Development of Virtual Reality-Based Runway Edge Light Installation Simulation Learning Media

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ABSTRACT

The Airport Electrical Engineering Program at Jayapura Aviation Polytechnic emphasizes practical learning, particularly in the Airfield Lighting System (AFL) course. However, limited access to on-campus AFL facilities requires students to conduct practical training at operational airports, which poses challenges related to safety, accessibility, and cost. This study aims to develop a Virtual Reality (VR)-based learning media for runway edge light installation simulation as an alternative practical learning solution. This research employs a Research and Development (R&D) approach using the ADDIE model (Analysis, Design, Development, Implementation, and Evaluation). Data were collected through observations and questionnaires involving three media experts, three material experts, and 24 students of the Airport Electrical Engineering Program. The application quality was evaluated based on ISO 25010 standards, covering functional suitability, compatibility, and usability aspects. The results show that the developed VR learning media achieved a media expert score of 4.29 (very feasible), material validity of 100% (valid), functional suitability of 100%, compatibility of 100%, and usability of 82.72% (very feasible). These findings indicate that the VR-based simulation is highly appropriate for supporting practical learning in high-risk technical training. This study demonstrates that VR-based task-oriented simulation can serve as an effective, safe, and scalable alternative to conventional practical training for complex Airfield Lighting System installation. *These findings indicate that virtual reality-based* simulation media can serve as an effective, safe, and scalable alternative for high-risk technical training in aviation vocational education, particularly in contexts with limited access to real operational facilities .

I. Introduction

The Airport Electrical Engineering Study Program is one of the departments at Jayapura Aviation Polytechnic. In its educational approach, the program emphasizes practical training over theoretical learning, so adequate facilities and equipment are essential to support hands-on practice. This is especially true for AFL courses, where students learn about angles, shapes, lighting directions, and lamp types. The Airfield Lighting System (AFL) course includes both theory and practical components. The theoretical part is taught in class before students perform practical activities in the laboratory. Currently, for practical activities, students must visit Sentani Airport because the Jayapura Aviation Polytechnic's electricity laboratory is not yet equipped with an Airfield Lighting System (AFL). Practical training in airport electrical systems, particularly in Airfield Lighting System (AFL) installation, presents significant challenges not only at Jayapura Aviation Polytechnic but also across many aviation and technical vocational institutions.

Strict safety regulations, operational risks, limited access to facilities, and high operational costs constrain training activities involving active airport infrastructure. Similar challenges have been widely reported in other high-risk technical education domains, such as electrical installation, industrial maintenance, and aviation engineering training, where students' opportunities to engage in real-world practice are often limited. Previous studies have demonstrated that Virtual Reality (VR) can effectively support technical and vocational education by providing immersive, interactive, and safe learning environments. VR-based simulations have been shown to improve learners' engagement, procedural understanding, and skill acquisition in various engineering and technical fields. However, most existing studies focus on general technical skills or low-risk training scenarios. In contrast, research on VR applications for complex, safety-critical aviation infrastructure systems, such as Airfield Lighting System (AFL) installation, remains limited. Furthermore, few studies have systematically evaluated VR-based learning media using comprehensive software quality standards such as ISO 25010.

Virtual reality (VR) is a technology that creates immersive, simulated experiences, allowing users to experience computer-generated 3D environments as if they were in them (Mystakidis, 2022). Through devices such as VR headsets and controllers, users can interact with digital objects and environments, providing a more interactive learning and play experience than traditional media (Pangestu & Rahmi, 2022; Wijayanto et al., 2023). In an educational context, VR offers a unique opportunity to enhance understanding of complex concepts through practical simulations, allowing students to practice technical skills in a safe, controlled environment (Bonafix & Nediari, 2022; Zhang et al., 2022). In addition, VR can increase student motivation and engagement, as the experience is more engaging and fun (Sulistiani et al., 2023). In various fields, including engineering, healthcare, and architecture, this technology has shown great potential to improve learning quality and prepare individuals for real-world challenges (Curran et al., 2023; Morimoto et al., 2022).

According to Wulandari et al. (2023), learning media are tools used to convey information about subject matter and to increase student interest. The results of the studies conducted show that the most crucial method for selecting learning media is to ensure students learn, gradually increasing their interest in learning. The practical learning of Jayapura Polytechnic students in the Airfield Lighting System (AFL) course remains inadequate due to the absence of a practical component. This problem makes students lack the concept of AFL equipment installation. In addition, the current learning media used by students is only in the form of regulatory documents from the government and PowerPoint learning that is less interactive. Interactive learning media are media used by students that are realistic or employ virtual reality as a teaching medium (Sukirman et al., 2019). The results of Zahwa & Syafi'i's (2022) research indicate that students will have more fun and that learning will be more interesting when they use interactive learning media applications based on virtual reality information technology. This can increase students' acceptance of learning information.

Prior research plays a crucial role in scientific articles, as it helps reinforce the theoretical foundation and the observed relationship or impact between variables (Bunahri et al., 2023). Based on the above problems, a media is needed to support the learning of Poltekbang students, especially learning that utilizes virtual reality technology. So, this study aims to develop simulation learning media and analyze the quality and feasibility of runway edge light installation simulation applications as virtual reality-based learning media for students of the Airport Electrical Engineering Study Program at Jayapura Aviation Polytechnic. This study is also expected to improve students' understanding of the Airfield Lighting System (AFL) course in the Airport Electrical Engineering study program, especially regarding runway edge light installation practice. This learning media will be beneficial and efficient, especially for campuses that still lack practical equipment for students. Therefore, this study aims to develop a Virtual Reality-based learning media for runway edge light installation and to evaluate its feasibility and quality based on ISO 25010 standards. The developed media is expected to provide a safe, interactive, and effective alternative for practical training in Airfield Lighting System (AFL) courses, particularly in vocational aviation education contexts with limited access to real operational facilities.

II. Method

This research uses the Research and Development (R&D) method with the ADDIE model, which comprises five stages: Analysis, Design, Develop, Implement, and Evaluate (Sugiyono, 2021).

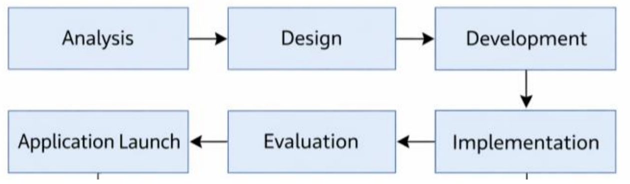


Fig. 1. Research stages

Data were collected through observation, documentation, and questionnaires. Application quality testing encompasses functionality, suitability, compatibility, and usability, as defined by ISO 25010. Usability testing used the USE Questionnaire, with 30 questionnaires completed by 24 students from the Airport Electrical Engineering Study Program, Batch 4. The functionality suitability aspect was tested using observation instruments, such as test cases that included application feature testing scenarios, with three expert respondents serving as testers. Compatibility testing is conducted operationally by researchers to ensure the application functions smoothly across a range of computer devices without constraints. Data were analyzed using quantitative techniques for media testing, materials, functionality, suitability, compatibility, and usability. The authors favored the quantitative method for its greater validity and ability to analyze a wide range of factors numerically, unlike the qualitative method, which relies solely on non-numerical descriptions and analysis (Bunahri, 2023). The results of media testing were converted into a Likert scale by calculating the average of respondents' answers, then interpreted according to Likert criteria. Material testing, functionality suitability, and compatibility using a Guttman scale with two answer options: success (1) and failure (0). Usability testing uses a Likert scale by analyzing the average answer from the USE Questionnaire. The results of the four tests were then converted to a percentage scale to determine the application's quality level.

III. Results and Discussion

A. Analysis

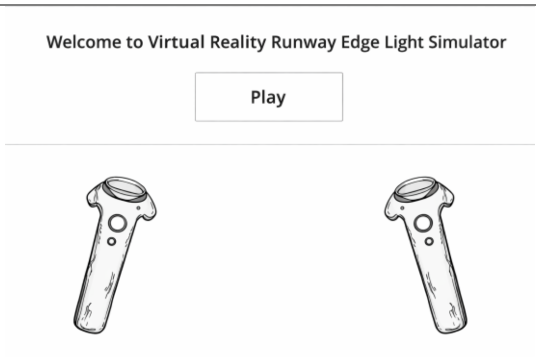
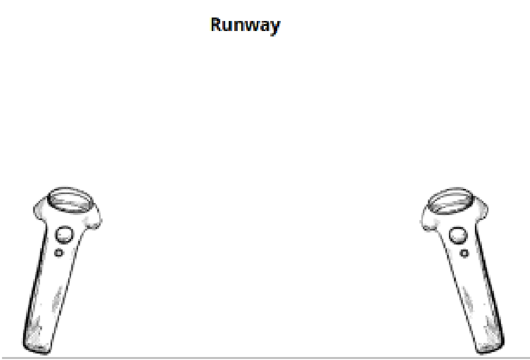
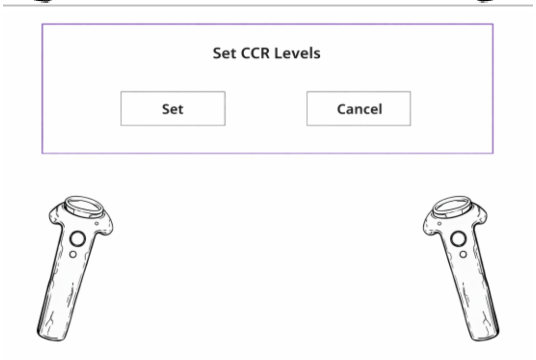
The problem identification stage was conducted to develop virtual reality (VR) based learning media for runway edge light installation at Jayapura Aviation Polytechnic. Observations showed that conventional learning methods were less interactive, and access to airport equipment was limited, resulting in uneven practical experience for students. In addition, training at the airport is limited by safety factors and operational costs. To overcome this, VR learning media are proposed to simulate the installation of runway edge lights, providing an interactive experience in a safe, controlled environment. The press includes installation and maintenance materials, adheres to international standards, and uses 3D animation to enhance learning flexibility.

The functional requirements analysis for the virtual reality (VR) based learning media for runway edge light installation at Jayapura Aviation Polytechnic identified several key features. The application should provide a 3D visualization of the runway edge light to make it easier for students to understand the components in detail, execute interactive commands based on menu selections, such as "Connect Cable," and offer a realistic simulation of cable and bulb installation and troubleshooting in a safe virtual environment.

B. Design

The design stage involves creating storyboards and HIPO (Hierarchy Input Process Output) diagrams to visualize the application's user interface and process flow. Storyboards contain sketches of images that summarize scenarios in sequence, while HIPO depicts the flow of inputs, processes, and outputs in the application. Both methods are used to ensure that the app design is easy to understand and efficient in use. HIPO (Hierarchy Input Process Output) consists of three diagrams: the VTOC (Visual Table of Contents) Diagram, the Summary or Overview Diagram, and the Detailed Diagram, which contains application details.

Table 1. Storyboard

Page	Board	Information
Main Scene		The main scene is the scene that first appears when the application is opened, containing: Play button leading to Runway
Runway Scene		The Runway Scene is a scene that will be used to carry out the process of installing lights and several other processes on the Runway.
Cable Installation Scene		Display buttons and text boxes for connecting/ installing cables on the runway

The summary diagram describes the input, process, and output flows in the "Runway Edge Light" app. When the user clicks "Open App," the app will display the main view with a play button. A Virtual Reality (VR) headset is integrated with head tracking, allowing the app's display to move with the headset. VR controllers are used to move the player, with controller animations that follow physical movements. Clicks on the controller pass commands to the app, and the grab feature allows direct interaction with objects in the app. In the main scene, double-clicking on the application file displays the scene with a play button. The VR headset controls the view for a realistic experience, while the controller moves the player, matching real movement with the app. In the runway scene, the “Plug” and “Unplug” buttons manipulate 3D objects to connect or disconnect connectors. In the main powerhouse scene, the button to attach to the CCR connects the connector, and the light-intensity setting button adjusts the brightness level. The grab button allows the player to virtually move the halogen lamp in sync with the controller's movement.

C. Development

The development stage is the process of implementing the design into the application, "Virtual Reality-Based.

Runway Edge Light Installation Simulation." At this stage, various development steps are carried out using software and technology to ensure the application functions as planned. The first process was to create 3D models of the runway edge light and its surrounding environment using Blender to produce detailed, realistic 3D objects, including runway edge light components and the airport environment at Jayapura Aviation Polytechnic.

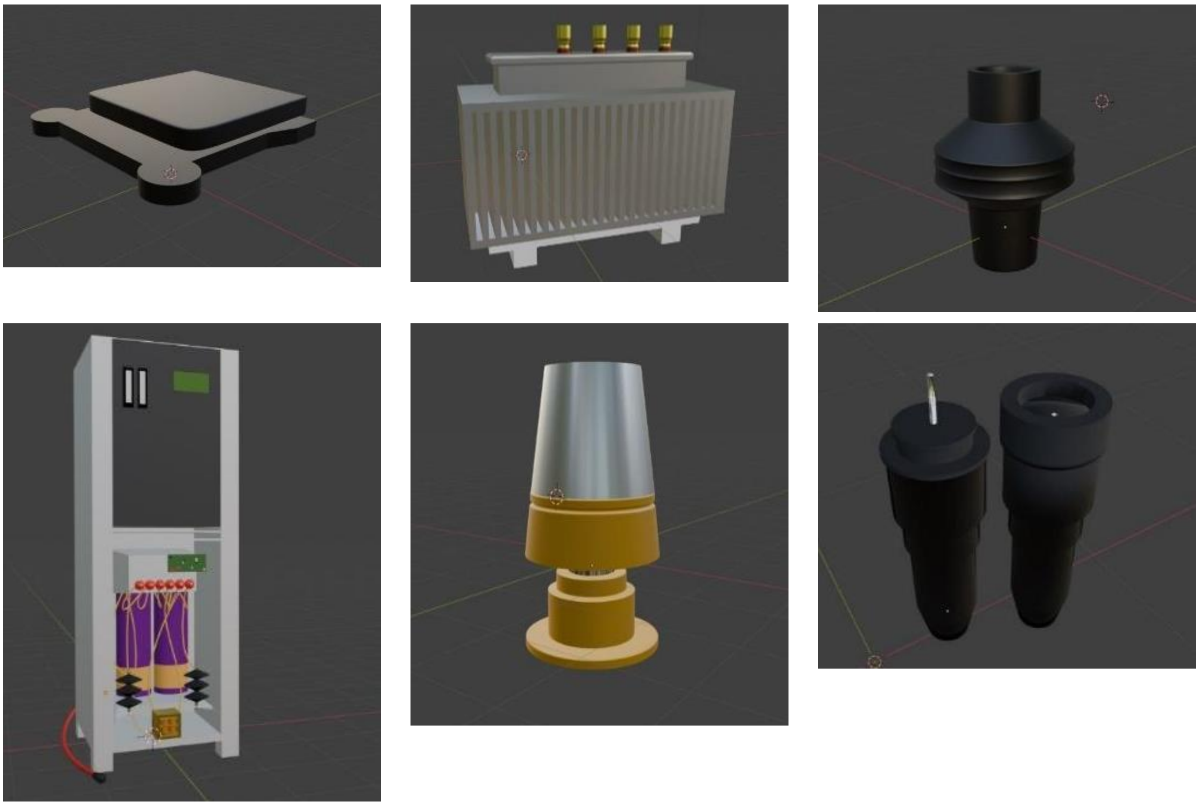


Fig. 2.3D object simulation

The 3D model was created in Unity, a VR application development platform, and imported there, where it was scripted for user interaction. Unity developed an interactive virtual environment that allows students to simulate wiring and bulb changes on the runway edge light. The development process using Unity began by creating a new project called REL VR using the Universal 3D template. After that, the XR Interaction Toolkit and XR Plugin Management packages were installed, and the Sample Starter Assets and XR Device Simulator were imported to facilitate development. After setting up the project by organizing Plug-in Providers using Open XR, two new scenes were named “Runway” and “Start Menu.” In each scene, XR Origin (VR) was added to configure Virtual Reality according to predefined settings. The pre-designed 3D models were copied into the 3D folder in Unity, placed in the correct object hierarchy, and the UI (User Interface) was used to provide instructions to the player.

PCoding of the simulation scenarios was done using C# in Unity with Visual Studio Code as the editor. These scenarios include procedures for wiring, changing light bulbs, and user interaction with virtual elements, ensuring the simulation runs according to the planned workflow. All program code is grouped in the “Scripts” folder within the “assets” folder. The scene-switching process uses the Load Scene function in Unity's Scene Manager to move the user from the “Start Menu” scene to the “Runway” scene. The code to control the Runway Edge Light is stored in a Game Object named “Edge Light Controller,” which governs the behavior, animation, and intensity of the light. The linear interpolation function is used to move objects during cable insertion and unplugging gently. The lamp change process code is stored in the file "Change Lamp.cs" which functions to set the animation in several states, including Ready, Disable Light, Open Lamp Glass, Remove Old Lamp, Add New Lamp, and Close Lamp Glass. The Update function executes each state to ensure smooth, responsive animation.

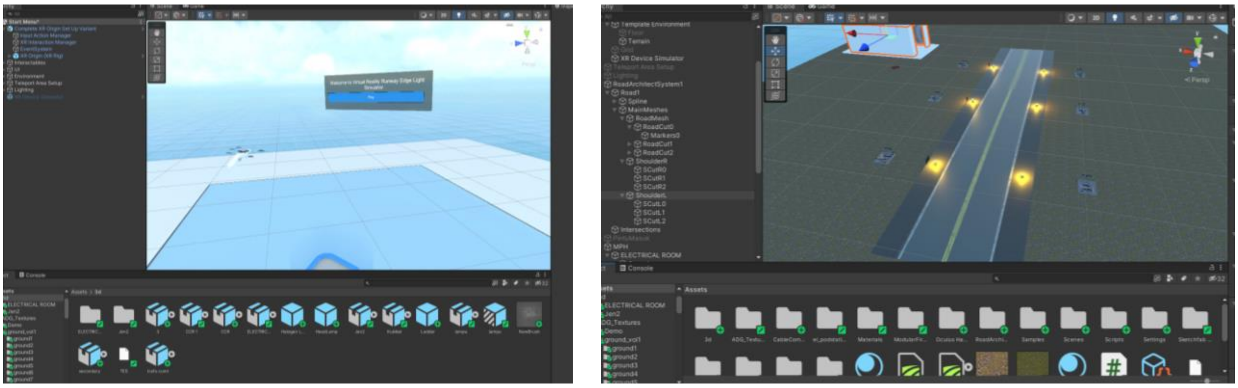
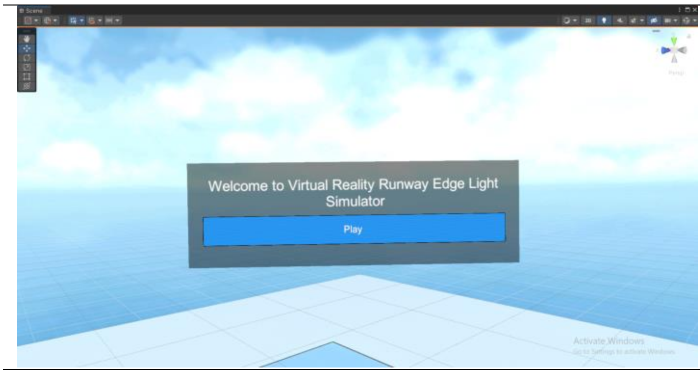
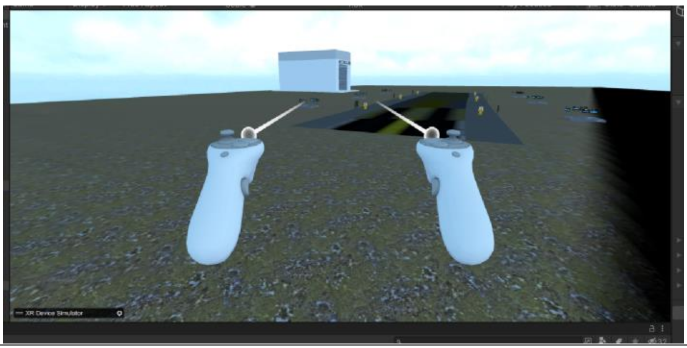


Fig. 3. First and second scenes

D. *Implementation*

The implementation stage is the stage of testing the application by installing it on a computer. Implementation is carried out to ensure that the application can run according to the design and development that have been done before. Implementation is carried out, including the interface, which explains the application's pages and functions.

Table 2. Interface implementation

Interface	**Information**
Main Interface	
	The Main Interface is the scene that first appears when the "Virtual AFL" application is opened through the Application containing a play button to move to the Runway. A simple environment with a blue background.
Runway Interface	
	The runway interface is a scene where the player will carry out the Runway Edge Light installation simulation procedures, consisting of Runway Edge Light lamps, handholes, manholes, and main powerhouse (MPH).
Main Powerhouse View	

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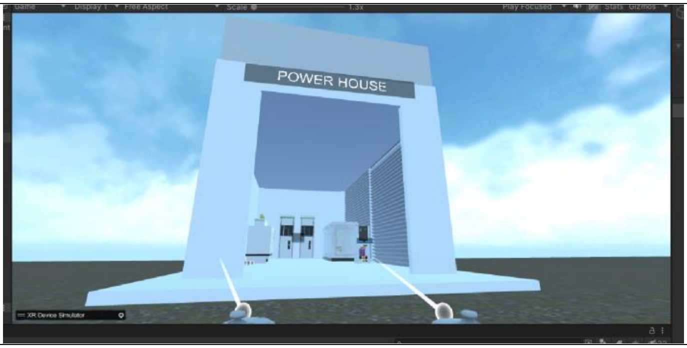
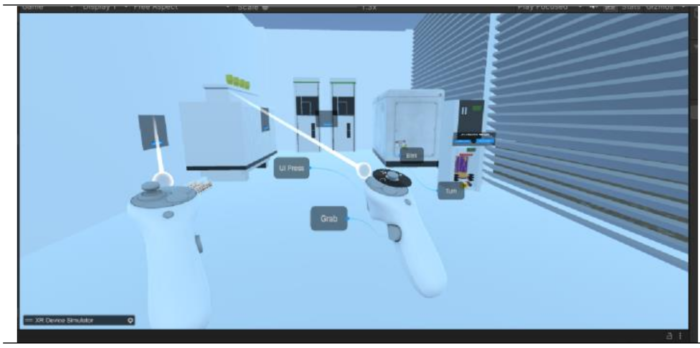
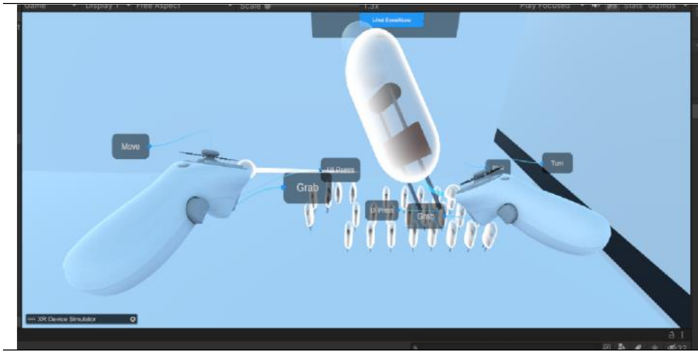
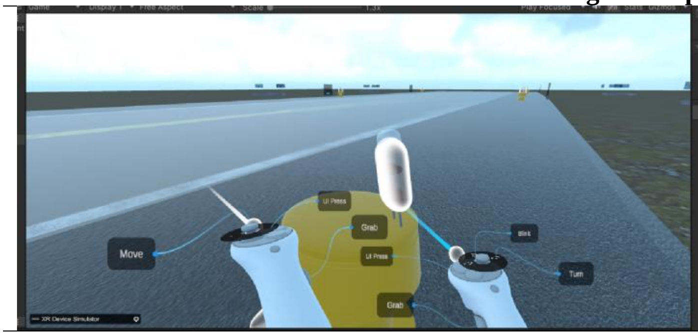
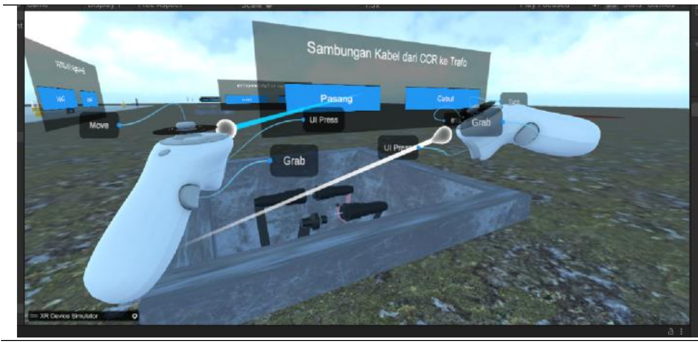
Interface	Information
	Main Powerhouse is a scene section that displays a Virtual Reality Main Powerhouse simulation, containing a 3D Cubicle Model, 3D Transformer Model, 3D Halogen Lamp Model, 3D Generator Model, and 3D CCR Model.
Main Powerhouse (MPH) Interior	
	The inside of the main powerhouse contains several buttons that can display the specifications of each component, there are also spare halogen lamps that can later be brought to the runway to simulate the lamp replacement process.
CCR Runway Brightness Setting Interface	
	This interface controls the light intensity of the lights on the runway, with five levels from 0 to 5, where 0 means off. There are two interaction buttons: one to lower and one to raise the light intensity of all connected lights on the runway.
CCR Rear View	
	The back of the CCR contains a 3D Model of the Primary cable Connector as well as 2 buttons for connecting and disconnecting the CCR cable.
Halogen Lamp Grab Process Interface	

Interface	Information
	The halogen lamps in the Main Powerhouse can be "grabbed" or brought to the runway using the side button and then attached to the lamps on the runway.
Scene of Halogen Lamp Installation on Runway	
	Showing a simulation of the process of installing halogen lamps to existing lamps on the Runway for maximum learning understanding.
Cable Installation Interface On Handhole	
	This interface functions to install cables in the handhole via the UI button for easier access.

E. Evaluation

At the evaluation stage, testing is carried out to ensure that the application developed meets standards and functions adequately. The test results are expected to identify application deficiencies for further improvement.

1) Application Eligibility Testing

Media expert validation was conducted by three experts, including a Computer Engineering lecturer and an IT instructor from Poltekbang Jayapura, to test the application engineering and visual communication aspects. The validation data includes both aspects.

Table 3. Assessment results for all media aspects

No	Indicator	Total Score	Average	Assessment Classification
1	Application engineering	156	4.33	Very Worth It
2	Visual Communication	112	4.26	Very Worth It
	Total Score	268	4.29	Very Worth It

Based on the media experts' results, the application engineering aspect receives an average score of 4.33, which can be categorized as "very feasible". Meanwhile, the visual communication aspect gets an average result of 4.26, which can be categorized as "Very Feasible". The overall average value gets 4.29, which is categorized as "Very Feasible". Therefore, this application is very feasible to use as a learning medium. Meanwhile, material expert validation was carried out by three lecturers from the airport electrical engineering study program using a questionnaire on AFL equipment, based on the total score of the material expert assessment. Based on the expert evaluation of the material, the total assessment was 21, which is 100%. So, the material in the "Virtual Reality" application falls under the "Valid" category, making it very suitable for use.

2) Application Quality Testing

Three media experts conduct functional suitability testing to ensure that all functions and features in the "Virtual Reality" application work correctly. The test results showed 100% success (27/27) and 0% failure.

Thus, functional suitability testing is declared "Very Feasible" because all functions run as expected. Researchers conducted compatibility testing to ensure the application functions appropriately on different devices and operating systems. The test results show that the application meets the compatibility criterion, rated "Very Feasible," as it runs smoothly.

Usability testing was conducted using a USE Questionnaire comprising 30 questions on a 5-point Likert scale, administered to 24 students in the Airport Electrical Engineering study program, Batch 4, at Jayapura Polytechnic. The total score from usability testing was 2978, while the maximum possible score is 3600, based on 24 respondents, 30 questions, and a maximum of 5 per question. The usability percentage calculation indicates the application has a value of 82.72%, which falls within the "Very Feasible" classification.

Based on the tests conducted on the application "Virtual Reality," conclusions can be drawn regarding its feasibility and quality. Evaluation results from media experts indicate a score of 4.29, indicating that this application is highly feasible. In addition, validation by material experts reached 100%, confirming that the application content aligns with learning needs. In terms of application quality, functional suitability testing shows that 100% of the functions in the application run well, fulfilling the category of "Very Feasible." Compatibility testing also revealed that the device and operating system ran well, earning the category "Very Feasible." On the other hand, usability testing yielded a percentage of 82.72%, indicating that this application meets the usability criteria, with the category "Very Feasible."

The results of this test are in line with previous research, which shows that Virtual Reality (VR) based applications can increase the effectiveness of learning in engineering and technology. Research by Erviana & Sepriansyah (2024) and Refdinal et al. (2023) shows that the use of VR in education not only increases motivation but also student engagement in the learning process, allowing them to experience practical experiences that are often difficult to access through conventional methods. Another study by Henstrom et al. (2024) and Silseth et al. (2024) emphasized that VR offers a more interactive and immersive learning experience, enabling students to explore complex concepts in a safe, controlled environment. This aligns with current findings that the VR application developed at Jayapura Aviation Polytechnic provides a practical and engaging learning experience for students.

The implications of these findings are significant, especially for technical education and training at Jayapura Aviation Polytechnic. Using "Virtual Reality," which has been proven highly feasible in terms of both feasibility and quality, educational institutions can consider integrating this technology more widely into their curricula (Rauschnabel et al., 2022). The use of VR can create a more immersive and interactive learning environment, where students not only learn in theory, but can also practice their skills in simulations that are close to real conditions (Lee & Takenaka, 2022). This is important, especially in the field of aviation, which requires a deep understanding and high practical skills. In addition, the application of VR in learning can increase student motivation and engagement, making the learning process more interesting and compelling (Ravichandran & Mahapatra, 2023). In addition, by adopting this technology, Jayapura Aviation Polytechnic will contribute to the development of human resources who are more competent and ready to face the challenges of the industrial world, enabling them to compete globally (Conrad et al., 2024). In addition, the institution can be a pioneer in the use of innovative technology in technical education in Indonesia, inspiring other institutions to follow suit and leverage technological advances to improve the quality of education (Laine et al., 2024).

Furthermore, the test results showing high usability (82.72%) confirm that the app is designed to be user-friendly, enabling cadets to operate it easily and comfortably. This usability is significant in an educational context, as it ensures that students can learn effectively without being hampered by technical difficulties or confusion when using the app. In the learning process, smooth, intuitive interaction with the app supports optimal absorption of the material, which in turn enhances understanding of complex concepts (Guerra-Tamez, 2023). Further development of the app is therefore highly recommended, including the addition of new relevant and innovative features, as well as improvements based on user feedback. This approach will not only improve the quality of learning but also ensure that the app remains relevant and effective in meeting educational needs in aeronautical engineering (Mallek et al., 2024). Thus, this continuous development has the potential to produce more prepared and skilled graduates, able to face various industry challenges. This readiness is essential to ensure they can adapt quickly to the ever-changing work environment and contribute significantly to the competitive aviation sector (Marougkas et al., 2023). In addition, implementing development practices responsive to user feedback can create a continuous improvement cycle, in which applications are constantly refined to meet the expectations and needs of students and industry.

IV. Conclusion

This research concludes that the "Virtual Reality" application as a learning media has been successfully developed through five stages: Analysis, Design, Development, Implementation, and Evaluation. The feasibility test results show that this application is rated "Very Feasible" by media experts (average 4.29) and "Valid" by material experts (100%). The application quality test showed excellent results, with a percentage of

100% for the aspects of functional suitability and compatibility, and 82.72% for usability, all in the category of “Very Feasible.” The suggestions for future development include adding types of AFL equipment, developing materials based on the latest sources, and adding or improving features based on user feedback and evaluation results to maintain the application's relevance and benefits as a learning medium.

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