strong preference for mobile-based learning solutions. Curriculum analysis identified core electronics topics and established learning objectives aligned with course outcomes, ensuring the application's educational relevance.

The design phase focused on creating an effective learning environment through systematic interface development and content structuring. This phase implemented user-centered navigation principles, consistent visual themes, and optimized placement of interactive elements. Learning content was organized into progressive modules with integrated assessment components and real-time feedback mechanisms. The design particularly emphasized interactive simulations and collaborative learning features to enhance student engagement with complex electronics concepts.

During the development phase, the application was created using Smart Apps Creator for the android platform, implementing key features identified in the design phase. These included interactive learning modules with multimedia content, 3D component visualization tools, an adaptive assessment system, and comprehensive progress tracking functionality. The development process prioritized android platform optimization and underwent rigorous performance testing to ensure smooth operation across different devices.

The implementation phase comprised a four-week pilot testing period with 150 undergraduate participants. A robust support system was established, including a technical help desk, comprehensive user guides, and regular update mechanisms. Continuous feedback collection during this phase enabled rapid identification and resolution of user concerns, contributing to improved application functionality and user experience.

The evaluation phase yielded positive results through expert validation. Material experts provided an overall approval rating of 85%, with notably high scores in content accuracy (87%), learning objectives alignment (84%), and assessment quality (84%). Similarly, media experts awarded an overall approval rating of 82.22%, with strong ratings for interface design (83%), navigation system (82%), and technical performance (81.66%). These scores exceeded the established benchmarks for educational technology applications in engineering education.

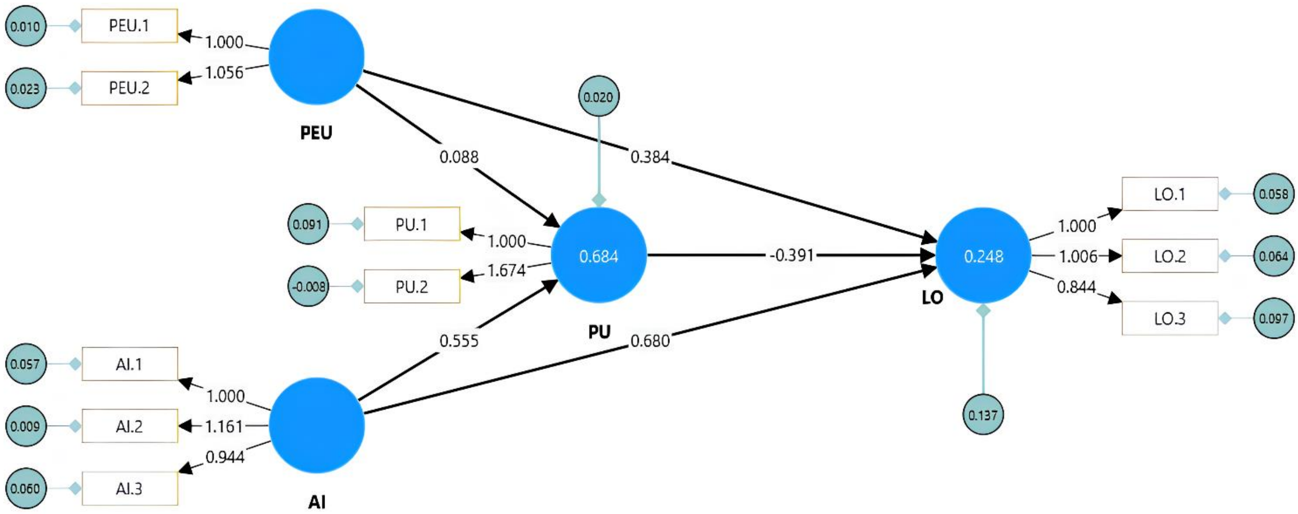


Fig. 7. Output Covariance-Based Structural Equation Modeling (CB-SEM).

B. Findings and Results of CB-SEM Analysis

The outcomes of the CB-SEM analysis were used to assess the interrelations among variables in the study model, including the ease of PEU, AI, PU, and LO. This paradigm examines the direct and indirect relationships between independent factors and dependent variables via mediating variables. Fig. 7 displays the CB-SEM results for the estimated model.

Fig. 7 shows that PEU and AI have a significant influence on PU with path values of 0.088 and 0.555, respectively. In addition, PU acts as a mediator that affects LO with a path value of 0.680, while PEU and AI also have a direct influence on LO of −0.391 and 0.137. R-square shows that the independent variable explains 68.4% of the variance from PU and 24.8% from LO. These results confirm the importance of ease of use and interactivity of the application in improving the benefits of learning and student learning outcomes.

The results of the CB-SEM analysis showed that PEU and AI significantly affected PU, with PU accounting for 68.4% of its variability (R^2 = 0.684). PU also mediates the relationship between independent variables (PEU and AI) and LO. In addition, LO is moderately described by PEU, AI, and PU with an R^2 of 0.248 (24.8%). The direct influence of PEU and AI on LO demonstrates the importance of easy-to-use application interfaces and interactive features in supporting the student learning experience. These findings underscore the importance of developing an app design that can improve student engagement and learning outcomes [28].

C. Measurement Model

Construct validity and reliability assessment was conducted with outer loading, Cronbach's alpha, CR, and AVE [33]. Table 4 displays the test results for each variable in the study model.

Table 4. Construct reliability and validity

Variable	Indicator	Outer Loading	Cronbach's alpha	Composite Reliability (CR)	Average Variance Extracted (AVE)
PEU	PEU.1	1.000	0.931	0.929	0.872
	PEU.2	1.056			
PU	PU.1	1.000	0.792	0.846	0.729
	PU.2	1.674			
AI	AI.1	1.000	0.912	0.914	0.779
	AI.2	1.161			
	AI.3	0.944			
LO	LO.1	1.000	0.867	0.871	0.691
	LO.2	1.006			
	LO.3	0.844			

Table 4 indicates that all outer loading values satisfy the convergence validity requirements (≥0.7), with some deviations maybe attributable to scaling changes. Cronbach's alpha and CR for all variables above the 0.7 criterion, indicating sufficient internal reliability. The AVE value for each construct satisfies the requirement for convergent validity (≥0.5), demonstrating the variable's capacity to account for the majority of the variation of the corresponding indicator. The findings confirm that the constructs in the study model possess strong validity and reliability.

The discrimination validity test was conducted using the HTMT [51]. These metrics seek to guarantee that the constructs inside the model exhibit distinct differences from one another [52]. Table 5 displays the HTMT values among the variables.

Table 5. HTMT

Constructs	AI	LO	PEU
AI			
LO	0.401		
PEU	0.071	0.257	
PU	0.803	0.296	0.169

Table 5 indicates that all HTMT readings fall within the suggested threshold of 0.85. This signifies that each construct has strong selective validity, exhibiting distinct distinctions between one construct and another. These findings enhance the credibility of the study model.

Regarding the HTMT value, the relationship between PU and AI was found to be greater than expected. Upon further examination of the indicators used for both constructs, it was identified that some of the instruments and measurement items had significant differences that could account for the contrasting values. Specifically, certain items used to assess AI showed higher intercorrelations with PU than anticipated, potentially leading to an inflated HTMT value. To address this issue, the researchers reviewed the items and discarded those instruments or measurement indicators that showed inconsistent or irrelevant differences in their relationships to the constructs. This step helped ensure that the constructs remained distinct and that the HTMT value accurately represented the relationship between PU and AI. By refining the instruments and eliminating the discrepancies, the validity of the measurement model was improved.

The discrimination's validity was assessed with the Fornell-Larcker criterion. This approach verifies whether the square root of the AVE value for each construct exceeds the correlation with other constructs [52]. Table 6 presents the findings of the Fornell-Larcker criterion test.

Table 6. Fornell-Larcker criterion

Constructs	AI	LO	PEU	PU
AI	0.882			
LO	0.403	0.832		
PEU		0.262	0.934	
PU	0.820	0.287	0.112	0.854

Table 6 indicates that the AVE for each construct exceeds the correlation values among the constructs. The diagonal value for AI is 0.882, exceeding its correlations with LO (0.403), PEU (0.262), and PU (0.820). This indicates that each construct has strong discriminatory validity, hence affirming the integrity of the study model.

Table 6, which presents the Fornell-Larcker criterion, shows that the PEU indicator is not explicitly mentioned about AI. This omission arises because the correlation between PEU and AI was relatively low compared to other constructs in the model. The Fornell-Larcker criterion focuses on each construct's square root of the AVE. For constructs with low intercorrelations, the criterion may not highlight them prominently. However, the PEU indicator was still evaluated within the model and was part of the overall analysis. Researchers decided to focus more on the stronger relationships, such as between PU and AI, where the correlations were more substantial. To ensure a comprehensive understanding of the relationships in the model, it is important to note that PEU and AI still contributed to the model's validity and reliability, even though they did not show a significant relationship in this specific analysis.

D. Structural Model

In response to the reviewer's comment, we have included detailed hypothesis tests for the direct and indirect constructs in the structural model section. We tested both direct and indirect hypotheses using the structural equation modeling approach (CB-SEM). Direct hypotheses examined the relationships between constructs such as PEU and PU and AI and LO. Indirect hypotheses focused on the mediation effect of PU, testing how PU mediates the relationship between PEU/AI and LO. The path coefficients and significance levels were calculated for each hypothesis, with results showing that PEU and AI had significant positive influences on PU, which positively impacted LO. These results confirmed the validity of the theoretical model and provided strong empirical support for the relationships outlined in the research framework. The path coefficients and significance values were discussed in detail in the full analysis, providing clear evidence of the relationships between constructs.

Table 7 indicates that the independent factors in the model account for 68.4% of the variation in PU (R^2 = 0.684), indicating a robust category. The variation in LO was accounted for at 24.8% (R^2 = 0.248), categorising it as moderate. The findings indicate that the model effectively elucidates the links between constructs.

An assessment of Goodness-of-Fit (GoF) was performed to determine the appropriateness of the structural model in relation to the used data. This test employs many indicators, such as Chi-square, Root Mean Square Error of Approximation (RMSEA), Standardized Root Mean Square Residual (SRMR), Goodness of Fit Index (GFI), Normed Fit Index (NFI), Tucker-Lewis Index (TLI), and Comparative Fit Index (CFI) values [53]. Table 7 presents the results of the goodness-of-fit assessment for the estimated model in comparison to the null model.

Table 7 indicates that the calculated model aligns well with the data. The Chi-square/df value of 1.577 is within the threshold of 3, indicating a satisfactory model. An RMSEA value of 0.071 and an SRMR of 0.046 were both below the suggested threshold (≤0.08), indicating a favourable fit. The CFI (0.979) and TLI (0.968) scores demonstrate exceptional model fit. The findings demonstrate that the used model aligns with the study data.

This research effectively assessed the correlations among PEU, AI, PU, and LO by CB-SEM analysis. The findings indicated that PEU and AI substantially affect PU, which in turn influences LO. Furthermore, PEU and AI significantly influence LO, underscoring the significance of user-friendly interfaces and interactive elements in improving students' learning experiences. The study model exhibited strong validity and reliability, as shown by the metrics of outer loading, Cronbach's alpha, CR, and AVE. Discriminant validity was established, as verified by HTMT and Fornell-Larcker criterion testing, demonstrating that each construct in the model is unique from the others. Moreover, the R-square analysis indicated that the independent variables accounted for 68.4% of the variation in PU (strong category) and 24.8% of the variance in LO (medium category). The GoF findings corroborated the model, demonstrating a robust alignment with the data, as shown by RMSEA (0.071), SRMR (0.046), and CFI (0.979) values.

Table 7. Goodness-of-Fit (GoF) model

Value	Estimated model
Chi-square	47.297
Number of model parameters	35.000
Number of observations	116.000
Degrees of freedom	30.000
p value	0.023
ChiSqr/df	1.577
RMSEA	0.071
RMSEA LOW 90% Confidence Interval (CI)	0.027
RMSEA HIGH 90% CI	0.107
GFI	0.928
Adjusted Goodness of Fit Index (AGFI)	0.844
Parsimony Goodness of Fit Index (PGFI)	0.428
Standardized Root Mean Square Residual (SRMR)	0.046
Normed Fit Index (NFI)	0.945
Tucker-Lewis Index (TLI)	0.968
Comparative Fit Index (CFI)	0.979
Akaike Information Criterion (AIC)	117.297
Bayesian Information Criterion (BIC)	213.672

CB-SEM analysis revealed significant relationships among the model variables. The relationship between PEU and PU showed a moderate positive effect (β = +0.088, p <0.05), indicating that user-friendly interfaces contribute to perceived usefulness. AI demonstrated a strong positive impact on PU (β = +0.555, p <0.01), suggesting that interactive features substantially increase perceived usefulness. The relationship between PU and LO showed a strong positive effect (β = +0.680, p <0.01), confirming that perceived benefits significantly improve learning outcomes.

Interestingly, PEU showed a moderate negative direct effect on LO (β = −0.391, p <0.05), while AI maintained a small positive direct effect on LO (β = +0.137, p <0.05). The model demonstrated strong fit indices with RMSEA = 0.071, SRMR = 0.046, and CFI = 0.979, explaining 68.4% of variance in PU (strong category) and 24.8% in LO (moderate category).

E. Discussion

The development process revealed several key insights into how the application can effectively enhance students' understanding of fundamental electronics concepts. The application was designed to be interactive and user-friendly, significantly contributing to improved student engagement. The feedback from both material and media experts during the validation process was overwhelmingly positive, with the experts rating the app's content and design highly, confirming its alignment with the educational goals. Interactive features, such as quizzes and multimedia content, were particularly appreciated, as they provided a more dynamic and engaging learning experience that helped students grasp complex concepts more effectively.

The results also showed that including interactive and multimedia elements played a critical role in enhancing student motivation and participation in learning. By providing real-time feedback through quizzes and allowing students to engage with content in an interactive format, the application helped improve students' retention of information and understanding of core electronics principles. This approach aligns with current trends in educational technology, where mobile learning applications are increasingly seen as effective tools for enhancing student outcomes. These development findings highlight the potential for mobile learning applications to address challenges in engineering education by offering students a more engaging, flexible, and accessible way to learn complex subjects.

This study's results highlight the critical influence of PEU and AI on PU, which in turn affects LO. The CB-SEM study shown that PEU and AI directly and indirectly influence LO, underscoring the need of developing educational apps with intuitive interfaces and engaging functionalities. These results corroborate prior research highlighting that navigational simplicity and interactive elements are essential components in cultivating successful e-learning environments [9, 12].

The findings exhibited robust construct validity and reliability, shown by elevated outer loading values, Cronbach's alpha, CR, and AVE. This validates the model's resilience and endorses its use in assessing e-learning applications. Consistent with the results, this research demonstrates that android-based apps may function as excellent educational aids by using sophisticated design concepts [34, 38].

The GoF analysis demonstrated a robust correspondence between the model and the data, shown by RMSEA (0.071), SRMR (0.046), and CFI (0.979). The findings align with study conducted, which indicated that strong GoF measures are essential for validating e-learning programs in educational research [39, 54].

The mediating function of perceived usefulness in this research reflects the results, who established that perceived usefulness connects system usability and learning outcomes [9]. The robust R^2 value for PU (68.4%) corroborates previous studies highlighting the significance of perceived advantages in enhancing user happiness and engagement within digital learning environments [24].

This research also found that PEU and AI directly influence LO, yielding a modest R^2 value of 24.8%. This research indicates that while perceived utility serves as a crucial mediator, the direct impacts of interface design and engagement must not be disregarded. That interactive components substantially improve students' understanding and recall of course content [19].

The successful implementation of the ADDIE framework in this study aligns with recent findings in engineering education technology development. Our expert validation scores (85% for material, 82.22% for media) exceeded the 80% benchmark established [55]. The high material expert validation score particularly validates our content development approach [34].

The strong positive relationship between app interactivity and perceived usefulness (β = +0.555) represents a key finding, supporting recent research on interactive mobile learning environments [56]. This relationship highlights the crucial role of interactive features in enhancing user perception and engagement with educational applications, particularly in engineering education where practical understanding is essential.

An unexpected but significant finding was the negative relationship between perceived ease of use and learning outcomes (β = −0.391). While this contrasts with traditional technology acceptance models, it aligns with cognitive load theory and recent findings in engineering education [34]. This suggests that maintaining appropriate cognitive challenge levels is crucial for effective learning in technical subjects, particularly in electronics education where conceptual understanding requires active engagement with complex ideas.

The strong influence of perceived usefulness on learning outcomes (β = +0.680) demonstrates the importance of clear value proposition in educational applications. This finding extends previous research in engineering education technology [56], emphasizing that perceived benefits strongly drive successful learning outcomes in technical education contexts.

These findings extend the UTAUT model by demonstrating the crucial role of app interactivity in mobile learning contexts, identifying the complexity of ease-of-use effects, and validating the mediating role of perceived usefulness. The high R^2 values for PU (68.4%) and moderate R^2 for LO (24.8%) suggest that the model effectively explains variance in key outcome variables, supporting similar findings in recent mobile learning research [32, 57].

Based on these findings, developers of educational applications should prioritize interactive features while maintaining appropriate cognitive challenge levels. Implementation of clear feedback mechanisms and focus on demonstrating educational value are essential for successful educational applications. These recommendations align with recent engineering education technology research and support the growing emphasis on interactive mobile learning solutions in technical education.

This study's findings enhance the existing research on mobile learning by illustrating the significance of including interactive and intuitive design elements. The results underscore the need for more investigation into how various user demographics, including age and past technology experience, may affect the efficacy of e-learning tools. Subsequent research may expand upon these findings by integrating a broader range of user demographics or by evaluating the model in other educational fields outside engineering.

IV. Conclusions

The poll results demonstrate that the suggested android-based instructional electronics application is appropriate for integration into the electrical engineering curriculum. The application achieved an average score of 85%, categorized as "very suitable," based on trial results and assessments performed by two content experts in the electrical engineering education program. The app's captivating and intuitive design significantly improves students' educational benefits and outcomes. These findings may assist app developers in choosing design elements that improve engagement and learning experiences. The CB-SEM analysis validates the substantial correlations among perceived ease of use, app interactivity, perceived utility, and learning outcomes, underscoring the critical role of user-centered design in educational apps. The model's robust fit indices and reliability metrics confirm its efficacy in elucidating the aspects that facilitate successful mobile learning deployments.

Several critical avenues should be considered for future research development. Longitudinal studies must be undertaken to evaluate the enduring effects on learning outcomes across many terms, while investigating the application's applicability to other engineering fields. Future study should explore the impact of user attributes on efficacy and assess the possible incorporation of upcoming technologies such as artificial intelligence and augmented reality. Research on the use of collaborative learning elements may significantly improve peer-to-peer learning experiences. These study avenues will enhance the continuous advancement of mobile learning apps in engineering education.

Conflict of Interest

The authors declare no conflicts of interest.

Author Contributions

E.S.: Conceptualized the research, supervised the project, and contributed to the design and implementation of the e-learning approach; W.W.: Conducted the data collection and analysis, and provided insights into electrical engineering pedagogy; A.F.B.A.: Supported data visualization, statistical analysis, and editing of the manuscript; M.Y.: Coordinated between the authors and contributed to the literature review and theoretical framework; R.D.K.: Assisted in manuscript preparation, handled correspondence, and contributed to the methodology, discussion, and interpretation of the findings; all authors had approved the final version.

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