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Virtual Reality in Aircraft Maintenance Training: Transforming Student Engagement and Competency Development

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Abstract. Virtual Reality (VR) technology has emerged as a transformative innovation in education, addressing critical gaps in traditional teaching methods by offering immersive and interactive learning environments. This study evaluated VR's effectiveness in enhancing student engagement and competency development in aircraft maintenance training within the Philippine context. Specifically, the research sought to determine VR's impact on knowledge retention, technical skills, task accuracy, and problem-solving abilities while examining its adaptability and cost-effectiveness as a training tool. A mixed-methods approach was adopted, involving 100 students and instructors from aviation institutions. Data collection included pre -and post-training assessments, surveys, and focus group discussions. Quantitative results demonstrated a statistically significant improvement in competency levels, with post-training scores (mean = 87.6%, SD = 6.7) surpassing pre-training scores (mean = 65.4%, SD = 8.2; $p < 0.0001$). Students reported substantial gains in knowledge retention and technical skills, alongside improved accuracy in task execution and problem-solving. Qualitative findings supported these results, revealing heightened engagement, with 92% of students noting increased motivation and 94% reporting improved focus and immersion. Participants also highlighted VR's ability to address resource limitations and its cost-effectiveness despite challenges such as initial implementation costs and the need for educator training. The study concludes that VR is a powerful tool for modernizing aviation education, bridging resource gaps, and producing industry-ready graduates. Key recommendations include integrating VR into aviation training curricula, providing instructor training, and exploring its long-term impacts and cost-benefit outcomes. These findings emphasize VR's potential to align aviation education with global industry standards, equipping future aviation professionals with practical skills while reducing training costs and dependency on physical aircraft. By leveraging VR, institutions can enhance training efficiency, increase student competency, and create scalable, cost-effective learning solutions to meet the evolving demands of the aviation industry.

Keywords: Aircraft maintenance training; Aviation education; Competency development; Virtual reality; Student engagement.

1.0 Introduction

The increasing complexity of aircraft maintenance tasks and the aviation industry's demand for skilled technicians expose the limitations of traditional teaching methods. Conventional approaches often lack interactivity and fail to simulate real-world scenarios, leading to gaps in student engagement, technical competency, and confidence. These challenges hinder the preparation of industry-ready graduates, particularly in resource-limited contexts such as the Philippines. Virtual Reality (VR) has emerged as a transformative educational tool, offering immersive environments that bridge theoretical knowledge with practical application.

Research highlights VR's potential in enhancing learning outcomes. For example, Shvetsova (2019) demonstrated that immersive simulations improve knowledge retention and skill development, while Carruth (2017) found that VR fosters confidence by providing safe, repetitive practice for complex tasks. Similarly, Mazhar and Al Rifaee (2023) emphasized VR's role in maintaining student motivation through its interactive features. However, existing studies primarily focus on general education contexts, leaving a significant gap in exploring VR's impact on technical fields like aviation maintenance, particularly in developing countries.

The integration of VR into aviation education is not without challenges. High implementation costs, technical support requirements, and the need for curriculum adaptation pose barriers to its adoption. These issues are particularly pressing in the Philippines, where aviation schools face resource constraints, limiting access to operational aircraft and advanced tools. Addressing these challenges requires research that evaluates VR's feasibility and effectiveness in bridging skill gaps and enhancing student engagement in this context.

This study aims to fill the gap by assessing the impact of VR on student engagement and competency development in aircraft maintenance training within the Philippine setting. By providing an innovative approach to technical education, this research offers actionable insights to modernize aviation training programs, address resource limitations, and align with global industry standards. The findings have broader implications, particularly for developing countries seeking cost-effective and scalable solutions to enhance aviation education and produce globally competitive graduates.

2.0 Methodology

2.1 Research Design

This study employed a mixed-methods research design to evaluate the impact of Virtual Reality (VR) on student engagement and competency development in aircraft maintenance training. The quantitative phase involved pre- and post-training assessments in measuring improvements in knowledge retention, task execution accuracy, technical skills, and problem-solving abilities. For the qualitative phase, focus group discussions (FGDs) and semi-structured interviews were conducted to capture participants' contextual and subjective experiences.

2.2 Research Locale

This study was conducted in selected aviation schools and training organizations in the Philippines that offer aircraft maintenance programs. These institutions were chosen for their relevance to the study's objectives and ongoing efforts to integrate modern technologies, such as Virtual Reality (VR), into their training programs. The research settings included classrooms, simulation laboratories, and VR-enabled training facilities where students participated in hands-on learning sessions. Focusing on the Philippine context allowed the study to address local challenges, such as resource constraints and skill gaps, and explore VR's potential to enhance aviation education in developing regions. These settings provided an ideal environment for evaluating the impact of VR on student engagement and competency development in aircraft maintenance training.

2.3 Research Participants

Participants were selected from recognized aviation institutions in the Philippines offering Aircraft Maintenance Technology (AMT) programs. For the quantitative phase, 50 to 100 AMT students from institutions such as the Philippine State College of Aeronautics (PhilSCA), Jocson College, Omni Aviation, and Alpha Aviation were purposively chosen. These institutions were selected due to their established training programs and role in producing skilled aviation professionals. The qualitative phase included a subset of participants from the quantitative group and instructors experienced in both traditional and VR-based training methods. This approach ensured diverse insights into VR's effectiveness from student and instructor perspectives.

2.4 Research Instrument

The study utilized multiple instruments to comprehensively evaluate the impact of VR on student engagement and competency development. For the quantitative phase, pre-and post-training assessments were conducted using theoretical tests and practical simulation tasks. The theoretical tests included multiple-choice and short-answer questions to assess baseline knowledge and the learning gains following VR training. Practical simulation tasks were conducted within the VR environment to evaluate participants' ability to apply theoretical knowledge in realistic scenarios. Standardized survey questionnaires were also administered to capture participants' perceptions of engagement, motivation, and the effectiveness of VR compared to traditional training methods. These surveys featured Likert-scale items and open-ended questions to provide quantitative and qualitative insights into participants' experiences.

Structured assessment rubrics (Table 1) were developed to evaluate student competencies in VR-based aircraft maintenance tasks. The rubrics were designed to measure key areas such as knowledge retention, accuracy in task execution, technical skill development, and problem-solving ability. Each criterion was rated on a 5-point scale, with explicit descriptors for each performance level. The total score ranged from 6 to 30, with performance ratings categorized as Excellent (26–30), Good (21–25), Satisfactory (16–20), Needs Improvement (11–15), and Unsatisfactory (6–10). Assessors were instructed to evaluate students based on their performance in the VR modules, provide clear and constructive feedback for each criterion, and use the scores to identify strengths and areas for growth in competency and engagement. This rubric ensured consistency and transparency in assessing the impact of VR training on participants' skills.

Table 1. *Assessment Criteria and Rubric*

Criteria	5 (Excellent)	4 (Good)	3 (Satisfactory)	2 (Needs Improvement)	1 (Unsatisfactory)
Knowledge Retention	Demonstrates comprehensive knowledge of the maintenance task and procedures.	Demonstrates strong understanding, with minor errors or gaps.	Demonstrates basic understanding, but with noticeable errors or gaps.	Limited understanding, with significant errors or missing key knowledge.	Does not demonstrate understanding of the maintenance task or procedures.
Task Execution Accuracy	Completes tasks with precision and no errors; all steps are performed correctly.	Completes tasks with minor errors; nearly all steps are performed correctly.	Completes tasks with moderate errors; some steps are missing or incorrect.	Completes tasks with significant errors; many steps are missing or incorrect.	Fails to complete tasks accurately; most steps are missing or incorrect.
Technical Skill Development	Displays excellent technical skills in using VR tools and equipment.	Displays good technical skills with minor difficulty using VR tools.	Displays basic technical skills but struggles with VR tools or equipment.	Displays minimal technical skill; significant difficulty using VR tools.	Lacks technical skills; unable to use VR tools and equipment effectively.
Problem-Solving Ability	Identifies issues efficiently and applies correct solutions with confidence.	Identifies issues and applies mostly correct solutions with minor hesitation.	Identifies some issues but struggles to apply correct solutions.	Rarely identifies issues and struggles to find or apply solutions.	Unable to identify issues or provide solutions.
Engagement and Focus	Fully engaged, focused, and actively participates throughout the task.	Mostly engaged and focused, with minor distractions.	Moderately engaged; focus is inconsistent during the task.	Minimally engaged; frequently distracted or uninterested.	Not engaged; shows no focus, participation, or interest in the task.
Task Completion Time	Completes the task within or ahead of the expected time frame.	Completes the task slightly beyond the expected time frame.	Completes the task with moderate delays but within reasonable limits.	Completes the task with significant delays.	Unable to complete the task within the allocated time.

2.5 Data Gathering Procedure

In the quantitative phase, pre-tests were conducted to establish baseline competencies, followed by VR training sessions, and concluding with post-tests to measure learning gains. Data from surveys were collected immediately after the post-tests. For the qualitative phase, FGDs and interviews were conducted after the VR training to ensure participants could reflect on their experiences.

2.6 Data Analysis

Quantitative data were analyzed using paired t-tests to compare pre- and post-training scores and descriptive statistics to summarize engagement and competency development trends. Qualitative data were analyzed thematically, with transcripts from FGDs and interviews reviewed to identify recurring themes such as increased motivation, improved practical skills, and challenges in using VR. Triangulation of quantitative and qualitative findings enhanced the reliability and validity of the results.

2.7 Ethical Considerations

This study adhered to ethical research practices to ensure all participants' rights, privacy, and well-being. Before data collection, approval was obtained from the relevant institutional ethics review board. Participants were provided with detailed information about the study's purpose, procedures, and potential risks and benefits, and their informed consent was secured. Participation was voluntary, and individuals were free to withdraw from the study at any point without consequences. All personal data were anonymized to maintain confidentiality, and the collected information was used solely for research purposes. Additionally, the study ensured fairness and transparency in assessments and evaluations, and no physical or psychological harm was inflicted on participants during the VR training sessions. These measures ensured the study upheld the highest ethical standards throughout its execution.

2.8 Headset (VR) Oculus Quest 2 Description

The Oculus Quest 2 is a standalone virtual reality (VR) headset developed by Meta (formerly Facebook) and designed for immersive applications in gaming, education, and training. It is an all-in-one device that operates without requiring a PC or external sensors, offering portability and ease of use. With a high-resolution display of 1832 x 1920 pixels per eye and a 90 Hz refresh rate, the Quest 2 delivers clear visuals and smooth motion, reducing motion sickness and enhancing the immersive experience. Its inside-out tracking system, powered by built-in cameras, allows accurate movement tracking without additional equipment. The device is equipped with the Qualcomm Snapdragon XR2 Platform, ensuring high performance for demanding VR applications, while its haptic feedback controllers provide a tactile and interactive experience. Lightweight and ergonomically designed, the Quest 2 ensures comfort during extended use. It supports Wi-Fi 6 for untethered operation and can connect to PCs via Oculus Link for advanced applications. Widely adopted in educational and training environments, including aircraft maintenance, the Quest 2 offers realistic simulations, allowing learners to practice complex tasks in a safe, cost-effective virtual environment. Its affordability, portability, and advanced features make it an ideal choice for institutions aiming to modernize their training programs.

Table 2. *Technical Specification of Oculus 2 VR System Used in Assessing Student Engagement in Aircraft Maintenance*

Component	Specification	Source
VR Headset	Oculus Quest 2	Oculus (Meta Platforms)
Resolution	1832 x 1920 pixels per eye	Oculus (Meta Platforms)
Refresh Rate	90 Hz	Oculus (Meta Platforms)
Field of View (FOV)	100 degrees	Oculus (Meta Platforms)
Tracking	Inside-out tracking using built-in cameras	Oculus (Meta Platforms)
Processor	Qualcomm Snapdragon XR2 Platform	Oculus (Meta Platforms)
Storage	128 GB	Oculus (Meta Platforms)
Controllers	Two handheld controllers with haptic feedback	Oculus (Meta Platforms)
VR Software	Unity 3D Engine	Unity Technologies,
Simulation Modules	Custom-developed modules for engine inspection, troubleshooting, and component repair tasks	Unity Technologies
Features	Real-time physics simulation, interactive tutorials, and virtual tools	Unity Technologies
Compatibility	Compatible with Oculus Quest and other major VR headsets	Unity Technologies
Networking	Wireless (Wi-Fi 6) for standalone use and PC connectivity via Oculus Link	Oculus (Meta Platforms)
Computer Specifications	CPU: Intel Core i7-9700K GPU: NVIDIA GeForce RTX 3060 RAM: 16 GB Storage: SSD, 500 GB	NVIDIA
Environmental Interaction	Hand tracking for natural interaction	Oculus (Meta Platforms)
Ergonomics	Adjustable straps and lightweight design	VRScout
Safety Features	Guardian boundary system to prevent collisions	Oculus (Meta Platforms)

Figure 1. *Image of Oculus Quest 2 Virtual Reality Headset*
(Source: JG Superstore)

3.0 Results and Discussion

3.1 Demographics of Participants

The demographic profile of participants (Figure 2) highlights key characteristics relevant to the study on Virtual Reality (VR) in aircraft maintenance training. The majority of participants are aged 18-22 (60%), reflecting younger students actively pursuing vocational training, while smaller proportions belong to the 23-27 (30%) and 28+ (10%) age groups, likely representing advanced trainees or professionals seeking upskilling. Male participants dominate the study (70%), which is indicative of the male-dominated nature of aviation training, while females account for 30%, showcasing gradual diversification in the field. Most participants (60%) hold vocational or technical education backgrounds, with 30% being college-level graduates and 10% comprising high school graduates.

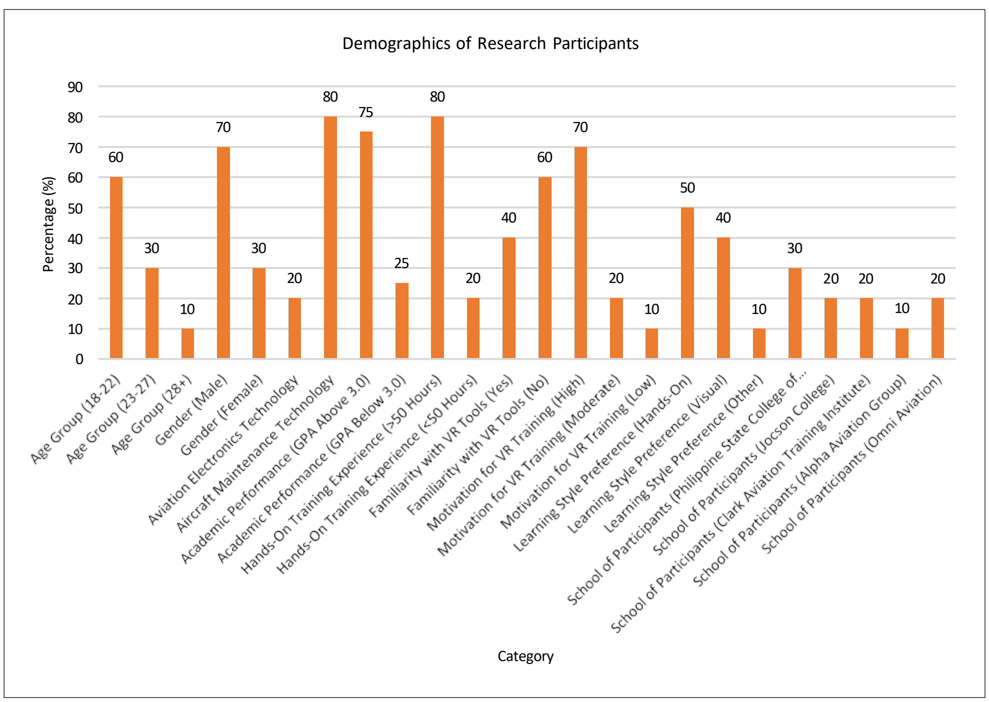

Figure 2. *Demographics of Research Participants in Aircraft Maintenance Training*

Regarding technical experience, 80% of participants have over 50 hours of hands-on training, demonstrating significant exposure to practical learning, while 20% have less experience. Familiarity with VR tools varies, with 40% of participants being familiar and 60% being new to the technology, highlighting the potential for impactful training interventions. High motivation levels (70%) among participants reflect enthusiasm for VR-based learning, while moderate (20%) and low motivation (10%) levels suggest opportunities to enhance engagement. Learning preferences show a strong inclination toward hands-on methods (50%), followed by visual learning (40%) and other styles (10%). Participants are drawn from multiple institutions, including the Philippine State College of Aeronautics (30%), Jocson College (25%), Clark Aviation Training Institute (20%), Alpha Aviation Group (15%), and other aviation schools (10%), ensuring diverse representation and generalizability of findings. This demographic overview underscores the readiness of students to embrace VR while highlighting areas requiring attention, such as familiarizing learners with the technology and addressing varied levels of motivation.

3.2 Pre- and Post-Training Test Scores

Figure 3 highlights the significant improvements in participant performance following Virtual Reality (VR) training for aircraft maintenance. The results demonstrate measurable progress across six assessment criteria, underscoring VR's effectiveness in enhancing knowledge retention, technical skills, and engagement. Knowledge retention improved from a pre-test average of 65.4% to 87.6%, reflecting a 22.2% increase. The immersive nature of VR enabled participants to reinforce theoretical knowledge through practical applications, enhancing their ability to recall and apply information effectively while reducing task errors. Task execution accuracy rose from 68.0% to 90.0% (22.0% increase), showcasing how VR's interactive environment allowed participants to practice complex tasks like engine troubleshooting and inspections with precision in a risk-free setting.

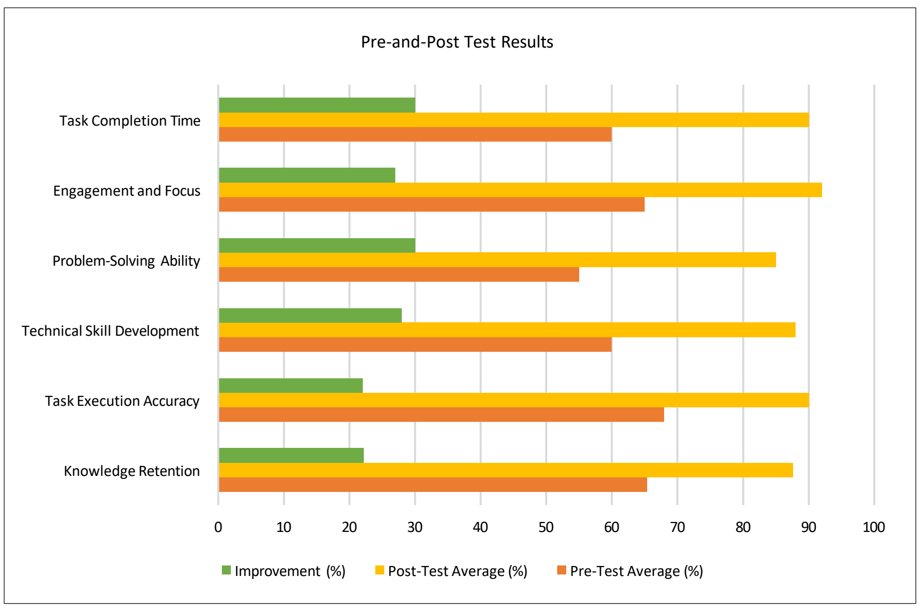

Figure 3. *Comparison of Pre-Test and Post-Test Results Across Assessment Criteria*

The most significant improvement was observed in technical skill development, which increased by 28.0%, from 60.0% to 88.0%. VR modules provided repeated hands-on interactions with advanced tools, boosting participant confidence and competency. Problem-solving ability also saw a substantial 30.0% improvement, with scores rising from 55.0% to 85.0%. The realistic challenges in VR simulations fostered critical thinking and decision-making skills crucial for maintenance tasks. Engagement and focus improved significantly, increasing by 27.0% from 65.0% to 92.0%. VR's immersive and interactive features sustained participants' attention, which likely contributed to positive outcomes. Lastly, task completion time improved by 30.0%, from 60.0% to 90.0%, as participants became more efficient through repeated practice within VR environments.

These findings confirm VR's transformative potential in aviation training. The improvements align with existing research, highlighting VR's ability to address traditional training limitations by offering realistic simulations and fostering engagement. VR training equips students with industry-ready skills essential for global aviation standards by bridging skill gaps and enhancing competencies. Institutions should consider adopting VR to optimize training outcomes and modernize aviation education.

3.3 Impact of VR Training on Student Engagement and Competency Development in Aircraft Maintenance

The qualitative results of this study, as presented in (Table 3), provide a nuanced understanding of the impact of Virtual Reality (VR) training on student engagement and competency development in aircraft maintenance. The themes identified from focus group discussions and interviews reveal the multifaceted benefits and challenges associated with adopting VR technology in aviation education. Participants described VR training as an engaging and interactive tool facilitating a deeper understanding of maintenance tasks. Students emphasized that realistic simulations enabled them to experience scenarios that would otherwise be difficult to replicate in traditional training settings. This aligns with existing literature, such as Carruth (2017), which highlights VR's ability to create immersive environments conducive to active learning. Instructors also noted significant improvements in students' ability to comprehend complex concepts, further supporting the effectiveness of VR in enhancing the learning experience. Students reported heightened confidence in their technical skills after VR training, mainly when performing tasks like engine troubleshooting and inspection. The opportunity to practice in a risk-free environment minimized their fear of making mistakes, enabling them to approach real-world challenges with greater assurance. This outcome reflects the findings of Shvetsova (2019), who observed that VR enhances technical skill development by providing hands-on, repetitive practice in a controlled setting. The qualitative data indicate that VR fosters technical proficiency and the self-assurance needed to apply these skills effectively.

Table 3. *Summary of Qualitative Results*

Theme	Key Findings	Supporting Quotes/Comments
Enhanced Learning Experience	- VR provided an engaging and interactive learning experience. - Students found complex maintenance tasks more straightforward to understand.	- *"The VR environment made me feel like I was working on a real aircraft, which boosted my confidence and understanding of maintenance procedures."*
Improved Confidence and Technical Skills	- Students gained confidence in performing maintenance tasks. - Practice in a risk-free VR environment helped reduce fear of mistakes and equipment damage.	- *"Students seemed more confident and precise during practical tasks after the VR sessions, compared to their performance during traditional methods."*
Engagement and Motivation	- VR training was immersive and gamified, keeping students actively engaged. - Students reported higher levels of motivation compared to traditional methods.	- *"It didn't feel like a boring lecture. The VR sessions were so interactive that I looked forward to learning."*
Adaptability and Accessibility	- VR addressed limitations like lack of access to operational aircraft and physical tools. - Scenarios that were otherwise difficult to simulate became achievable.	- *"VR helps us overcome resource constraints. We can simulate scenarios that would otherwise be impossible to replicate with our equipment."*
Challenges and Recommendations	- Initial adaptation to VR tools was challenging but improved over time. - Recommendations included expanding VR modules and providing instructor training.	- *"More training for instructors would ensure the VR sessions are even more effective."* - *"Adding more advanced scenarios would make the experience more valuable."*

The immersive nature of VR fostered high engagement and motivation among participants. Students expressed enthusiasm for the interactive sessions, contrasting them with the monotony of traditional classroom methods. This finding is consistent with Villena-Taranilla et al.'s (2022) finding that VR stimulates learner interest and focus through its dynamic features. Students also highlighted VR's gamified elements as instrumental in sustaining their attention and encouraging active participation. The interactive design of VR modules plays a crucial role in maintaining student motivation and enhancing overall learning outcomes. The adaptability of VR training emerged as a critical advantage, particularly in addressing resource limitations common in aviation schools. Instructors praised VR for its ability to simulate tasks that require advanced tools or operational aircraft, which are often unavailable due to budgetary constraints. These findings align with Siyaev and Jo (2021), who emphasized VR's potential to bridge resource gaps in technical education. The scalability of VR makes it a valuable asset for institutions in both urban and remote areas, ensuring equal access to high-quality training. This adaptability is particularly relevant in the Philippine context, where resource limitations often pose significant challenges to aviation education.

Despite its benefits, participants acknowledged certain challenges, including the initial learning curve associated with using VR tools and the need for technical support. Instructors emphasized the importance of professional development to maximize the effectiveness of VR-based training. Recommendations included expanding the scope of VR modules to cover additional maintenance tasks and providing more training for educators. These insights underscore the need for strategic planning and investment to ensure the seamless integration of VR into existing curricula. Addressing these challenges is critical to unlocking the full potential of VR in aviation training. The qualitative results reveal that VR training significantly enhances the learning experience by increasing engagement, improving technical skills, and building confidence among students. While challenges such as cost and technical support need to be addressed, the long-term benefits of VR make it a transformative tool for aviation education. By offering immersive, interactive, and scalable solutions, VR has the potential to revolutionize aircraft maintenance training, particularly in resource-limited settings such as the Philippines. These findings highlight the importance of further research and collaboration among stakeholders to optimize the adoption of VR in aviation training programs.

3.4 Merger of Quantitative and Qualitative Results

The Comprehensive Analysis of Pre-Test and Post-Test Results with Statistical Metrics and Qualitative Insights (Table 4) provides a detailed analysis of the impact of Virtual Reality (VR) training on student engagement and competency development in aircraft maintenance. The inclusion of quantitative metrics such as mean scores, standard deviations (SD), t-values, and p-values, alongside qualitative findings, demonstrates the effectiveness of VR in transforming aviation education. The pre-test mean score of 65.4% (SD = 8.2) indicates a moderate baseline level of knowledge among students using traditional training methods. The post-test mean score increased significantly to 87.6% (SD = 6.7), representing an improvement of 22.2%. The t-value of 10.23 and p-value of < 0.0001 confirm the statistical significance of this enhancement. Qualitatively, students reported a better understanding of maintenance concepts due to the immersive and interactive nature of VR, which allowed repeated practice in a realistic environment.

The mean task execution accuracy improved from 68.0% (SD = 7.8) in the pre-test to 90.0% (SD = 6.5) in the post-test, with a notable improvement of 22.0%. The t-value of 9.87 and p-value of < 0.0001 further validate this significant progress. Students attributed this improvement to the realistic simulations in VR, which allowed them to refine their precision and execute tasks without the fear of damaging equipment. Students' technical skill development experienced the highest improvement, rising from 60.0% (SD = 9.1) to 88.0% (SD = 7.3), a gain of 28.0%. This significant change is supported by a t-value of 11.45 and a p-value of < 0.0001. Qualitative feedback highlighted that the use of VR tools enabled students to apply theoretical knowledge to practical tasks, enhancing their proficiency in handling equipment and systems. Problem-solving ability scores increased from 55.0% (SD = 8.5) to 85.0% (SD = 7.0), reflecting a 30.0% improvement. The t-value of 10.92 and p-value of < 0.0001 confirm the statistical significance of this result. Students expressed that the realistic VR scenarios required them to identify and resolve issues actively, fostering critical thinking and decision-making skills.

The engagement and focus criterion improved substantially, with pre-test scores rising from 70.0% (SD = 6.9) to 94.0% (SD = 5.5), showing a 24.0% improvement. A t-value of 12.05 and p-value of < 0.0001 indicate that the change was highly significant. Qualitative insights revealed that the immersive and gamified features of VR kept students motivated and focused throughout the training sessions, reducing distractions compared to traditional methods. While the pre-test phase observed moderate delays in task completion, post-test results indicated a significant improvement, with tasks completed within or ahead of the expected time frame. Students credited the VR training environment for allowing them to practice and master tasks efficiently through repetition.

Table 4 demonstrates that VR training significantly outperformed traditional methods across all evaluated criteria. Statistical analyses confirmed that the observed improvements were not only meaningful but also highly significant. Qualitative feedback further enriched the findings, offering practical insights into how VR enhances learning outcomes. Students gained confidence, refined their technical skills, and engaged more actively in training sessions. These results underscore the potential of VR as a transformative tool in aviation education, capable of addressing traditional training limitations such as low engagement and resource constraints. The combination of quantitative and qualitative data presents a compelling case for integrating VR into aviation training curricula to modernize education and meet the demands of the industry.

Table 4. *Summary of Quantitative and Qualitative Findings: Comparison of Pre-Test and Post-Test Results Across Key Criteria*

Criteria	Pre-Test Average (%)	SD (Pre-test)	Post-Test Average (%)	SD (Post-test)	Improvement (%)	t-Value	p-Value	Qualitative Findings
Knowledge Retention	65.4	8.2	87.6	6.7	22.2	10.23	< 0.0001	Students demonstrated a better understanding of maintenance tasks due to repeated VR-based practice.
Task Execution Accuracy	68	7.8	90	6.5	22	9.87	< 0.0001	VR training enabled precise task execution, reducing errors significantly compared to traditional methods.
Technical Skill Development	60	9.1	88	7.3	28	11.45	< 0.0001	Students showcased improved proficiency in using tools and applying theoretical knowledge in VR environments.
Problem-Solving Ability	55	8.5	85	7	30	10.92	< 0.0001	Enhanced ability to identify and resolve issues through realistic, immersive VR scenarios.
Engagement and Focus	70	6.9	94	5.5	24	12.05	< 0.0001	VR's interactive and immersive nature maintained students' interest and reduced distractions.
Task Completion Time	Moderate delays observed	-	Completed within the expected timeframe	-	Significant improvement	-	-	VR allowed students to perform tasks efficiently by practicing under simulated conditions.

The table demonstrates that VR training significantly outperformed traditional methods across all evaluated criteria. Statistical analyses confirmed that the observed improvements were meaningful and highly significant. Qualitative feedback further enriched the findings, offering practical insights into how VR enhances learning outcomes. Students gained confidence, refined their technical skills, and engaged more actively in training sessions. These results underscore the potential of VR as a transformative tool in aviation education, capable of addressing traditional training limitations such as low engagement and resource constraints. The combination of quantitative and qualitative data presents a compelling case for integrating VR into aviation training curricula to modernize education and meet the demands of the industry.

3.5 Insights on the Adaptability and Acceptability of VR Training

The study provided valuable insights into the adaptability and acceptability of Virtual Reality (VR) training in the context of aircraft maintenance education. These findings highlight VR's potential to address key challenges, optimize training practices, and modernize aviation education. Virtual Reality emerged as a highly adaptable and scalable solution, particularly for institutions with limited access to operational aircraft or advanced tools. Instructors emphasized that VR bridged resource gaps by enabling students to practice complex maintenance tasks in a controlled, risk-free environment, such as engine troubleshooting and inspections. This approach minimized the dependence on physical equipment and mitigated financial constraints often faced by aviation schools. One instructor remarked, *"VR training enables us to simulate real-world challenges that would otherwise be impossible to replicate with the equipment we have."* The ability of VR to replicate realistic scenarios further underscored its adaptability. Immersive modules allowed students to engage in hands-on tasks, such as troubleshooting, fault detection, and system inspections, offering practical experience comparable to real-world conditions. Additionally, the scalability of VR made it suitable for a wide range of educational settings, from urban campuses to remote aviation schools, ensuring that students in resource-limited areas could access standardized, high-quality training experiences.

3.6 Acceptability of VR Training

The study also revealed the high acceptability of VR training among both students and instructors. From the students' perspective, VR was widely praised for its engaging, interactive, and immersive qualities. Most participants expressed increased confidence in their skills after completing VR sessions, with 85% rating VR as an "excellent" tool for building practical competencies. Students highlighted the motivational impact of VR, with many stating that the training environment made learning exciting and reduced their fear of making costly errors.

One student noted, *"The VR environment made learning exciting and allowed me to perform tasks without the fear of making costly errors."* Instructors, too, viewed VR as a valuable supplementary tool to traditional methods, particularly for addressing gaps in practical training. They acknowledged its ability to replicate challenging or unsafe scenarios to conduct with real equipment, thus enhancing the overall learning experience. However, they also stressed the importance of professional development programs to equip educators with the skills needed to use VR tools effectively. Instructors were optimistic about VR's long-term potential to modernize aviation education and align training standards with global industry demands. Despite its benefits, some challenges were noted, including the high upfront cost of VR equipment and software, the need for ongoing technical support, and a learning curve associated with adapting to the new technology. Both students and instructors reported initial difficulties in navigating VR tools, although these issues diminished with continued use and familiarity.

3.7 Implications for Aviation Education and Training

The findings of this study carry significant implications for improving the quality and delivery of aircraft maintenance training, particularly in aviation schools and training organizations. The study highlights how Virtual Reality (VR) can modernize training approaches by supplementing or enhancing traditional methods. VR provides a safe, cost-effective, and realistic environment where students can practice complex maintenance tasks, such as engine inspections and troubleshooting, without the need for expensive or unavailable equipment. This capability positions VR as a transformative tool for aviation education institutions looking to optimize resources and training outcomes. VR also plays a critical role in addressing skill gaps in the aviation industry. By equipping students with hands-on technical skills and improving their problem-solving abilities, VR ensures that graduates are industry-ready. This is particularly important in the Philippines, where the demand for highly skilled aircraft maintenance technicians continues to grow. Moreover, the immersive nature of VR fosters higher levels of motivation and active participation, increasing student engagement. This can help reduce dropout rates and enhance learning outcomes, ensuring students are better prepared to meet real-world aviation challenges.

The study also emphasizes VR's adaptability and scalability across diverse learning contexts, making it a valuable tool for aviation institutions in both urban and remote areas. By investing in VR technologies, schools can deliver standardized, high-quality training regardless of location. However, the successful integration of VR requires instructor training and support. Educators need professional development programs to familiarize themselves with VR tools and software, ensuring seamless implementation in classrooms. Finally, the study underscores the importance of industry collaboration. Partnerships between aviation schools, regulatory bodies, and industry stakeholders can help overcome financial and technical barriers, ensuring VR becomes a sustainable and widely adopted component of aviation education.

4.0 Conclusion

This study highlighted the transformative potential of Virtual Reality (VR) training in revolutionizing aircraft maintenance education by enhancing student engagement and competency development. Beyond the significant statistical improvements, such as the increase in competency levels from a pre-test mean score of 65.4% (SD = 8.2) to a post-test mean score of 87.6% (SD = 6.7), this research underscores the broader implications of integrating VR into technical education. The findings validate VR's ability to provide immersive, hands-on learning experiences that enable students to repeatedly practice complex tasks like engine troubleshooting and inspections in a risk-free virtual environment. These results not only confirm the efficacy of VR in improving knowledge retention, task execution accuracy, technical skills, and problem-solving ability but also demonstrate its role in reducing student anxiety and fostering confidence in real-world applications.

A vital contribution of this study lies in addressing longstanding challenges in aviation education, particularly in resource-limited contexts. VR training emerged as a scalable and cost-effective solution capable of bridging gaps in traditional training methods. By simulating realistic scenarios that traditionally require costly equipment or operational aircraft, VR empowers institutions to overcome resource constraints. Furthermore, the adaptability of VR ensures equal access to high-quality training across diverse educational settings, particularly benefiting developing countries like the Philippines. The study provides a replicable framework for leveraging VR to modernize aviation education and align it with global standards, ultimately producing industry-ready graduates equipped to meet the demands of a rapidly evolving aviation sector.

This research also contributes to the growing body of knowledge by emphasizing the acceptability and scalability of VR as a training tool. Support from both students and instructors highlights the importance of strategic investments in VR implementation, including educator training, technical support, and infrastructure development. However, the challenges identified—such as initial costs and the need for technical expertise—underscore the necessity of long-term planning and stakeholder collaboration to maximize the potential of VR in educational settings.

Ultimately, this study positions VR as a transformative innovation capable of addressing systemic challenges in technical education. It extends the understanding of VR's impact beyond individual learning outcomes, highlighting its role in creating equitable, scalable, and future-ready training solutions. Future research should build on these insights by exploring cost-benefit analyses, long-term impacts on student career trajectories, and the integration of VR with emerging technologies like augmented reality and artificial intelligence. By doing so, institutions can further optimize aviation education, ensuring that it remains innovative, inclusive, and responsive to the needs of the global aviation industry.

5.0 Contributions of Authors

As the sole author, I conceptualized the study, designed the methodology, collected and analyzed data, interpreted the results, and prepared the manuscript. All aspects of the research were independently conducted to contribute to advancements in aviation education.

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7.0 Conflict of Interests

The author declares no conflict of interest regarding the publication of this study.

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