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THE DEVELOPMENT OF A VIRTUAL REALITY TRAINING MODULE FOR AIRCRAFT FLIGHT INSTRUMENT

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ABSTRACT

This study addresses the challenges faced by aircraft maintenance students in identifying and understanding basic flight instruments due to limitations in traditional teaching methods. To improve learning outcomes, a Virtual Reality (VR) based application was developed to provide an immersive and interactive training experience. The project followed three main phases: design, development, and evaluation. Using 3D modelling and the Unity platform, six essential flight instruments were recreated in a virtual cockpit environment. The application allowed students to explore instrument functions through realistic interaction. Its effectiveness was assessed through pre- and post-tests conducted with diploma level aircraft maintenance students. Results showed a significant improvement in post-test scores, with the mean score increased significantly to 94%. Feedback also indicated increased engagement, ease of use, and interest in learning. These findings highlight the value of VR as a complementary tool in aviation education, supporting deeper comprehension and greater student involvement compared to conventional methods. The study concludes that VR-based learning can enhance both the quality and effectiveness of technical training.

1. Introduction

In recent years, technological advancements have increasingly reshaped the landscape of technical and vocational education, particularly in the aviation sector. Traditional training in aircraft maintenance and flight instrumentation heavily depends on classroom-based theoretical instruction and limited hands-on exposure to real or mock-up cockpits. While these methods have long served the industry, they often lack interactivity, immersion, and scalability especially in the context of large cohorts and limited resources. To address these limitations, educators are exploring emerging technologies such as VR, which offers immersive, safe, and cost-effective environments for experiential learning (Radianti et al., 2020; Kavanagh et al., 2017).

VR enables users to interact with 3D simulations of real-world environments through head-mounted displays (HMDs) and motion-tracked controllers. In aviation training, VR can simulate aircraft cockpits and flight instruments in realistic scenarios without exposing students to the risks and costs associated with actual flight training. According to Jensen et al. (2022), the application of VR in aviation education is particularly beneficial in helping students develop spatial awareness, familiarize themselves with cockpit layouts, and comprehend the function of flight instruments in various operational conditions.

Flight instruments such as the altimeter, airspeed indicator, vertical speed indicator, attitude indicator, heading indicator, and turn coordinator are fundamental to aircraft operation and safety. For students in aircraft maintenance engineering programs, understanding these instruments is essential not only for maintenance tasks but also for effective communication with pilots and interpreting flight data. However, Yildirim et al., (2020) studied due to the cost and complexity of actual flight decks, students may not have ample opportunity to engage with instrument panels in realistic settings during their studies. This pedagogical gap calls for scalable and immersive training tool an area where VR holds great promise.

Recent studies have shown that VR enhanced learning improves knowledge retention, engagement, and self-efficacy among students in science, technology, engineering, and mathematics (STEM) disciplines (Lee & Wong, 2021; Jensen et al., 2022). Furthermore, VR can support competency-based education frameworks by enabling learners to practice procedures repeatedly and receive immediate feedback without the risk of damaging equipment or compromising safety (Gonzalez-Zamar & Abad-Segura, 2021). In aviation education, VR has been successfully applied in pilot simulation, emergency response training, and aircraft system familiarisation. However, there remains a gap in research and implementation focused specifically on using VR to teach the functionality and configuration of flight instruments to maintenance students. Current VR tools in aviation remain limited, as most are pilot-centric, costly, and lack depth in instrument functionality for maintenance training. They often require high-end hardware, offer little curriculum customisation, and rarely integrate assessment features, leaving a significant gap for technician-focused educational innovation (Al-Azzam & Ramkumar, 2023).

This study aims to bridge that gap by developing a VR-based training module focusing on flight instruments. The research explores the design, development, and usability evaluation of a virtual cockpit environment where students can interact with and learn about key flight instruments in a simulated yet realistic setting. Through Virtual Reality of Aircraft Flight Instrument (VRAFI), the study contributes to the growing body of knowledge on immersive technology in technical education and proposes a scalable, engaging, and effective method for aviation maintenance training.

2. Methodology

This study adopted a Design and Development Research (DDR) framework, a methodological approach suitable for creating and evaluating educational technologies such as VR simulations. The methodology was structured into five sequential phases: (1) needs analysis, (2) design, (3) development, (4) implementation/testing, and (5) evaluation. Each phase was carefully planned to ensure the resulting VR application met the learning objectives of flight instrument familiarization for students enrolled in the Diploma Engineering in Aircraft Maintenance (DAM), Politeknik Banting Selangor (PBS).

2.1 Need Analysis

The design phase translated the needs analysis findings into a functional prototype. At this stage, learning objectives were aligned with technical requirements, and appropriate tools, platforms, and interaction models were identified. The process ensured that the VR flight instrument simulation addressed student learning gaps effectively and systematically.

2.2 Design Phase

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2.2.1 Function Tree

The main function of the VRAFI was defined as centered on the comprehensive design, development, and evaluation of six essential flight instruments within a VR environment to enhance aviation training. It is consisting of user onboarding, dashboard, learning modules, interactive simulation and formative assessment.

2.2.2 Morphological Matrix

Table 1 shows several combinations of components and features were explored, generating four ideas design concepts:

Table 1: Morphological Matrix

Criteria	**Idea 1**	**Idea 2**	**Idea 3**	**Idea 4**	**Idea 5**
Type	Game	Game	Explore	Game	Game
Software	Maya	Unreal Engine	Unity	Unity	Unreal Engine
Hardware	Motion Controller	Motion Controller	Oculus Quest 2	HTC Vive Pro	Oculus Quest 2
Programming Language	Java	C++	C++	C#	C#
Interaction	Hand Movement	Hand Movement	Hand Tracking	Full Body Tracking	Hand Tracking

Idea 5 was chosen because it offers the best balance between feasibility, functionality, and innovation compared to other alternatives in the Morphological Matrix. This concept integrates

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affordable hardware with a user-friendly VR platform, making it suitable for classroom deployment without heavy infrastructure costs. Unlike other ideas that required advanced sensors or high-end simulators, Idea 5 leverages existing VR technology, reducing development risk while still providing immersive and interactive learning experiences. This solution stands out for its easy installation, which simplifies the integration process, and its free and open-source nature, which not only reduces costs but also provides flexibility for customization to suit the specific needs of the project. Additionally, Idea 5 offers a comprehensive package with a wide range of tools and functionalities essential for simulating and implementing flight instruments within a VR environment. Additionally, it directly addresses the learning gaps identified in the needs analysis, ensuring alignment with educational objectives. The design also demonstrates strong potential for scalability, commercialisation, and future integration with other training modules.

2.2.3 Evaluation and Selection

The concepts were evaluated using a Pugh Matrix against criteria which enables to evaluate and choose the optimal option by systematically comparing each possibility to a set of criteria. Concept 5 scored the highest as shown in Table 2.

Table 2: Pugh Matrix

Criteria	Idea 1	Idea 2		Idea 3	Idea 4	Idea 5
Type	3	3		D	2	3
Software	1	3		A	3	3
Hardware	1	1		T	2	3
Programming Language	1	3		U	3	3
Interaction	3	3		M	1	3
Total	9	13		-	10	15
Ranking	4	2		-	3	1

Legend = 3(+), 2(=), 1(-)

The VR cockpit was designed to mimic a general aviation aircraft panel (similar to a Cessna 172), as it features standard analog instruments used in most foundational aviation courses. The layout was based on FAA and EASA instrument standards (Federal Aviation Administration, 2022). The learning interface included features such as clickable instruments for detailed views and explanations, simulation of flight scenarios showing how instruments respond to altitude, pitch, bank, and airspeed changes as well as quizzes and tooltips for formative assessment.
User interface (UI) design principles, such as simplicity, feedback, and consistency, were employed to ensure the application was intuitive for students without prior VR experience (Lee & Wong, 2021).

2.3 Development Phase

In this phase, pedagogical and technical specifications were determined. Figure 1 shows the the flowchart outlines a VR development cycle starting from defining learning objectives, followed by storyboard creation, multimedia asset development, system testing, and validation. Each phase requires approval before progressing. If not approved, revisions are made. Upon successful user acceptance, the project concludes with implementation for training deployment.

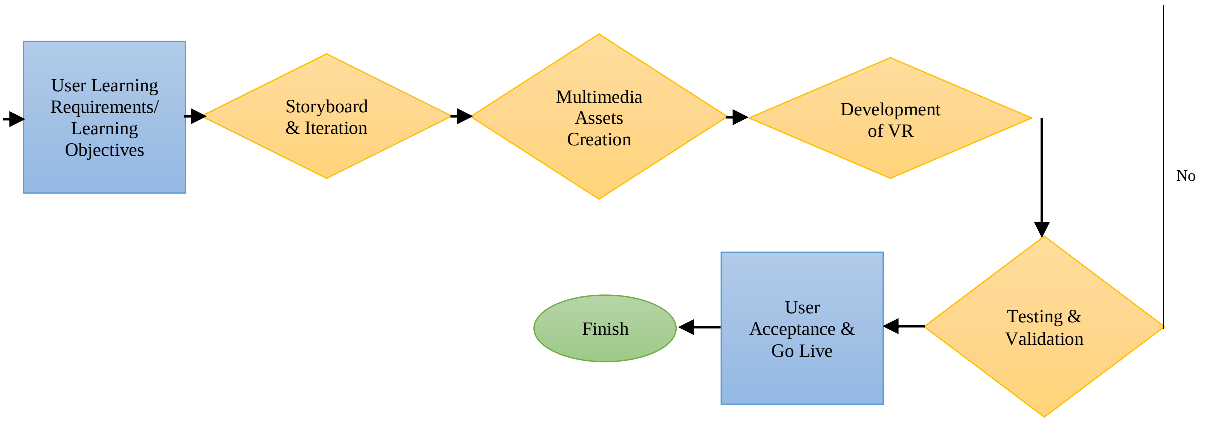

Figure 1: Overall Project Flow Chart

The development was conducted using Unity 3D, a widely used game engine for VR application creation. Instrument models were designed and animated in Blender, then imported into Unity. Scripting was done using C# to implement interactions, physics-based simulations, and instructional logic.

To make the experience accessible, the application was developed for Oculus Quest 2, a standalone VR headset requiring no external sensors. This decision was based on the headset's affordability, mobility, and compatibility with Unity's XR toolkit (Kavanagh et al., 2017; Yildirim et al., 2020). The VR system was structured to run offline, which was essential given the limited internet access in some classroom environments. User interface panels were developed using Unity's Canvas UI system, enabling overlays for instructions, tooltips, and quizzes.

2.4 Implementation and Testing Phase

Figure 2 shows the implementation and testing process began with users wearing VR headsets and calibrating controllers before logging into the simulation. Upon successful login, users accessed the main menu and entered "Explore Mode" to interact with virtual flight instruments. After completing this mode, users returned to the main menu to access "Quiz Mode" to assess their understanding. The system recorded responses, provided feedback, and allowed result review. This structured flow ensured both instructional exposure and assessment within a controlled VR environment. After the functional prototype was completed, pre and post test was conducted with 53 students. The goal of pre- and post-tests is to assess the effectiveness of instructional interventions by measuring learners' knowledge before and after training.

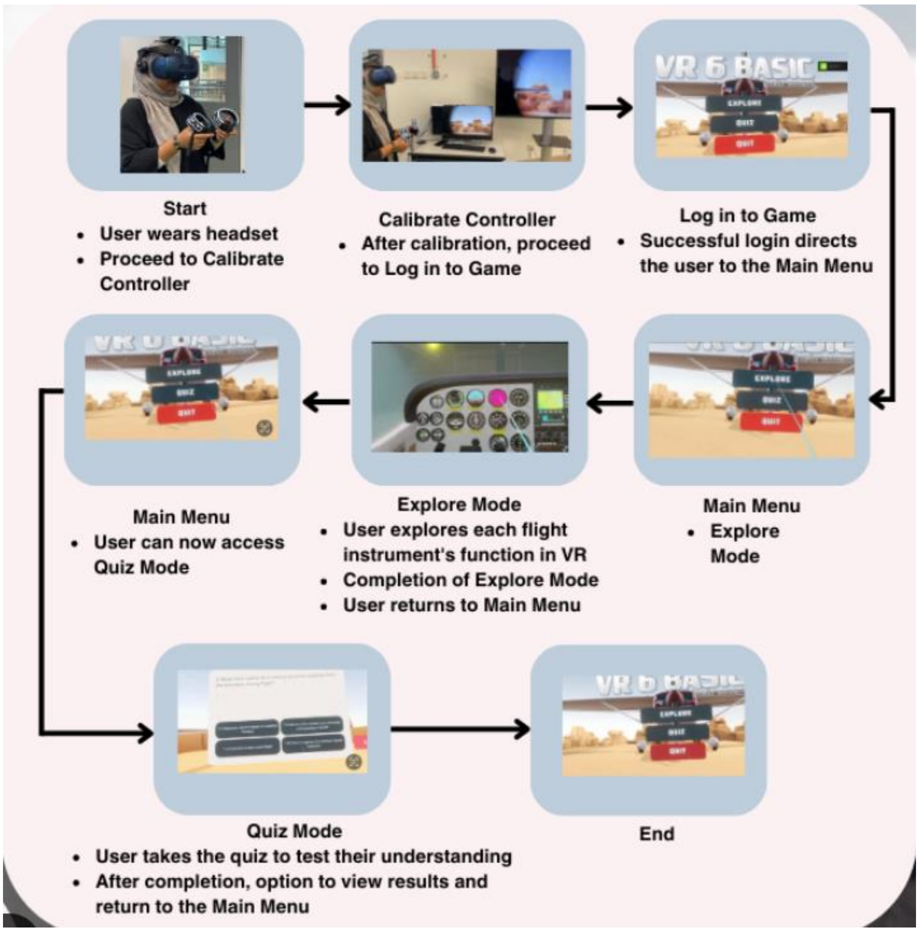

Figure 2: Implementation and testing phase

2.5 Evaluation and Analysis

Instructors observed a marked improvement in students' ability to identify and interpret the effectiveness. After the functional prototype was completed, pre and post test was conducted with 53 students. The goal of pre- and post-tests is to assess the effectiveness of instructional interventions by measuring learners' knowledge before and after training. Students completed a 10-question multiple-choice quiz focused on the function, reading, and interpretation of the six flight instruments before and after using the VR application.

3. Result and Discussion

3.1 Need Analysis

Findings revealed that while theoretical knowledge about flight instruments was covered in lectures, 60.4% students reported difficulty in identify aircraft instruments as shows in Figure 3, 64.2% struggle to grasp how aircraft instruments work and operate and 94% facing boredom in conventional method.

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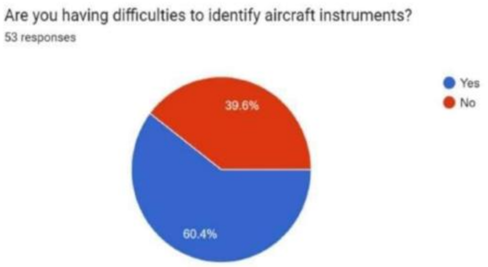

Figure 3: Survey finding to identifying the learning gap

To further substantiate these findings, a review of relevant literature was conducted. Prior studies confirmed that VR can enhance learning in technical domains by improving spatial visualization and procedural understanding (Johnson et al., 2022). Moreover, immersive simulations have been proven effective in aviation training by increasing learner engagement and retention (Dincer et al., 2023; Dela et al., 2024). Based on this, the research proceeded with the hypothesis that VR could bridge the theoretical-practical gap in flight instrument training.

3.2 General Product Features and Functionalities

Students can completely immerse themselves in a Cessna 172N Skyhawk cockpit with a dynamic, interactive virtual reality experience as shows in Figure 4. The software has two modes: "Quiz" to test users' knowledge and encourage learning, and "Explore" to allow users to explore the aircraft, sit in the pilot's seat, and receive comprehensive explanations and tutorials for each of the six fundamental flight instruments as shown in Figure 4. The goal is to provide a contemporary approach to experiential learning by making the study of aviation instruments both approachable and interesting.

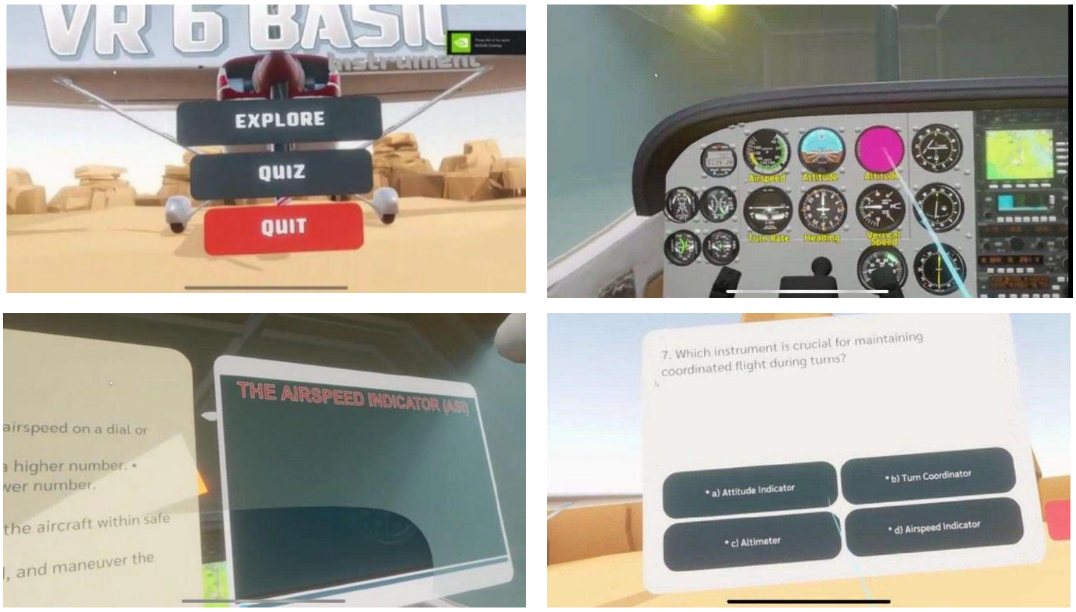

Figure 4: App's features

3.3 Learning Effectiveness

Table 3 shows the pre-test establishes baseline understanding with mean score was 52% reflects a moderate understanding among students, revealing several common areas where knowledge was lacking. This score reflects that, while some students had foundational knowledge of flight instruments, there were considerable gaps in their understanding of the specifics related to the Cessna 172N cockpit layout and instrument functions. The pre-test results suggest that most students would benefit from additional instruction, especially in areas requiring a deeper understanding of instrument operation and flight dynamics.

While the post-test evaluates knowledge gained through the learning experience shows mean score was 94% showcasing an impressive improvement in understanding. This improvement reflects the effectiveness of the VRFI app in enhancing students' understanding, as they could interact directly with 3D models, access detailed explanations, and view video tutorials within the virtual environment. These immersive tools appear to have played a crucial role in bridging knowledge gaps identified in the pre-test.

Table 3: Pre and Post Test Result

	N	**Mean**
Pre-test	53	52%
Post-test	53	94%

The VRAFI app's immersive 3D models, interactive explanations, and audio-visual guides likely contributed to this enhanced comprehension. The increase in scores suggests that students not only improved their ability to identify and interpret each instrument but also gained a deeper understanding of how these instruments function in real flight scenarios. Comparing both results helps determine the impact of the instructional method, in this case, the VR-based flight instrument simulation. Significant improvement in scores indicates effective learning and supports the validity of the educational tool, while minimal change may highlight areas for instructional improvement. This approach provides measurable, evidence-based insight into learning outcomes (Radianti et al., 2020).

Students who used the VR tool before theory revision showed a 42% average increase in quiz scores compared to peers who received only classroom instruction. This aligns with prior findings by González-Zamar and Abad-Segura (2021), who noted that VR significantly improves performance in procedural and spatial learning tasks.

4. Discussions

Based on the thesis findings, the integration of VR in flight instrument training significantly enhanced student comprehension, engagement, and learning outcomes. The 42% increase in post-test scores demonstrates the effectiveness of immersive visualization in reinforcing abstract aviation concepts. These results align with previous studies showing that VR fosters experiential learning, promotes spatial awareness, and increases learner motivation (Radianti et al., 2020; Jensen et al., 2022). Instructors also reported reduced instructional time and improved student readiness for hands-on tasks. While minor challenges such as motion sickness and device limitations were observed, they did not overshadow the educational benefits. The VR module functioned not only as a simulation but also as a self-paced, revision-friendly tool that supported blended learning strategies. The successful adoption of this tool supports broader calls for digital transformation in technical education, particularly in resource-limited environments (Garzón et al., 2021).

5. Conclusion

This study has demonstrated the effectiveness of VR as an innovative educational tool in flight instrument training for aircraft maintenance students. Through the development and deployment of a VR-based cockpit simulation, students were able to interact with and understand the function of key flight instruments altimeter, airspeed indicator, attitude indicator, heading indicator, vertical speed indicator, and turn coordinator in a realistic, immersive environment. The significant improvement in students' post-test scores and positive feedback from both learners and instructors affirm the potential of VR to enhance technical comprehension, engagement, and retention.

The use of VR addressed limitations in traditional instructional methods, such as the lack of real aircraft availability and reduced hands-on exposure. Furthermore, the self-paced nature of the simulation, combined with real-time feedback and interactive learning, offered learners a more flexible and engaging experience. Instructors noted improved classroom efficiency and better-prepared students for practical tasks.

Despite minor issues such as occasional motion sickness and device availability, the overall implementation was successful and well-received. The findings support wider integration of VR technologies in technical and vocational education, particularly in resource-constrained institutions seeking scalable and cost-effective solutions.

Future research should explore long-term retention effects, scalability across different aviation modules, and the integration of advanced analytics for personalized learning. With continuous refinement, VR has the capacity to revolutionize training delivery and elevate the quality of education in aviation and beyond.

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This research paper was prepared with the assistance of generative AI tools, including ChatGPT by OpenAI, which supported the drafting, language editing, and structuring of various sections. All content, findings, and interpretations remain the result of human-led research and decision-making, with AI tools serving as supplementary aids for improving clarity and academic quality.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this manuscript, the author(s) used OpenAI's ChatGPT to assist in improving the readability and language of the text. All content generated by ChatGPT was subject to thorough review, editing, and revision by the authors to ensure its accuracy, completeness and alignment with the research objectives. The author(s) take full responsibility for the integrity and content of the published work. This declaration complies with ICGESD 2025 guidelines on the use of generative AI in scientific writing.

References

Radianti, J., Majchrzak, T. A., Fromm, J., & Wohlgenannt, I. (2020). A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda. *Computers & Education*, *147*, 103778. https://doi.org/10.1016/j.compedu.2019.103778

Kavanagh, S., Luxton-Reilly, A., & Wuensche, B. (2017). A systematic review of virtual reality in education. *Themes in Science and Technology Education*, *10*(2), 85–119.

Jensen, L., Pedersen, M., & Konradsen, F. (2022). Learning in immersive virtual reality: A scoping review and future research agenda. *Computers & Education*, *179*, 104429. https://doi.org/10.1016/j.compedu.2021.104429

Yildirim, G., Elban, M., & Yildirim, S. (2020). Analysis of use of virtual reality technologies in education: A content analysis. *Asian Journal of Education and Training*, *6*(1), 68–75. https://doi.org/10.20448/journal.522.2020.61.68.75

Lee, E. A. L., & Wong, K. W. (2021). An empirical review of using immersive virtual reality for student learning. *Education and Information Technologies*, *26*, 629–653. https://doi.org/10.1007/s10639-020-10239-7

González-Zamar, M.-D., & Abad-Segura, E. (2021). Virtual reality in the learning process: A bibliometric mapping in educational research. *Education Sciences*, *11*(6), 306. https://doi.org/10.3390/educsci11060306

Al-Azzam, A., & Ramkumar, M. (2023). *Virtual reality applications in aviation education and training: Opportunities and challenges*. Journal of Aviation Technology and Engineering, 12(1), 45–58. https://doi.org/10.7771/2159-6670.1285

Johnson, C. I., Bailey, S. K., Schroeder, B. L., & Marraffino, M. D. (2022). Procedural learning in virtual reality: The role of immersion, interactivity, and spatial ability.

Dinçer, N. (2023). Elevating aviation education: A comprehensive examination of technology's role in modern flight training. *Journal of Aviation*, *7*(2), 317-323.

Dela Peña, A. (2024). Virtual Reality in Aircraft Maintenance Training: Transforming Student Engagement and Competency Development. *Available at SSRN 5294472*.

Federal Aviation Administration. (2022). *Pilot's handbook of aeronautical knowledge* (FAA-H-8083-25C). U.S. Department of Transportation. https://www.faa.gov

Garzón, J., Pavón, J., & Baldiris, S. (2021). Systematic review and meta-analysis of the effectiveness of augmented reality in educational settings. *Virtual Reality*, *25*(4), 919–933. https://doi.org/10.1007/s10055-020-