Journal of Hypermedia & Technology-Enhanced Learning
Vol. 3, No. 3, October (2025), Pages 202–222
e-ISSN: 2985–9166 | 10.58536/j-hytel.195

RESEARCH ARTICLE

Empowering Vocational Learners: Development and Validation of Android-Based Interactive Media for Electronics Education

Jefri Wahyudianto[1]*, Ilmiyati Rahmy Jasril[1], Juan Luis Cabanillas García[2], Constantina Corazon Argyrakou[3]

[1] Department of Electronics Engineering, Faculty of Engineering, Universitas Negeri Padang, Padang, **Indonesia**
[2] Department of Educational Sciences, University of Extremadura, Badajoz, **Spain**
[3] Department of Geography, Harokopio University of Athens, Kallithea, **Greece**

**Corresponding Author: jefriwahyu007@gmail.com*

This article contributes to:

4 QUALITY EDUCATION

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ABSTRACT

This study developed an Android-based interactive learning media to support teaching *Fundamentals of Electronics Engineering* in vocational high schools. Grounded in principles of technology-enhanced learning and systematic instructional design, the development process followed the Waterfall model, encompassing analysis, design, implementation, testing, and refinement stages. Expert validation and student field testing assessed the media's feasibility and practicality. Results demonstrated that the application met high standards of pedagogical effectiveness, usability, and content relevance. Integrating multimedia elements and aligning the curriculum improved learner engagement and instructional clarity. These findings highlight the potential of mobile learning technologies to enhance subject mastery in technical and vocational education, providing scalable and contextually relevant solutions for developing 21st-century skills.

KEYWORDS

Android learning application; electronics education; simulation-based instruction; multimedia learning (CTML); waterfall model

Received: Jun. 02, 2025; *Revised:* Aug. 25, 2025; *Accepted:* Sep. 23, 2025; *Published Online:* Oct. 14, 2025

How to Cite: Wahyudianto, J., Ilmiyati Rahmy Jasril, García, J. L. C., & Argyrakou, C. C. (2025). Empowering Vocational Learners: Development and Validation of Android-Based Interactive Media for Electronics Education. *Journal of Hypermedia & Technology-Enhanced Learning*, *3*(3), 202–222. https://doi.org/10.58536/j-hytel.195

Published by Sagamedia Teknologi Nusantara

1. INTRODUCTION

Education serves as one of the fundamental pillars of national development and must continuously adapt to technological advancements to remain relevant and responsive to societal needs. In recent years, the rapid progress of digital technology has driven its integration into the educational sector to enhance the effectiveness and efficiency of learning processes [1], [2]. The application of technology as a pedagogical tool is crucial in optimizing knowledge transfer from educators to students [3], [4]. Empirical studies have demonstrated that digital technology-based learning media significantly improve students' understanding of abstract theories and practical concepts in various subjects [5], [6].

Globally, the digitalization of vocational education has become a central focus in enhancing workforce skills that align with the demands of modern industry. Fitrihana (2023) emphasizes that the integration of digital technology into vocational education not only accelerates transformations in pedagogical approaches but also contributes to the development of 21st-century skills, including digital literacy, creativity, and collaboration [7]. At the national level, Indonesia's educational policy through the *Kurikulum Merdeka* (Independent Curriculum) encourages the utilization of digital technology with an emphasis on contextual learning, competency development, and the strengthening of the *Profil Pelajar Pancasila* (Pancasila Student Profile) [8]. This policy aims to strengthen students' competencies so they are better prepared to learn and work in digitally rich environments [9], [7].

In the context of *Sekolah Menengah Kejuruan* (SMK) or Vocational High School, particularly in the subject *Fundamentals of Electronics Engineering* (*Dasar-Dasar Teknik Elektronika*), students are required not only to understand theoretical concepts but also to master practical skills. However, materials such as electrical laws, electronic components, and measurement techniques are often difficult to grasp when taught solely through traditional methods [10]. International research highlights the importance of digital media innovation in vocational education. Martin et al. [11] found that interactive mobile applications enhance motivation and learning outcomes among technical students. Juera [12] demonstrated that mobile simulation-based learning is effective in developing vocational skills through safe and repetitive practice. Similarly, Mohammadi et al. [13] emphasized participants' positive perceptions of mobile learning, highlighting its ability to facilitate access, enhance learning quality, and expand learning opportunities. A synthesis of these findings indicates that simulation- and mobile-based digital media serve as a bridge between abstract theory and real-world practice.

Observations from the *Praktik Lapangan Kependidikan* (PLK) or Educational Field Practice at SMK Negeri 5 Padang revealed similar challenges: teachers still struggle to deliver complex material despite having *Alur Tujuan Pembelajaran* (ATP) or Learning Objectives Flow and modules. Conventional media such as textbooks, PowerPoint slides, or Canva visuals are insufficient to support students' in-depth understanding [14]. This condition is consistent with the findings of [15], which emphasize that countries with advanced vocational education systems consistently integrate mobile and flexible technologies to strengthen practical learning, particularly in the fields of STEM (Science, Technology, Engineering, Mathematics). This indicates that the pedagogical challenges observed locally in Indonesia are part of the broader global challenges in vocational education.

In addressing these limitations, mobile-based interactive learning strategies, particularly those utilizing the Android platform, hold significant potential to enhance student engagement, motivation, and comprehension in technical subjects [16], [17]. Android-based interactive media present a promising solution by providing simulations, animations, video tutorials, and audio narration that support flexible, engaging, and student-centered learning [18], [19]. This technology also reduces reliance on costly laboratories, time constraints, and safety risks, while enabling repeated experimentation [20]. The choice of Android is further reinforced by Davis's Technology Acceptance Model (TAM) [21], which emphasizes that perceived ease of use and perceived usefulness are the key determinants in the adoption of educational technologies. As the most widely used mobile operating system globally, Android offers high accessibility, broad compatibility, and ease of development, making it an appropriate platform for interactive learning in Vocational High Schools (SMK).

Furthermore, the characteristics of vocational students tend to prefer hands-on activities and visual demonstrations, further underscoring the urgency of utilizing simulation- and interaction-based media. Such media not only support self-directed learning but also provide realistic visualizations of industrial processes. Consequently, students are better able to comprehend abstract and technical materials, such as component operation, circuit analysis, and measurement techniques [22], [23].

Despite the growing body of literature on mobile learning, few studies have specifically focused on designing and developing Android-based interactive media tailored to the learning needs of vocational high school students in electronics engineering [24]. Most existing solutions are either generic or not aligned with the curriculum structure of SMKs. This reveals a notable research gap in developing localized, curriculum-integrated, and practice-oriented mobile learning applications supporting meaningful learning in the *Fundamentals of Electronics Engineering* course.

The novelty of this study lies in its focus on designing and validating an Android-based interactive learning application that is contextually adapted to the Indonesian vocational education system, pedagogically aligned with the *Merdeka Curriculum*, and technologically optimized to facilitate the visualization of complex electronics concepts. This approach aims to enhance students' digital literacy and conceptual understanding, preparing them for learning and participation in digitally rich educational environments and lifelong learning.

This study aims to design, develop, and validate an Android-based interactive learning medium for the subject *Fundamentals of Electronics Engineering*. The objective is to enhance student engagement, digital competence, and mastery of essential electronics concepts among tenth-grade students in vocational high schools (SMK).

Based on these objectives, the research questions (RQs) formulated are as follows:

1. How is the design and development process of the Android-based interactive learning media for the *Fundamentals of Electronics Engineering* (*Dasar-Dasar Teknik Elektronika*) subject carried out using the Waterfall model?

2. To what extent is the learning media evaluated as valid, feasible, and practical according to assessments from experts and vocational students?

By utilizing Android-based learning media, students can explore basic electronics simulations and materials digitally and interactively. This medium is expected to serve as an effective solution to overcome the limitations of conventional methods while simultaneously enhancing learning motivation, strengthening digital literacy, and providing a practical, engaging, and easily accessible learning experience anytime and anywhere.

2. Methods

This study adopted the Waterfall development model as the foundational methodology for designing and developing Android-based interactive learning media. This model was chosen because it has clear, systematic stages that are suitable for developing software-based learning media. Several previous studies have also demonstrated that the Waterfall model is effective in educational software development, as it provides a transparent structure and facilitates replication in subsequent studies [25].

The Waterfall model consists of five sequential phases: (1) requirements analysis, (2) design, (3) development, (4) testing, and (5) operation and maintenance [26]. Each phase was carried out thoroughly to ensure the instructional media was pedagogically grounded, technically functional, and aligned with the learning goals of vocational high school students. Figure 1 illustrates the Waterfall model.

Figure 1. Waterfall development model

2.1. Requirements Analysis

A comprehensive analysis was conducted during the initial phase to identify the instructional requirements and technical specifications necessary to develop the interactive learning media. This process involved classroom observations, analysis of curriculum documents, and informal interviews with SMK Negeri 5 Padang subject teachers. Core competencies and intended learning outcomes (LOs) for Grade 10 students in the subject *Fundamentals of Electronics Engineering* (*Dasar-Dasar Teknik Elektronika*) were identified. Referring to the national Merdeka Curriculum, these competencies were structured into a Learning Objectives Flow (LOF) to ensure alignment between instructional content and competency-based education standards.

The hardware requirements specified included Android-based devices (minimum version 5.0), a computer workstation for development, and a smartphone emulator for application testing. The software tools employed in the development process were as follows:

1) Adobe Illustrator CS6 for asset creation,
2) Microsoft Word 2019 for content preparation,
3) Adobe Flash CS6 and ActionScript 3.0 are used to program the application.

Learning topics were selected based on their relevance to curriculum guidelines and instructional needs in the classroom. The content covered three principal areas:

1) Electrical measurement tools and techniques,
2) Basic electronic components and circuits,
3) Instrumentation principles in electronics.

2.2. Design

After the needs analysis stage, the project proceeds to the design phase, which focuses on translating specifications into structured instructional and technical designs for interactive learning media. In this process, the system interface is designed systematically, taking into account aesthetics, comfort, and ease of use, to provide an enjoyable experience while increasing user interest in the developed application [27]. Several key design components have been developed, such as:

1) A detailed storyboard outlining the flow of content and user interactions,
2) Flowcharts to describe navigation pathways and learning sequences,
3) User interface (UI) mock-ups with intuitive navigation schemes,
4) Visual and multimedia elements, including illustrations, icons, and layout prototypes.

Adobe Illustrator CS6 was used to develop all graphic and visual elements, including UI mock-ups and illustrations. Microsoft Word 2019 was utilized to structure and format textual content, including learning materials, instructions, and narration scripts. The multimedia elements were selected based on their instructional relevance and cognitive support functions. These included narrated audio, instructional videos, interactive quizzes, and animated demonstrations of abstract technical concepts.

The design phase yielded a comprehensive blueprint that guided the subsequent development stage, ensuring consistency among educational objectives, user experience, and technological implementation.

2.3. Development

At this stage of development, all previously designed assets and instructional structures are converted into a fully functional, interactive application [28]. Adobe Flash CS6 served as the primary development platform, and ActionScript 3.0 was employed as the programming language to support interactivity, animation, and multimedia integration.

Media development is carried out using Adobe Flash CS6 and ActionScript 3.0 [29]. Although this software is relatively old and no longer widely used in the commercial industry, there are several reasons for its selection, namely:

1) The features in Flash CS6 and ActionScript are still capable of meeting the animation, interactivity, and audio-visual integration requirements of this learning media.
2) The availability of the latest software and device compatibility in vocational schools remains limited, making the use of Flash CS6 a more realistic option for the context of this research.

The development process included the following key activities:

1) Assembling the interface and screens,
2) Embedding multimedia (audio narration, simulations, videos),
3) Programming navigational buttons and interactions,
4) Integrating quizzes and feedback systems.

The development phase concluded with a fully operable version of the instructional media, ready for validation and further usability testing. The outcome of this phase served as the prototype for subsequent evaluation stages.

2.4. Testing

Upon completion of the application development, a comprehensive two-stage testing and validation process was implemented to evaluate the feasibility, usability, and instructional quality of the Android-based interactive learning media [30]. This phase encompassed expert and user validation, each designed to address different dimensions of effectiveness.

Expert validation focused on evaluating the pedagogical soundness and technical quality of the instructional content and media design through expert judgments. In contrast, user validation (practicality testing) emphasized the user experience, ease of use, and perceived learning support reported by the target student group. These procedures ensured the product met the required standards from both instructional design and end-user perspectives.

The research subjects consisted of two groups:

1) Expert validators (n = 4), including:
   - 2 media experts (lecturers/teachers experienced in instructional design and multimedia).
   - 2 subject matter experts (lecturers/teachers in the field of electronics).
2) Vocational students (n = 15) who were respondents in the media practicality test.

The selection of validators and students was conducted purposively by considering expertise (for validators) and direct involvement in electronics learning (for students).

The research instrument used was a questionnaire that was systematically compiled based on the assessment aspects for each validator. The compilation of the questionnaire began with formulating indicators that aligned with the research objectives, specifically evaluating the quality of learning media in terms of content, design, and practicality of use. Next, the instrument grid was first validated through expert judgment by expert lecturers so that each statement item was in accordance with the construct being measured. After obtaining input from the validators, the instrument was adjusted and revised before being used in the trial phase. The instrument grid consisted of:

1) Media expert instrument: ease of use and navigation, visual appearance, media integration, and media benefits.
2) Material expert instrument: relevance of material, organization of material, language, and effect on learning strategies.
3) User practicality instrument (students): ease of use, material presentation, appearance, and effect on learning strategies.

The evaluation framework then uses a combination of Likert-based assessment instruments, quantitative analysis, and predetermined interpretation scales, providing a strong basis for determining the overall feasibility of the media developed as a digital learning tool in a vocational education setting. The following details outline the testing process (Sections 2.4.1 and 2.4.2).

2.4.1. Expert Validation

The expert validation process was categorized into two primary components: material validation and media validation. Material validation focused on four critical aspects that ensured the instructional content met educational standards and pedagogical principles. The first aspect was the *relevance of content*, which examined the alignment of the material with established learning objectives and the national curriculum. This was followed by the *organization of content* and the assessment of the logical sequencing, coherence, and structure of the presented materials. The *language use* dimension evaluated the textual content's clarity, appropriateness, and readability, ensuring it was suitable for Grade 10 learners. Finally, the *impact on the learning strategy* aspect was analyzed to determine the extent to which the instructional materials supported active learning, conceptual reinforcement, and pedagogical effectiveness.

Media validation was similarly structured around four essential dimensions of usability and instructional design quality. The *navigation and usability* component evaluated whether the application interface facilitated intuitive interaction and was user-friendly, thereby enhancing student engagement. The *visual design* aspect evaluated the aesthetic quality, visual consistency, and layout organization of the media elements. The *integration of media* considered the technical coherence and effectiveness of embedded multimedia components, such as audio narrations, animations, and interactive features.

Lastly, the *instructional value* component focused on how much the media enhanced student comprehension, motivation, and overall learning outcomes. Four experts conducted these validations: two university lecturers and two vocational school teachers, who provided scores for each aspect using a standardized rubric.

2.4.2. User Validation

User validation, also known as practicality testing, was conducted with 15 students from the Electronics Engineering Department at SMK Negeri 5 Padang. During this phase, students independently explored the application and completed a structured questionnaire to evaluate four key aspects: *ease of use*, *material presentation*, *application interface/visual appearance*, and *impact on learning strategies*.

The evaluation instruments for both expert and user validation employed a five-point Likert scale, where respondents rated each item based on the following categories: Strongly Agree (score = 5), Agree (4), Somewhat Agree (3), Disagree (2), and Strongly Disagree (1). The total average score for each evaluation aspect was calculated using the formula (1):

$$\bar{x} = \frac{\Sigma x}{N} \tag{1}$$

Where $\bar{x}$ is the average score, Σx represents the total score across all items, and N is the number of indicators assessed.

The study adopted a classification system based on a five-point scale with statistical parameters to interpret the average score qualitatively [31], [32]. The average score obtained is classified using a five-point scale with the following criteria: a score of 4.21–5.00 was classified as *Highly Feasible*, 3.41–4.20 as *Feasible*, 2.61–3.40 as *Less Feasible*, 1.82–2.60 as *Not Feasible*, and 0.00–1.81 as *Highly Not Feasible*.

In addition to average score analysis, a percentage-based feasibility calculation was performed to support comparative evaluation. The feasibility percentage was obtained using the formula (2) [33]:

$$Feasibility\ Percentage = \frac{Score\ Obtained}{Maximum\ Score} x100\% \tag{2}$$

The resulting percentage was then matched against predefined feasibility categories [34]. A product scoring between 81–100% was considered *Highly Valid*, 61–80% Valid, 41–60% Moderately Valid, 21–40% Not Valid, and 0–20% *Highly Not Valid*.

These quantitative analyses provided a robust foundation for determining the overall validity and usability of the developed media. The dual validation strategy, combining expert judgment with student feedback, ensured that pedagogical effectiveness and learner satisfaction were rigorously assessed and met the minimum standards for educational technology interventions.

2.5. Operation and Maintenance

The maintenance phase involves activities related to improvements and corrections of errors not identified in the previous stages. This stage ensures continuous maintenance and development to correct the mistakes, add features, and adapt to external changes after implementation [35]. Maintenance activities include providing ongoing technical support, resolving issues during application use, and developing additional features tailored to user needs [36]. However, this phase was not carried out in the present study, as the research scope was limited to the development process and feasibility testing of the learning media.

3. Results

3.1. Application

This phase details the transformation of conceptual frameworks and design prototypes into a fully operational interactive learning media application. The development process was guided by user-centered design principles to ensure the final product is functional, intuitive, and engaging for its primary users, namely students and educators in the vocational electronics engineering domain. The application facilitates active learning by integrating multimedia elements and interactive features that support a range of learning styles. Figure 2 illustrates the initial user interface that is encountered upon launching the application, reflecting the careful attention to usability and aesthetic appeal in its design.

3.1.1. Intro Page Display

The introductory page serves as the application's gateway, offering users a welcoming and informative first impression. It is strategically designed to provide clear navigation cues and contextual information, establishing the purpose and scope of the instructional media. As shown in Figure 2, the intro page features a clean layout with visually balanced elements that enhance readability and user engagement. Key components include the application title, logo, and a concise overview that orients users before they proceed to the content modules. This design aims to minimize cognitive load and foster a positive user experience from the outset, critical for sustained interaction and effective learning outcomes.

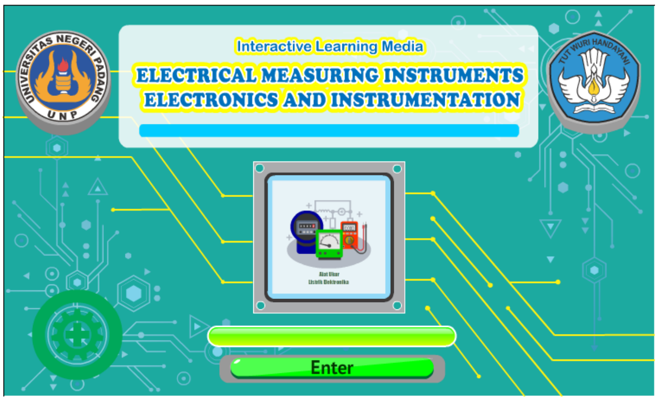


Figure 2. Intro page

3.1.2. Main Menu Display

The main menu serves as the central navigation hub of the application, offering users straightforward access to its core functional modules. It is designed to promote seamless interaction by grouping key instructional components, including the Learning Objectives menu, which represents the Learning Outcomes (CP) and Learning Objectives (TP) menus, the material menu, the practicum menu, and the evaluation menu, into clearly labeled, easily identifiable buttons. This organization facilitates efficient task execution and supports learners in navigating the curriculum logically and sequentially. Additionally, the top section of the main menu screen includes auxiliary navigation buttons such as Guide, Settings, Profile, and Exit, which are accessible at any point during the user's engagement with the application.

Upon activation, these buttons display pop-up pages overlaying the main menu, allowing users to access supplementary functions without losing their current context. This design choice enhances usability by minimizing unnecessary screen transitions and cognitive disruptions. Figure 3 illustrates the main menu interface, showcasing its clean, user-friendly layout that strikes a balance between visual clarity and functional richness. The integration of intuitive navigation elements within this screen underscores the application's emphasis on providing a learner-centered experience that supports autonomy and ease of use.

Figure 3. Main menu display

3.1.3. Learning Objectives Page Design Display

The Learning Objectives Page, which represents Learning Outcomes (LO) and Learning Objectives (LO), is a fundamental element in the learning media developed for the subjects of Electrical Measurement, Electronics, and Instrumentation. This page is meticulously designed to communicate the targeted competencies and specific goals that students are expected to accomplish upon completing the instructional activities embedded in the media. Presenting these outcomes in a clear, organized, and accessible format ensures that learners are well-informed about the expected achievements, which can significantly enhance their motivation and engagement throughout the learning process.

Beyond simply listing learning objectives, the Learning Objectives Page serves a strategic pedagogical function by providing an overarching overview of the subject matter. This contextualization enables students to grasp the scope and sequence of the material, thereby facilitating cognitive structuring and enhancing content retention. By framing the instructional content within a transparent learning pathway, the page supports learners in aligning their efforts with clearly defined goals, contributing to more focused and purposeful study sessions.

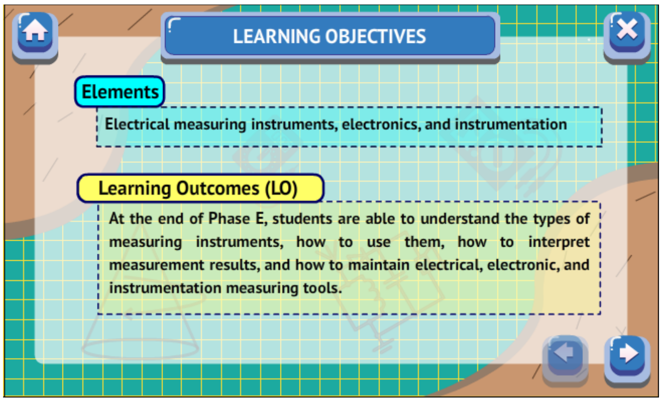


Figure 4. Learning objectives page display

Figure 4 illustrates the layout of the learning objectives page, showing how the content is visually structured for optimal readability and user experience. The design emphasizes clarity using segmented sections and legible typography, reinforcing the instructional intent of guiding students systematically through the learning objectives before delving into detailed material.

3.1.4. Material Page Display

The material page is aligned with the Learning Outcomes (CP) and Learning Objectives Flow (ATP) outlined in the curriculum. Figure 5(a) shows the material menu page design, while Figure 5(b) presents the content of the material page. To improve usability, the material page features navigation buttons, including "back" and "next," which facilitate smooth transitions between pages and sections. These interactive elements contribute to an efficient learning experience by allowing students to control the flow of their study sessions and revisit previous content as needed. The overall design, shown in Figure 5, balances aesthetic appeal with functional navigation, optimizing learner accessibility and instructional clarity.

(a) (b)

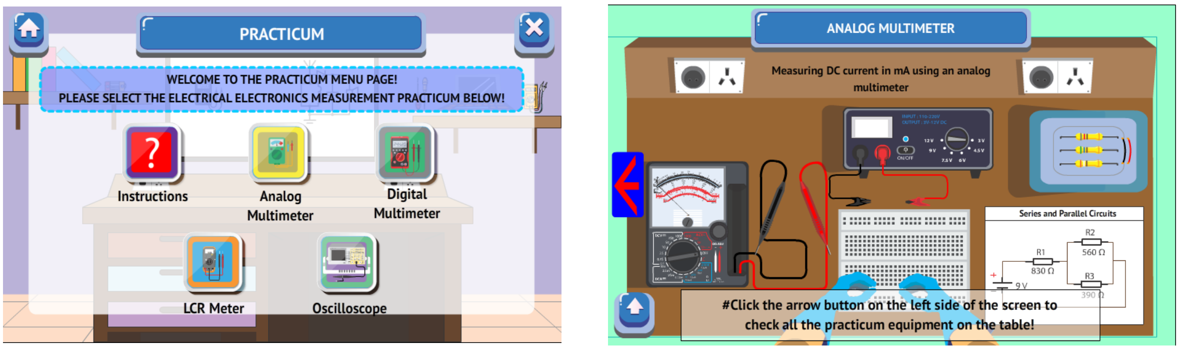
Figure 5. Pages: (a) material menu, (b) learning content

3.1.5. Practicum Page Display

The practicum page represents a vital component of the interactive learning media, designed to provide students with virtual hands-on experience in using various electronic measuring instruments. This feature simulates practical activities that typically require physical laboratory equipment, enhancing accessibility and enabling experiential learning within a digital environment.

The practicum section comprises four key activities that allow learners to engage with widely used tools in electronics engineering: the analog multimeter, digital multimeter, LCR meter, and oscilloscope. Each simulation is carefully crafted to replicate the operational procedures and measurement techniques of these instruments, offering a realistic and pedagogically sound practice platform.

Figure 6(a) illustrates the practicum menu page, which organizes these simulation activities in a straightforward and user-friendly interface, enabling students to select and navigate between different practical modules with ease. Meanwhile, Figure 6(b) illustrates the simulation interface of the practicum, showcasing interactive elements that facilitate active learner participation and reinforce technical competencies. This hands-on approach through virtual practicum supports the development of practical skills and bridges the gap between theoretical knowledge and real-world application.



a) (b)

Figure 6. Pages: (a) practicum menu, (b) practicum simulation

3.1.5. Evaluation Page Display

The evaluation page is essential for assessing learners' comprehension and mastery of the instructional content. It consists of multiple-choice questions, each offering four answer options labeled A, B, C, and D. This format facilitates objective assessment while providing immediate feedback on student performance.

Users can select their responses interactively, and upon completion of the assessment, the evaluation score is calculated and displayed, allowing learners to gauge their understanding and identify areas for improvement. The design emphasizes ease of use and clarity to ensure the evaluation process is straightforward and accessible.

Figure 7(a) illustrates the data entry interface where users input necessary details before commencing the evaluation. Figure 7(b) presents the question interface, showcasing the layout of the multiple-choice items and answer options within the evaluation module. This evaluative feature reinforces learning outcomes and supports formative assessment practices within the interactive media.

(a) (b)

Figure 7. Pages: (a) data entry, (b) evaluation questions

3.2. Results of Validation Testing

The validation of interactive learning media, which includes content validation, media validation, and practicality testing, was conducted systematically to ensure its quality and suitability for implementation. This process involved expert validation and user practicality testing, with feedback from each stage used to refine and improve the media. Following revision based on expert recommendations, the media was revalidated to confirm that all suggested improvements had been effectively incorporated. The objective of this comprehensive validation was to produce a learning tool that is pedagogically sound, technically robust, and practically feasible for the target learners.

3.2.1. Validation Results by Experts

The validation of the interactive learning media, encompassing both content and design aspects, was systematically carried out by four expert validators: two university lecturers and two vocational school teachers. Feedback from these experts was used to revise and improve the initial version of the media. The revised application was revalidated after incorporating the suggested improvements to ensure the refinements aligned with expert recommendations. This validation process was critical to confirming the content's instructional integrity and the media's technical suitability before implementation. The validation results are summarized in Table 1.

Table 1. Summary of Expert Validation Results

Validation Type	Aspects Evaluated	Mean Score	Feasibility Category
Material	Relevance of Content	4.80	Highly Feasible
	Content Organization	4.73	Highly Feasible
	Language Use	4.25	Highly Feasible
	Impact on Learning Strategy	4.50	Highly Feasible
Media	Navigation and Usability	4.50	Highly Feasible
	Visual Design	4.75	Highly Feasible
	Media Integration	4.50	Highly Feasible
	Instructional Value	4.65	Highly Feasible
Overall Mean		**4.58**	**Highly Feasible**

Based on Table 1, the results of expert validation of the learning media show a very high level of feasibility in all aspects. The material validation covers four essential elements. *The material received the highest score of 4.80, confirming that the content presented aligns* with the curriculum requirements. *The organization of the material* received a score of 4.73, indicating a coherent and easy-to-understand presentation structure. The aspect *of impact on learning strategies* received a score of 4.50, showing that this media is capable of supporting a more active and effective learning approach.

Meanwhile, the aspect *of language use* achieved a score of 4.25, remaining in the highly feasible category and demonstrating good comprehensibility. In the media validation results, the visual aspect scored 4.75, showing an attractive and consistent appearance, while the instructional value reached 4.65, confirming its significance in the learning process. The aspects of navigation, usability, and media integration all scored 4.50, reflecting ease of use and harmony between media sections. Overall, the media received an average score of 4.58 and was categorized as "Highly Suitable," indicating the success of the development in producing learning media that is not only technically sound but also pedagogically relevant.

3.2.2. Practicality Results by Students

The results of the practicality test for the interactive learning media developed were obtained through a student response questionnaire after the media had been validated and improved based on expert validator input. This test involved 15 vocational school students as respondents, each of whom provided an assessment of the aspects of ease of use, material presentation, visual appearance, and impact on learning strategies. The questionnaire data was then converted into percentages to determine the practicality level of the media. The percentages obtained were used as the basis for determining the practicality category of the interactive learning media developed. The practicality test results, as illustrated in Figure 8, show that the interactive learning media developed was considered very feasible by student users in various evaluation dimensions.

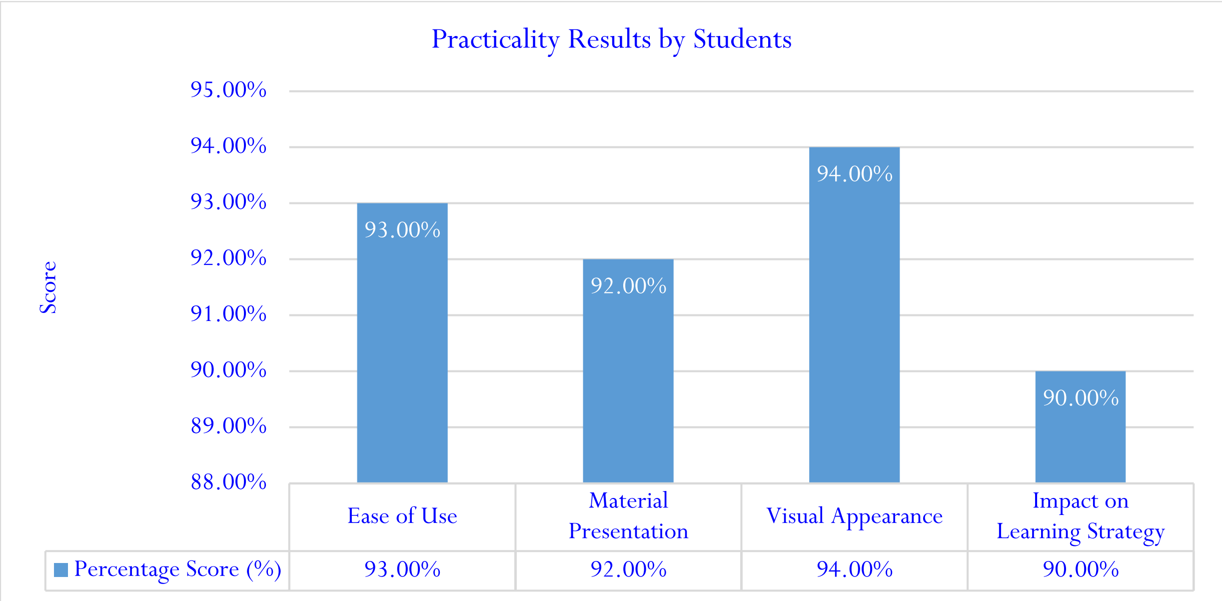


Figure 8. User practicality results

Based on Figure 8, the results of the practicality test by students further reinforce this finding. The visual display aspect received the highest score of 94%, indicating that the media design is visually appealing and capable of enhancing learning motivation. Ease of use reached 93%, confirming that this media is intuitive and easy to operate by students. The presentation of material scored 92%, indicating that the content is clear, structured, and well-suited to the learning needs in the field of electronic engineering. Meanwhile, the aspect of impact on learning strategies scored 90%, indicating the media's contribution to supporting active and student-centered learning. Overall, this application was considered very practical by students, as reflected not only in the high average score but also in a more interactive, meaningful, and contextual learning experience.

4. Discussion

The development and validation of Android-based interactive learning media for vocational electronics education in this study shows alignment with the latest international paradigm in educational technology, particularly the learner-centered approach, multimedia integration, and the application of constructivist learning principles. The results of expert validation and student practicality tests provide strong evidence of the media's feasibility, usefulness, and instructional value, thereby reinforcing its potential as an effective learning tool.

4.1. Validation Outcomes and Pedagogical Implications

Findings from expert validation confirm that this media has met the principles of good instructional design, as recommended in Merrill's *First Principles of Instruction* [37]. The relevance of the content and the regularity of the presentation support deeper cognitive engagement [38], while the integration of active learning strategies aligns with the constructivist view [39]. This is reinforced by Wibawanto's (2022) research, which shows that interactive multimedia simulations can improve the practical learning outcomes of vocational students [40].

From a visual design and usability perspective, this media adheres to the heuristic principles of usability [41] and aligns with Mayer's Cognitive Theory of Multimedia Learning (CTML) [42], which emphasizes the importance of multimodal presentation through text, images, animation, and interactivity. Thus, the developed media not only support multimodal learning but also provide opportunities for personalizing the learning experience, in line with global trends in digital education. These findings are reinforced by recent research, such as that conducted by Nurhikmah (2022), which shows that Android-based multimedia learning media can improve learning effectiveness in vocational schools [43]. Similarly, Gustina et al. (2024) reported that the use of interactive Android multimedia in welding materials can significantly increase students' interest and learning outcomes [44]. Therefore, this media is not only consistent with classical pedagogical principles but also relevant to the latest innovations in learning technology.

4.2. Practicality and Learner Engagement

Positive responses from students indicate that this medium is easily accessible and encourages learning engagement. Intuitive interface factors and a pleasant user experience play a crucial role in increasing motivation and supporting self-regulated learning [45], [46]. These findings are also in line with the Technology Acceptance Model, which confirms that perceptions of ease and usefulness influence vocational students' adoption intentions toward virtual laboratories [47].

In addition, clear and organized content presentation demonstrates good alignment with learning objectives, which is crucial in vocational education. Wu (2024) emphasizes that the use of multimedia in vocational education is directly correlated with increased learning satisfaction [48]. However, further improvements in metacognitive scaffolding and feedback mechanisms are still needed to optimize instructional effectiveness.

4.3. Contribution to Vocational Engineering Education

Interactive practical simulations integrated into this media provide a solution to the limited access to physics laboratories in many vocational schools [49]. Through safe, flexible, and repeatable virtual experiences, students can develop practical skills with the support of Kolb's Experiential Learning framework [50], [51]. This finding aligns with recent research demonstrating that virtual laboratories are effective in supporting the mastery of practical skills across various disciplines, including renewable energy [52].

In a global context, Bödding et al. (2025) demonstrated, through a systematic review, that the use of mixed reality in vocational education improves cognitive, affective, and behavioral learning outcomes [53]. Ghosh & Ravichandran (2024) also highlight the role of new technologies such as AI, IoT, gamification, and big data in driving pedagogical transformation in modern vocational education [54]. Thus, the media developed in this study contributes to the direction of global transformation in technical vocational education, which is increasingly oriented towards digitization, interactivity, and personalization of learning.

4.4. Limitations and Future Directions

Despite the positive outcomes, the main limitation of this study is the relatively small sample size, which has implications for the limitations of generalization. Additionally, this media was developed using Adobe Flash CS6, a software that is no longer widely supported, which may compromise its long-term sustainability. Therefore, a transition to modern platforms based on HTML5, Android native, or Unity is recommended, allowing the media to be more adaptable to technological developments. Beyond sample size, external validity is limited by the single-site, purposive sampling and short exposure. The evaluation relied primarily on self-report questionnaires and expert judgments. Device heterogeneity and classroom infrastructure were not controlled, and accessibility compliance was not systematically examined.

Future research should be conducted with larger and more diverse samples, as well as a longitudinal approach, to evaluate the long-term impact on learning outcomes and skill retention. The integration of adaptive learning features, learning analytics, and online collaboration can also strengthen the personalization and social aspects of learning [39]. Zou (2025) emphasizes the importance of 21st-century digital learning readiness and the need for inclusive pedagogical innovation [55]. Additionally, Álvarez Ariza (2024) demonstrates that integrating mobile learning, practical experiments, and content production by students can enhance motivation, self-efficacy, and academic outcomes [56].

The limitations of this study lie in the aspects of licensing and access to media distribution. Although learning media have been developed and can be used by other educators, their distribution remains limited to the scope of this study. Therefore, further research is recommended to expand access by providing media on open platforms and including clear usage licenses (e.g., Creative Commons), so that the media can be utilized more widely and sustainably.

5. Conclusion

This study designed, developed, and validated an Android-based interactive learning application for Fundamentals of Electronics Engineering in SMK settings using the Waterfall model. Expert reviews indicated high feasibility across content, visual/instructional design, and usability, while student responses showed strong practicality with respect to engagement, clarity of material presentation, and the usefulness of simulation-supported practicum activities. These results indicate acceptability and instructional promise, as reflected in feasibility and practicality findings, without claiming demonstrated learning gains.

While limited by a relatively small, single-site sample and a legacy authoring stack, the work provides a transparent blueprint for curriculum-aligned, simulation-rich resources in resource-constrained classrooms. Practically, the application can serve as pre-lab preparation or targeted remediation to support conceptual understanding of measurement instruments. Future studies should migrate the toolchain to modern, maintainable platforms (e.g., HTML5, Android-native, or Unity), employ multi-site and longitudinal designs with pre–post and retention measures, and examine accessibility, implementation fidelity, and analytics-based usage patterns. Such steps will clarify effectiveness while supporting wider, sustainable adoption.

DECLARATIONS

Author Contributions

Jefri Wahyudianto: Conceptualization, Formal Analysis, Methodology, Software, Investigation, Data Curation, Visualization, Writing - Original Draft, Writing - Review & Editing. **Ilmiyati Rahmy Jasril:** Supervision, Validation, Formal Analysis, Writing - Review & Editing. **Juan Luis Cabanillas García:** Validation, Writing - Review & Editing. **Constantina Corazon Argyrakou:** Writing - Review & Editing. All authors have read and approved the final version of this manuscript.

Acknowledgments

The authors extend their sincere appreciation to all parties who have supported and contributed to the development of this research. Special thanks are directed to the Faculty of Engineering, Universitas Negeri Padang, for providing the facilities and resources that enabled the successful implementation of this study.

Ethical Approval

This research was conducted in accordance with the ethical standards and guidelines established by the institution. Before data collection and user testing, ethical clearance was obtained from the Research Ethics Committee of Universitas Negeri Padang (UNP), Indonesia. The research involved no physical or psychological harm, and all participants were provided with clear information regarding the objectives, procedures, and their rights, including the right to withdraw at any time without penalty.

Informed consent was obtained from all participants, including expert validators and student respondents, before their involvement in the study. All data were collected anonymously and treated with strict confidentiality to ensure privacy and integrity. The development and testing of the interactive learning media adhered to ethical standards concerning digital content, user interaction, and educational interventions.

Funding

This study was conducted independently and received no external funding from any party. All aspects of the research, including data collection, analysis, and manuscript preparation, were carried out independently without the involvement of grants or sponsorships.

Competing Interests

The authors declare that they have no conflicts of interest.

Generative AI and AI-Assisted Technologies Statement

In the final stages of preparing this manuscript, the author(s) utilized Grammarly to improve readability, coherence, and linguistic precision. Specifically, Grammarly was employed to identify and rectify grammar, punctuation, sentence structure, and style issues. The author(s) take full responsibility for the accuracy, content, and conclusions presented in the manuscript, with the final version being thoroughly vetted for clarity, consistency, and scholarly integrity.

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AUTHOR BIOGRAPHIES

Jefri Wahyudianto holds a Bachelor's in Electronics Engineering Education from the Faculty of Engineering, Universitas Negeri Padang, Indonesia. His current research focuses on developing interactive learning media based on Android for Basic Electronics Engineering to enhance students' understanding of technical and abstract concepts. He has a strong interest in integrating digital technology into education and is committed to implementing innovative methods to improve the quality of teaching in electronics engineering.

Ilmiyati Rahmy Jasril is a lecturer in the Electronics Engineering Education Study Program at Universitas Negeri Padang. She has published extensively in the fields of vocational education and electronics education. Her research interests include the development of learning methods and innovations in educational media, as well as microcontroller-based projects aimed at enhancing the teaching and learning of electronics.

Juan Luis Cabanillas García is a postdoctoral researcher and professor at the Universidad de Extremadura, where he teaches in the Department of Education Sciences and focuses on Research Methodology and Educational Diagnosis. He holds a Ph.D. in Education, a Master's degree in Research in Teacher Training and ICT, and a degree in Physical Education. He was awarded the Margarita Salas postdoctoral fellowship and has conducted international research stays in Portugal and Honduras. His research interests center on higher education, the well-being of university students, leisure and free time, and educational inclusion. He has participated in several national and international research projects and actively collaborates with institutions and researchers in Latin America and Europe.

Constantina Corazon Argyrakou is a Ph.D. candidate in Cultural Geography at Harokopio University of Athens and a lecturer at Aegean College, Greece. She has over 10 years of experience in elementary education, with a specialization in music gamification. She has published extensively in the fields of multicultural and interdisciplinary education and has received recognition from the Greek Writers' Society for her scientific contributions. Her current research focuses on cultural geography and migration.