

Development and User Acceptance Evaluation of a Gamified Virtual IoT Laboratory for Students at SMKN 1 Sambeng

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ABSTRACT

Objective: This study develops and evaluates gamification-based learning media integrating a virtual Internet of Things (IoT) laboratory for Computer and Network Engineering students at SMKN 1 Sambeng, and examines user acceptance of the application using the Technology Acceptance Model (TAM). **Method:** This Research and Development (R&D) study follows the ADDIE model—Analysis, Design, Development, Implementation, and Evaluation. The learning media was validated by two media experts, and user acceptance was assessed through a TAM-based questionnaire administered to 51 students after implementation. **Results:** Validation results show the media is valid and suitable for IoT instruction, with a total score of 74 out of 100 (average 3.70), comprising Functional Suitability (4.33), Usability (4.00), and Reliability (3.25). Based on TAM evaluation, 64.7% of students found the application useful for supporting learning, while 54.9% found it easy to use. These findings indicate the application is perceived as useful and easy to use in teaching basic IoT concepts within the Computer and Network Engineering program. **Novelty:** This study integrates Gamification-Based Learning with a virtual IoT laboratory environment in a single application designed for vocational education, producing a validated, well-received learning media product suitable for implementation at SMKN 1 Sambeng.

INTRODUCTION

The swift advancement of digital technology has fundamentally changed how knowledge is accessed, constructed, and applied across nearly every sector of modern society, including education. The advent of Industry 4.0, marking the fourth industrial revolution, has expedited structural changes in the labor market, increasing the demand for graduates equipped with advanced digital competencies (Kipper et al., 2021; Zhang et al., 2024). As a result, schools and universities around the world have undertaken large-scale digital transformation initiatives, embedding information and communication technology (ICT) into teaching practices to develop the competencies required by today's workforce (Valverde-Berrocoso et al., 2022; Zou et al., 2025). Despite these widespread efforts, evidence from the literature consistently shows that ICT integration alone does not automatically result in meaningful improvements in learning outcomes. Research indicates that the impact of technology on academic achievement ranges from small to moderate, depending heavily on how the technology is used pedagogically, rather than merely on the presence of digital tools (Bond et al., 2020; Timotheou et al., 2023). The gap between technology adoption and genuine educational benefits underscores the urgent need for carefully designed, evidence-based learning media that move beyond conventional teacher-centered approaches and actively engage students in meaningful, interactive learning experiences (Ningsi & Hartono, 2025).

This issue is especially pronounced in vocational education, where equipping students with industry-relevant competencies requires more than theoretical knowledge alone—it also requires genuine, hands-on practical experience. Industry 4.0 has driven

the rapid expansion of the Internet of Things (IoT) as a foundational technology across various sectors, from manufacturing to telecommunications, creating an ever-widening skills gap between what current vocational graduates possess and what industry requires (Chakraborty et al., 2023; Haqiq et al., 2026; Qiu et al., 2025). Vocational schools, including those offering Basic Computer Networking and Telecommunications Engineering programs, are anticipated to furnish students with the ability to assemble IoT devices, configure wiring circuits, and develop microcontroller programming skills (Annisa et al., 2024; Habibi, 2025; Vrbančič & Kocijančič, 2024; Wildan Habibi & Asto Buditjahjanto, 2024). These competencies are inherently practical and spatial in nature, requiring learners to visualize abstract system architectures and interact with hardware configurations that are difficult to convey through conventional teacher-based instruction alone (Demir et al., 2019). Compounding this challenge, many vocational education institutions lack the physical components and specialized equipment needed to conduct hands-on IoT laboratory sessions, forcing educators to rely more heavily on didactic delivery methods that offer limited opportunities for experiential learning (Badshah et al., 2024; Ghashim & Arshad, 2023; Kwasi Dake et al., 2023; Suwastika et al., 2025). The result is a persistent mismatch between the competencies students acquire and the practical skills demanded by industry—a gap that undermines the fundamental purpose of vocational education.

Virtual laboratory technology has surfaced as a promising approach to closing the divide between classroom-based instruction and direct practical learning, particularly in contexts where physical equipment is expensive, scarce, or potentially hazardous. By enabling students to visualize, manipulate, and test virtual representations of real hardware systems through Graphical User Interface (GUI)-based environments, virtual laboratories provide contextual and experiential learning opportunities that cannot easily be replicated by conventional classroom settings (L. Li et al., 2024; Reyes et al., 2024; Sharifkhani et al., 2025). Most importantly, virtual platforms allow learners to independently and safely explore IoT component configuration, circuit assembly, and programming tasks, without the risk of equipment damage or workplace accidents that could otherwise inhibit exploratory learning behavior (Almutairi et al., 2024; Badshah et al., 2024; Deriba et al., 2024; J. Li & Liang, 2024; YAMAGISHI et al., 2025). Recent research examining the application of remote and virtual IoT laboratories has confirmed that such environments can effectively enhance students' practical understanding of networking concepts and system integration when designed with pedagogically sound interaction principles (Alkhalidi et al., 2016; Masril et al., 2024; Savu-Jivanov et al., 2026). Nevertheless, the majority of prior virtual laboratory research has concentrated on tertiary education contexts or general science fields, and has not yet integrated interactive IoT device simulations within a learning environment specifically designed with gamification for secondary vocational education.

Game-Based Learning (GBL) and gamification are complementary pedagogical strategies that address the motivational limitations of conventional teaching by embedding game elements—such as points, badges, level-based challenges, and narrative progression—into educational activities. A growing body of meta-analytic studies shows that carefully designed gamified learning systems—featuring elements such as progress tracking, immediate feedback, and story-based tasks—can substantially strengthen students' engagement, tenacity, and self-motivation (Furkan Kurnaz & Koçtürk, 2025; L. Li et al., 2024; M. Li et al., 2023). Gamification activities have shown

particular effectiveness in STEM-related subjects, where engagement and conceptual understanding are closely intertwined, and where the active problem-solving orientation of game mechanics naturally aligns with the inquiry-based competencies demanded by these disciplines (M. Li et al., 2023; Soriano-Sánchez et al., 2026; Videnovik et al., 2023). Furthermore, recent research on gamification development processes has established the ADDIE model – consisting of the Analysis, Design, Development, Implementation, and Evaluation phases – as a systematic and flexible framework well suited to integrating pedagogical principles with technological innovation in the design of educational media (Shi et al., 2026; Tsagaris & Chatzikyrkou, 2026). Although prior studies have explored gamification and virtual simulation as separate interventions, or combined them using commercial game engines or VR platforms (Güvenç et al., 2026; Sakkas et al., 2025), or developed gamification for basic electronic circuit concepts without an IoT context (Weng et al., 2024), research applying a drag-and-drop GUI-based IoT circuit assembly environment within a gamification framework built on a lightweight native graphics library such as SDL3 – particularly in a vocational education context – remains relatively limited. Existing IoT game development studies also tend to be web-technology-based without a vocational focus (Santos & Seabra, 2024), while gamification development studies in Indonesian vocational schools (SMK) have focused on non-IoT domains such as basic programming and hardware introduction (Arif & Rosyid, 2019; Enstein & Benufinit, 2019). This gap is further reinforced by two recent systematic reviews on gamification in vocational education (Dahalan et al., 2024; Prasetya et al., 2025), which together reviewed 38 empirical studies but did not include a single IoT-themed study.

Therefore, this study addresses a clear and critical gap by developing IoT learning media that integrates Game-Based Learning and a drag-and-drop Virtual Laboratory, built using the SDL3 framework and designed following the ADDIE development model, for students in the Basic Computer Networking and Telecommunications Engineering program at SMKN 1 Sambeng. The originality of this study lies in combining gamification mechanisms with an interactive SDL3-based IoT assembly simulation to provide a contextual and practical learning environment for vocational students. Accordingly, this study is guided by three research questions: (RQ1) How can IoT learning media integrating Game-Based Learning and a drag-and-drop Virtual Laboratory be developed using the ADDIE model? (RQ2) To what extent is the developed learning media feasible based on expert validation of its functional suitability, usability, and reliability? and (RQ3) How do students perceive the developed learning media in terms of perceived usefulness and perceived ease of use after its implementation in a vocational classroom context?.

RESEARCH METHOD

Research Design

This study was conducted through several main stages, including media development using the ADDIE model and technology acceptance evaluation using the Technology Acceptance Model (TAM) instrument. R&D was chosen for its capacity to produce learning products which are legitimate, usable, and successful at enhancing learning quality, while the ADDIE model was selected for its systematic yet adaptable structure in designing technology-based learning media (Ade Rahayu, 2025; Moses Adeleke Adeoye et al., 2024; Spatioti et al., 2022). The flow of the research stages is illustrated in Figure 1.

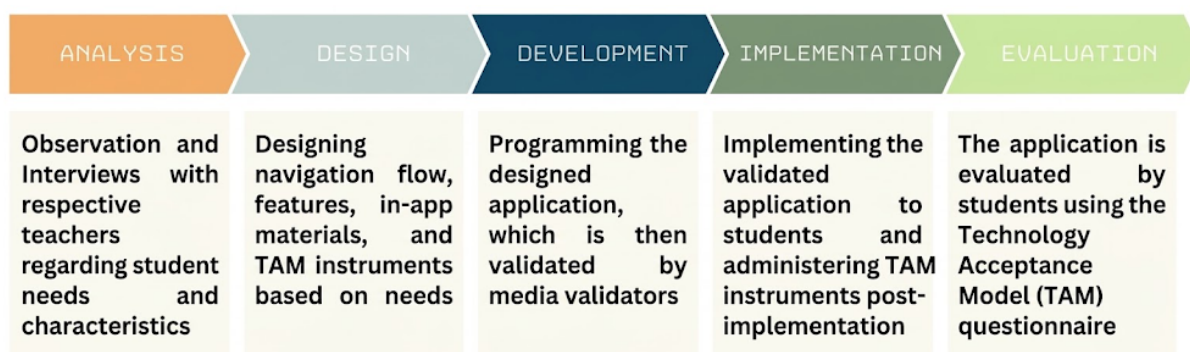


Figure 1. Research Stage Flow

Research Population and Implementation Procedure

The participants comprised 51 tenth graders from the Computer and Network Engineering (CNE) program at SMK Negeri 1 Sambeng, enrolled in the elective Internet of Things (IoT) course, were recruited as respondents in this study. The sampling process employed a saturated sampling method, involving all tenth-grade CNE students taking the basic IoT material as respondents, without a randomization process. This technique was chosen because the population of tenth-grade CNE students was relatively limited and fully accessible, so that total sampling allowed data to be obtained from the entire relevant population rather than only a portion of it. Accordingly, this sample can be considered fully representative of the target CNE student population for media development, as no part of the population was excluded and the respondents' characteristics—including grade level, major, and scope of material studied—were homogeneous and consistent with the research context. Media implementation was carried out in a single session lasting two lesson hours (± 90 minutes). Before the activity began, all students were given an informed consent form as a statement of agreement to participate in the study. Students were subsequently grouped into small teams of 2–3 members per device, each operating one unit of the media collaboratively. During the session, students worked in groups to run the gamified learning media to complete drag-and-drop GUI-based IoT circuit assembly challenges, while the researcher acted as a facilitator, monitoring the activity and providing technical assistance when needed without intervening in the students' exploration process. At the end of the session, students completed the Technology Acceptance Model (TAM) questionnaire to measure their acceptance of the media.

Expert Validation Procedure

The learning media product's validity was assessed by two experts in the media field, selected based on the suitability of their expertise with the technical aspects and implementation context of the product. Details of the expert validators' identities are presented in Table 1.

Table 1. Details of the expert validators' identities

Name	Affiliation	Background	Expert
Assoc. Prof. Dr. Yeni Anistiyasari, S.Pd., M.Kom.	Surabaya State University	C++ Programming	Media Expert
Aris Siswanto Ribowo, S.Kom	SMKN 1 Sambeng	Computer and Network Engineering	Media Expert

The first expert, Assoc. Prof. Dr. Yeni Anistiyasari, S.Pd., M.Kom., was selected to assess the technical programming and software architecture aspects of the media, which was developed using a native graphics library. The second expert, Aris Siswanto Ribowo, S.Kom., was selected for his understanding of CNE students' characteristics and the relevance of IoT material to the vocational curriculum in the field. Both experts conducted their assessments using a questionnaire instrument covering three aspects—functional suitability, usability, and reliability—using a five-point Likert scale (strongly agree = 5, agree = 4, neutral = 3, disagree = 2, strongly disagree = 1) applied to 10 statement items. The validation results were calculated by summing the scores of each item from both validators to obtain the overall total score, with the overall average derived by dividing the total score by (10 items × 2 validators), while the average for each aspect was calculated by dividing the total score of both validators for that aspect by (number of items in the aspect × 2 validators). Drawing on the input gathered, several revisions were made to the product, including: (1) expanding the testing scope from a single scenario to all five learning scenarios, to make the media's performance data more representative; (2) providing the product in installer/executable form to facilitate installation and use across various student devices; (3) adding extended-duration usage testing to ensure the media's stability during prolonged use; and (4) preparing a brief user guide so that students could operate the media independently without requiring special training.

Instrument

The framework for the expert validation instrument was developed based on the ISO/IEC 25010 software quality standard (Systems and Software Quality Requirements and Evaluation), which defines eight software product quality characteristics, including functional suitability, usability, and reliability, which served as the reference for this study. These three characteristics were selected because they align with the objectives of expert media validation—namely, assessing whether the Game-Based Learning and Virtual IoT Lab media features function in accordance with learning objectives (functional suitability), are easy for users to operate (usability), and can run stably without technical disruptions during use (reliability). This instrument was developed adaptively rather than adopted directly from a standardized instrument, drawing on the conceptual definitions of each characteristic in ISO/IEC 25010, which were then elaborated into operational statements adapted to the context of the Game-Based Learning and Virtual IoT Lab media in this study. Details of the expert validation instrument framework are presented in Table 2.

Table 2. Expert Validation Instrument Framework

Nu	Aspect	Statement
1.	Functional Suitability	All features and functions in the Game-Based Learning and Virtual Lab IoT media operate in accordance with the learning objectives.
2.	Usability	The developed media is user-friendly and easy to use.
3.	Reliability	The media runs stably without experiencing any interruptions (crashes/hangs) during use.

Evaluation of ease of use and perceived usefulness of the application was conducted using a questionnaire instrument based on the Technology Acceptance Model (TAM) developed by Davis (1989). The research instrument consisted of a Perceived Usefulness (PU) questionnaire and a Perceived Ease of Use (PEOU) questionnaire. The PU dimension was used to measure the extent to which the application was considered useful in

supporting the IoT learning process, while the PEOU dimension was used to measure the ease with which students could operate the (Al-Adwan et al., 2023; Wang et al., 2025). The TAM instrument statements are presented in Table 3.

Table 3. TAM Instrument Statements

Nu	Aspect	Statement
1	Perceived Ease of Use	I found it easy to learn how to use this app.
2	Perceived Ease of Use	I found this app clear and easy to understand.
3	Perceived Ease of Use	Using this app didn't require much effort.
4	Perceived Ease of Use	I felt proficient using this app.
5	Perceived Ease of Use	Overall, I found this app easy to use.
6	Perceived Usefulness	Using this app improved my work performance.
7	Perceived Usefulness	This app helped me complete tasks more quickly.
8	Perceived Usefulness	This app improved the quality of my work output.
9	Perceived Usefulness	Using this app made my tasks easier.
10	Perceived Usefulness	Overall, I found this app very useful.

Data Collection

Research data collection was conducted from February 2026 to June 2026. The research participants were Grade X students majoring in Computer and Network Engineering who were enrolled in the basic IoT learning course. Prior to the commencement of the study, all participants were given an explanation of the research objectives and procedures, and were then asked to complete an informed consent form as an expression of willingness to participate. Every student was asked to fill out the survey once the lesson had concluded.

Validity and Reliability

The instruments were initially examined for their validity and reliability with the participation of respondents with characteristics similar to those of the research subjects. The validity of the instrument was determined through Pearson Product Moment correlation analysis, while reliability was determined using Cronbach's Alpha coefficient. Validity for an item was confirmed if the Corrected Item-Total Correlation score met 0.30 or higher (≥ 0.30), while items with values below 0.30 were declared invalid; the instrument as a whole was considered reliable if the Cronbach's Alpha coefficient exceeded 0.70.

Reliability Statistics			Item-Total Statistics					
			Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted	
Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items	PU1	35.0588	82.256	.929	.929	.965
			PU2	34.9608	89.918	.829	.803	.968
			PU3	35.0392	87.198	.846	.805	.967
			PU4	34.9412	90.216	.836	.801	.968
			PU5	34.7843	89.093	.915	.919	.965
			PEOU1	34.8824	87.786	.844	.797	.967
			PEOU2	35.0000	88.880	.826	.746	.968
			PEOU3	34.9804	87.140	.848	.841	.967
			PEOU4	35.0196	87.740	.850	.795	.967
			PEOU5	34.9216	86.634	.904	.910	.965

Figure 2. Results of Validity and Reliability Test for PU & PEOU Instruments

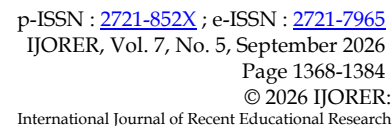


Figure 3. Results of Validity and Reliability Test for Validator Assessment Instrument

Data Analysis

The data collected in this research were examined through descriptive statistical approach with the aid of SPSS software, including calculations of frequency distribution, percentages, central tendency in the form of median, and the range of minimum and maximum values. This technique was chosen because the purpose of the analysis was descriptive-evaluative in nature—describing the level of media feasibility based on expert assessment and the level of user acceptance—rather than testing causal relationships or between-group differences, which would require inferential statistics. Before the descriptive analysis was conducted, the user acceptance score data were first tested for normality using the Kolmogorov-Smirnov test. This test was selected based on the sample size ($n = 51$), which is classified as a large sample; the Kolmogorov-Smirnov test is generally more appropriate for samples larger than 50. Since the test results indicated that the data were not normally distributed ($p < 0.05$), the median was used as the measure of central tendency, and the Perceived Usefulness (PU) and Perceived Ease of Use (PEOU) scores were categorized based on the median value (median split) into two groups to facilitate interpretation of the overall trend in user acceptance levels.

Expert validation scores were analyzed by calculating the average score for each aspect and the overall score on a 1-5 Likert scale, which was then converted into a feasibility percentage and classified according to Riduwan's (2022) score interpretation criteria: 81%-100% (highly feasible), 61%-80% (feasible), 41%-60% (moderately feasible), 21%-40% (less feasible), and 0%-20% (not feasible). The media was declared feasible for use with minor revisions if the score percentage fell within the "feasible" or "highly feasible" category, while scores in lower categories indicated the need for substantial revision before proceeding with trials.

The TAM results were interpreted based on the proportion of respondents in the high-score group (above the median) compared to the low-score group (below the median) for each dimension, with a 50% threshold used as the criterion for determining the direction of the majority respondents' perception. The Perceived Usefulness (PU) dimension was measured through five statement items covering improvement in task

performance effectiveness, task completion speed, quality of work results, ease of task completion, and the overall usefulness of the application. If the proportion of respondents in the high-score group exceeded 50%, the application was categorized as *useful*, indicating that the majority of respondents perceived the application as beneficial for completing their learning tasks; conversely, if the proportion was below 50%, the application was categorized as *useless*, indicating that the majority of respondents had not perceived significant benefit from using the application.

Using the same logic, the Perceived Ease of Use (PEOU) dimension was measured through five statement items covering ease of learning how to use the application, clarity and comprehensibility of the application, the level of effort required, the level of skill perceived by users, and the overall ease of using the application. If the proportion of respondents in the high-score group exceeded 50%, the application was categorized as *easy*, indicating that the majority of respondents found the application easy to use; conversely, if the proportion was below 50%, the application was categorized as *difficult*, indicating that the majority of respondents experienced difficulty operating the application.

RESULTS AND DISCUSSION

Results

This study produced a gamification and IoT virtual laboratory-based learning medium developed using the ADDIE model. The medium was built using Simple DirectMedia Layer (SDL3) with a drag-and-drop GUI interface to simulate IoT device assembly virtually.

Analysis Stage

Based on observations and interviews with CNE teachers at SMK Negeri 1 Sambeng, it was found that current IoT teaching is still dominated by one-way PowerPoint-based methods—not as a pedagogical choice, but due to limited availability of learning media and IoT devices at the school. As a result, students tend to be passive and struggle to understand technical concepts such as sensor-actuator systems, communication protocols, and system integration without hands-on experience, ultimately creating a gap in understanding between teachers and students. On the other hand, the characteristics of CNE students as members of the digital generation show low engagement and concentration with monotonous teaching methods, along with a greater tendency toward gaming activities, indicating a need for more interactive, visual, and gamification-based learning stimulation. This condition is reinforced by the demands of the Merdeka Curriculum for the CNE program, whose learning outcomes focus on developments in computer networking technology and telecommunications devices as benchmarks for content, material depth, and the form of media interaction. Based on this analysis, an urgent need was identified for alternative learning media capable of replacing the function of physical IoT components—thereby reducing component procurement costs—while also adopting gamification elements to still provide a learning experience close to real-world conditions and designed to potentially support students' practical competencies.



Figure 4. Interviews with CNE teachers at SMK Negeri 1 Sambeng

Design Stage

The conceptual design of the Game-Based Learning and IoT Virtual Laboratory integration application was developed at this stage. This stage involved the planning and determination of learning modules, software tools, and material concerning the fundamentals of Internet of Things (IoT) technology. The development of this desktop GUI-based learning medium aimed to establish a responsive and interactive learning atmosphere that fosters IoT simulation practice virtually. Several software tools and technologies used in developing this learning medium include Visual Studio Code and Simple DirectMedia Layer 3 (SDL3). Visual Studio Code was used for the coding and development process of the IoT Game-Based Learning application, while SDL3 served as the primary technology for building the graphical interface, animations, and user interactions within the application. SDL3 was selected as the primary development library due to its capability in handling 2D graphics rendering, user input, and event management efficiently. SDL3 is multiplatform, allowing the developed medium to be run on various operating systems without significant code modifications. Visual Studio Code was used as the primary IDE because it is lightweight, free, and possesses a rich extension ecosystem, including full support for the C++ programming language, integrated debugging, and a version control system. The development stages are illustrated in Figures 5, 6, and 7.

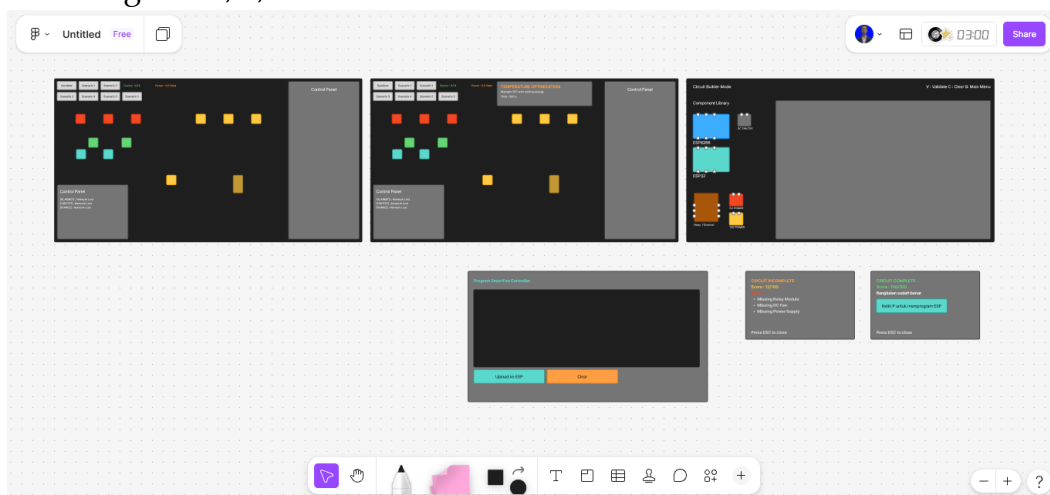


Figure 5. Application Design Development in Figma

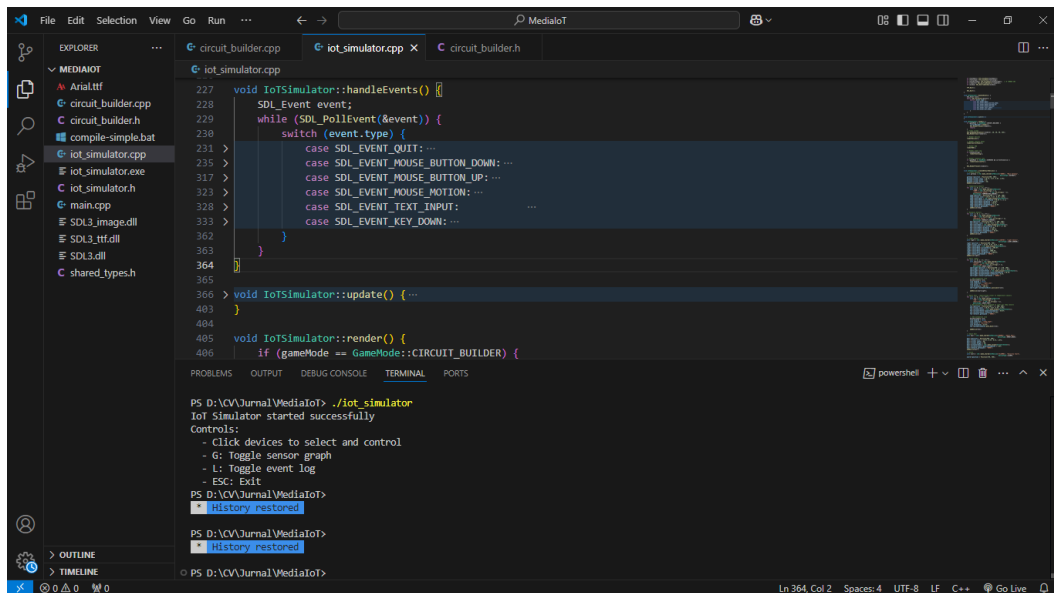


Figure 6. Interface/Working Window in Visual Studio

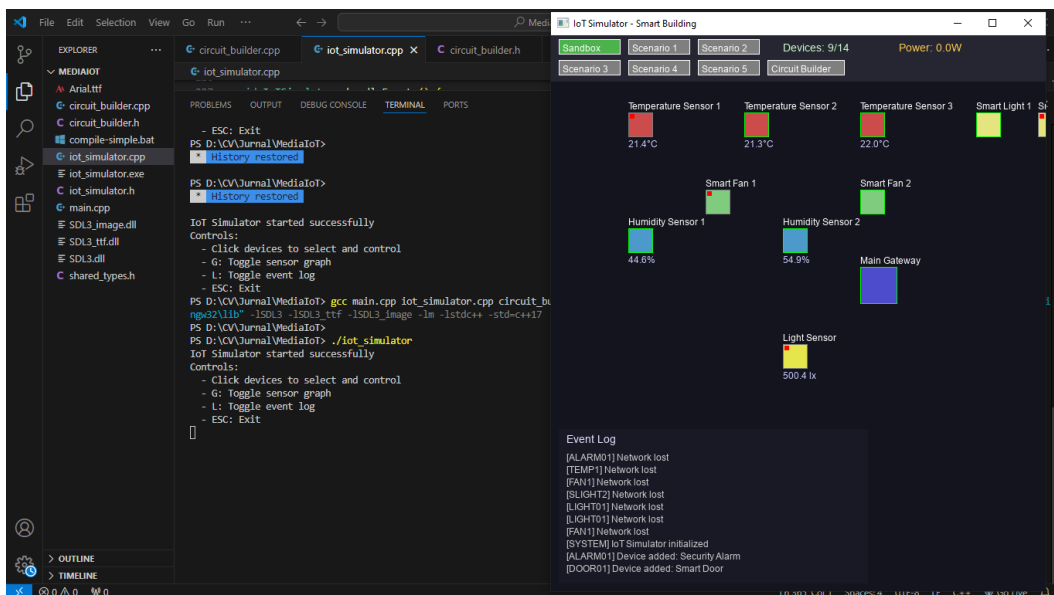


Figure 7. Application Testing on Desktop for Debugging

Development Stage

The development stage was carried out by building desktop-based learning media in accordance with the blueprint established in the previous stage. The application integrating Game-Based Learning and the Virtual IoT Laboratory was then validated by two media experts to determine the application's feasibility as learning media. The media expert validation results indicate that the Game-Based Learning and Virtual IoT Laboratory features in the application function in accordance with the learning objectives, accurately represent IoT circuits and systems, and are suitable for use in CNE competencies, with a total score of 74 out of 100 and an average of 3.70, comprising the Functional Suitability aspect with an average of 4.33, Usability with an average of 4.00, and Reliability with an average of 3.25. The application interface and its main developed features are shown in Figures 8, 9, and 10.

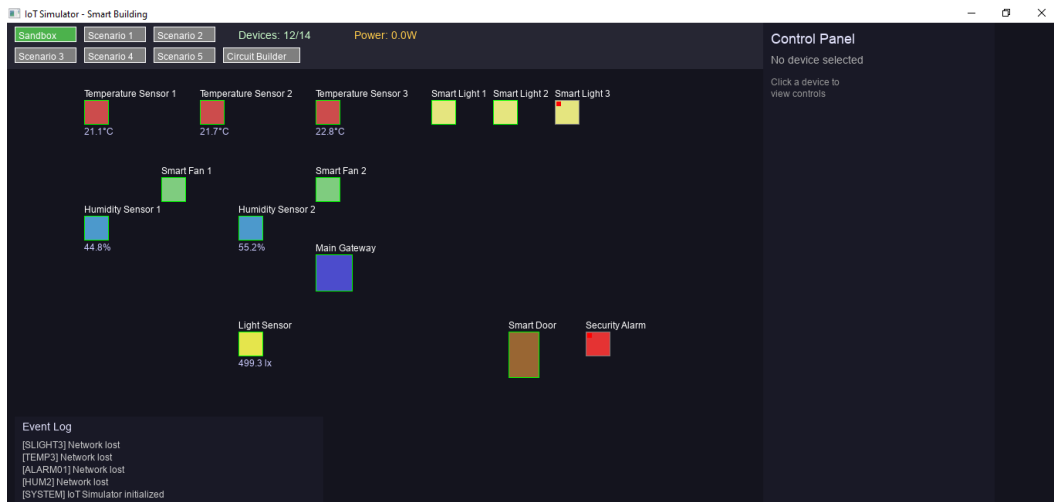


Figure 8. Main Menu Page Display

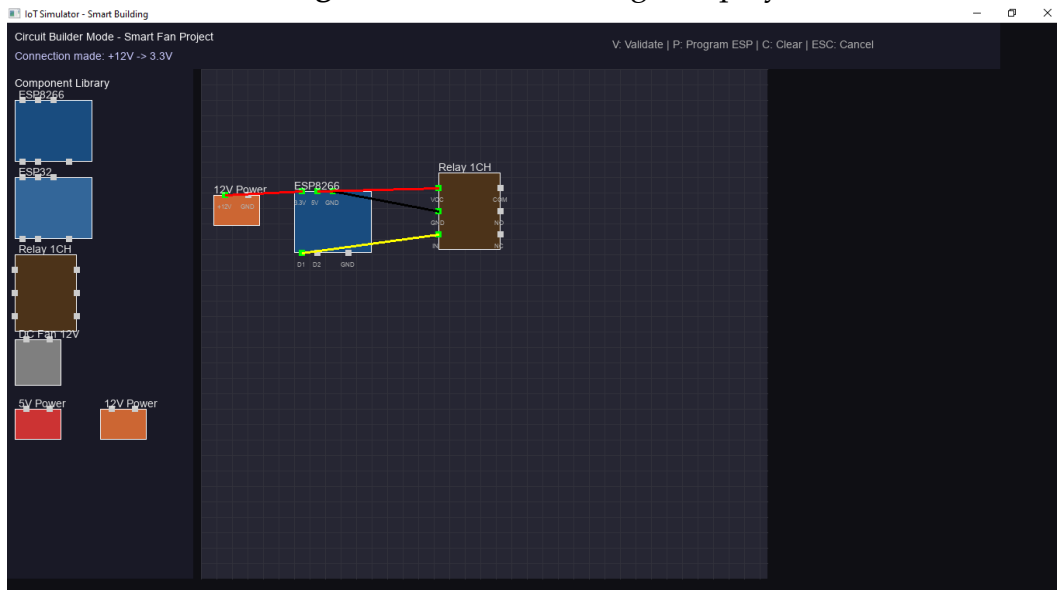


Figure 9. Circuit Builder Page Display

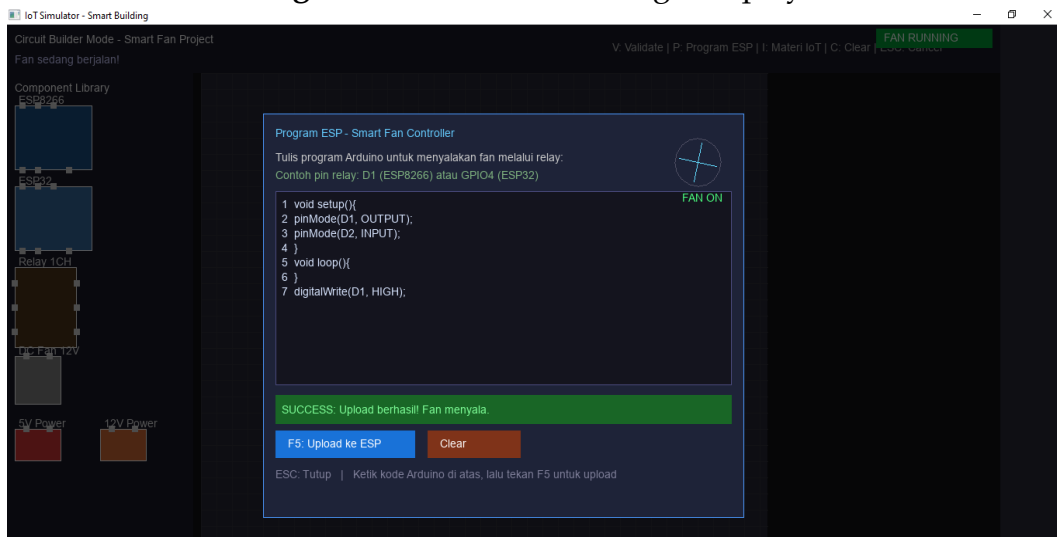


Figure 10. ESP Programming IDE Display

Implementation Stage

The developed medium was used during the basic IoT learning process by students who consented to participate as research respondents and had completed the informed consent form. Upon completion of the learning process, students were asked to complete the Perceived Usefulness (PU) and Perceived Ease of Use (PEOU) questionnaires to assess the degree of usefulness and ease of use of the application.

Evaluation Stage

The developed application was evaluated by students using a Technology Acceptance Model (TAM) questionnaire consisting of the Perceived Usefulness (PU) and Perceived Ease of Use (PEOU) scales. Since the respondent count surpassed 50, the Kolmogorov-Smirnov test was applied to assess normality. As presented in Figure 11, the results indicated a non-normal data distribution, given that the significance level fell below 0.05.

Tests of Normality

	Kolmogorov-Smirnov ^a			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
PU	.200	51	.000	.849	51	.000
PEOU	.255	51	.000	.847	51	.000

a. Lilliefors Significance Correction

Figure 11. Results of the TAM Questionnaire Normality Test

Therefore, the PU and PEOU data were grouped based on the median value to facilitate the analysis of user acceptance levels toward the developed learning media. The evaluation results show that 33 students (64.7%) considered the application useful, with a median value of 21, a minimum score of 7, and a maximum score of 25. In addition, 28 students (54.9%) considered the application easy to use, with a median value of 22, a minimum score of 7, and a maximum score of 25. These results indicate that the developed learning media can function well in supporting the interactive learning of basic Internet of Things (IoT) concepts and is easy for students to use.

Table 4. Technology Acceptance Model (TAM) Questionnaire Results

PU and PEOU	Description (N=51)		
	n	%	Median (Min-Max)
Perceived Usefulness (PU)			
a. Useful	33	64.7	21
b. Useless	18	35.3	(7-25)
Perceived Ease of Use (PEOU)			
a. Easy	28	54.9	22
b. Difficult	23	45.1	(7-25)

Discussion

The results of this study show that the learning media integrating Game-Based Learning and a Virtual IoT Lab, developed using the ADDIE model, was declared valid with only minor revisions by the media experts (total score of 74 out of 100; mean 3.70), and received fairly positive perceptions from students, with 64.7% rating the application as useful (PU) and 54.9% rating it as easy to use (PEOU). The high expert validation score on the Functional Suitability aspect indicates that the virtual simulation was considered capable

of representing IoT circuits and systems through the drag-and-drop GUI interface as designed in the media. This finding aligns with the views of Li et al. (2024), Reyes et al. (2024), Sharifkhani et al. (2025) that virtual laboratories provide contextual and experiential learning opportunities that cannot easily be replicated by conventional classroom settings, particularly by enabling students to visualize, manipulate, and test virtual representations of hardware systems. In the context of SMKN 1 Sambeng, this function is particularly relevant because the initial analysis identified limited availability of physical IoT devices and learning media as a practical constraint in IoT instruction. Consequently, the virtual laboratory provides an alternative learning environment that allows students to engage with simulated IoT components and system configurations without depending entirely on the availability of physical hardware. Beyond the technical simulation aspect, this media also embeds gamification elements in the form of tiered challenge scenarios and immediate feedback on user actions. The presence of these elements was also assessed within the Functional Suitability aspect of the expert validation, which obtained a mean score of 4.33, indicating that the integration of game mechanics into the IoT simulation flow was considered to function as designed. The TAM evaluation results, showing positive perceptions of usefulness and ease of use, are consistent with the findings of Alkhalidi et al. (2016), Masril et al. (2024), and Savu-Jivanov et al. (2026) regarding user acceptance of virtual IoT laboratories. The acceptance percentages in this study (64.7% for PU and 54.9% for PEOU) are considered fairly good, though they also indicate room for improvement, particularly in the ease-of-use aspect, which scored relatively lower than the usefulness aspect.

CONCLUSION

Fundamental Finding : This study successfully developed gamification-based learning media integrated with a virtual IoT laboratory using the ADDIE model, built on the SDL3 framework with a drag-and-drop GUI interface that allows students to simulate the virtual assembly of IoT devices through component identification, wiring configuration, microcontroller programming, and device testing. Expert validation confirmed the validity and feasibility of the media, while the TAM-based evaluation showed that the perceived usefulness (64.7%) and perceived ease of use (54.9%) were fairly good. **Implication :** These findings indicate that SDL3-based gamified virtual laboratory media represents a valid and acceptable alternative. **Limitation :** This study is limited by a single-school sample of 51 students, a single post-implementation TAM measurement without a pretest, and the absence of a comparative experimental design to measure learning outcomes against a control group receiving conventional instruction. Accordingly, this study can only draw conclusions regarding product validity and initial user acceptance perceptions. These limitations should be considered when interpreting the findings, as the study does not provide sufficient evidence to determine the effectiveness of the media in improving learning outcomes or to generalize the findings to broader educational contexts. **Future Research :** Future studies should adopt a quasi-experimental design with a broader multi-school sample, incorporate instruments to directly measure learning outcomes or competencies, integrate longitudinal tracking of technology acceptance, and explore the integration of adaptive learning mechanisms to personalize the learning experience delivered by the media.

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