

11-12-2025

Evaluating the Impact of Virtual Reality-Integrated Flight Training Compared to Traditional Methods on Student Pilot Performance

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This study evaluated the efficiency and effectiveness of traditional flight training methods compared to virtual reality (VR)-integrated instruction at a large FAA Part 141 university flight program. Through the integration of the Pre-Flight Immersion Laboratory for Operations Training (PILOT) Program, which used VR technologies to simulate real-world flight conditions, this research examined whether VR-integrated flight training resulted in differences in total flight hours required to complete a flight rating and checkride pass rate outcomes. Using a quasi-experimental design, internal flight program student learning achievement/progression data were analyzed to compare checkride pass outcomes between students trained via traditional methods and those utilizing the VR-integrated curriculum. Results suggest that VR-integrated flight training contributed to reduced total flight hours required to complete a flight rating while maintaining comparable checkride pass rates. VR-integrated flight instruction may help provide a more efficient approach to training new pilots. These findings have practical implications for curriculum design and training efficiency in collegiate flight training programs.

Recommended Citation:

Gu, Y., Pan, B., Vincenzi, D., & Liu, D. (2025). Evaluating the impact of virtual reality-integrated flight training compared to traditional methods on student pilot performance. *Collegiate Aviation Review International*, 43(2), 220–242. Retrieved from <https://ojs.library.okstate.edu/osu/index.php/CARI/article/view/10357/9188>

Introduction

The first step in pursuing an aviation career is obtaining a Private Pilot rating, with students typically choosing between Federal Aviation Administration (FAA) certified Part 61 or Part 141 flight schools (Federal Aviation Administration [FAA], 2024). Part 61 programs are generally more flexible and suited for independent learners, such as those training part-time or outside formal academic settings (Rotaru, 2024). In contrast, Part 141 programs follow a highly standardized and structured curriculum that is FAA-approved, with detailed lesson plans, stage checks, and minimum flight hour requirements that are lower than those of Part 61 (Rotaru, 2024). These Part 141 programs are commonly housed within universities as collegiate aviation programs, where students simultaneously pursue academic degrees in aviation-related fields in addition to obtaining the certifications required to become a professional pilot (Hampton et al., 2017). A bachelor's degree in aviation has also been linked to higher rates of airline hiring and long-term career advancement, highlighting the relevance of collegiate aviation programs (Smith et al., 2010).

Many collegiate aviation programs integrate airline-style flight training concepts early in Private Pilot instruction, beginning with flight simulator sessions and ground-based theoretical coursework before transitioning to hands-on in-airplane flight experience (Hampton et al., 2017). To further enhance student preparedness and address common training challenges, certain Part 141 institutions have implemented virtual reality (VR)-based immersive flight training programs that simulate preflight and in-flight scenarios as part of their flight course curricula. These VR-based simulation training programs often include components such as air traffic control (ATC) communication practice, preflight procedural labs, and advanced flight control simulation, providing students with immersive, risk-free environments to develop essential piloting skills. By bridging the gap between theory and practice, these VR-based initiatives may help build students' confidence and competence.

Traditional flight training methods are often resource-intensive, requiring significant time and financial investment (Dahlström, 2008). With advancements in immersive technology, VR has emerged as a promising tool for enhancing aviation training by potentially reducing required training hours while maintaining or improving pilot competency (Thomas et al., 2023). This study examined the impact of VR-integrated training on student pilot flight training outcomes, focusing on total flight hours and checkride success rates needed to obtain a Private Pilot rating. The objective was to evaluate whether a VR-enhanced training model could match or exceed the effectiveness of a traditional Private Pilot training curriculum. Specifically, the research explored whether incorporating VR could improve training efficiency and shorten the time to proficiency without compromising critical skill development.

Operational Definitions of Constructs Used in this Study

- **Oral Instruction Time:** The total number of hours students spend receiving instructor-led knowledge in designated oral instruction and examination rooms, as part of the approved training syllabus.

- **Simulator Time:** The total duration students engage in training using certified flight simulation devices, in accordance with the structured curriculum requirements of a university-based flight training program.
- **VR-Integrated Training:** VR-based training sessions that were included in the FAA-approved institutional curriculum but not counted towards the minimum flight hour requirements for course completion. These VR-based training sessions included three components: ATC communication practice, a preflight preparation lab, and flight simulation exercises.
- **Total Flight Time:** The combined number of hours a student accumulates in flight training, including both instructor-led and solo flights.
- **Checkride:** A comprehensive practical exam necessary for pilot certification, consisting of both an oral knowledge evaluation and an in-flight performance assessment.
- **Checkride Pass Rate:** The proportion of students who successfully complete both portions, oral and flight, of the checkride examination on their first attempt.

Definition of VR Environments in this Study

In this study, VR is defined as a fully immersive, computer-generated environment in which users interact with simulated aircraft systems, controls, and procedures through head-mounted displays and motion controllers (Guthridge & Clinton-Lisell, 2023). Augmented reality (AR) refers to the overlay of digital elements or instructional cues onto a real-world environment (Al-Ansi et al., 2023), whereas mixed reality (MR) combines both physical and virtual elements, allowing users to interact simultaneously with real and simulated components (Crogman et al., 2025). The Pre-Flight Immersion Laboratory referenced in this study incorporated elements of both VR and AR. While most procedural training occurred within a fully virtual cockpit and environment, the preflight inspection component utilized AR-based overlays that enable students to examine physical training aircraft while receiving digital annotations and system feedback. For the purposes of this research, both modalities were collectively described as VR-integrated training to reflect their shared immersive and interactive instructional design.

VR-Integrated Pre-Flight Immersion Laboratory for Operations Training (PILOT) Program Background

The VR-integrated Private Pilot training curriculum (Pre-Flight Immersion Laboratory for Operations Training [PILOT] Program) evaluated in this study consisted of three structured phases. The first phase comprised a four-week VR-based training module designed to introduce foundational flight knowledge and skills prior to aircraft operation. Students participated in weekly four-hour sessions, which included one hour of flight simulation, 30 minutes of ATC communication practice, 30 minutes in a preflight laboratory simulation, one hour of oral instruction with a certified flight instructor (CFI), and an additional hour of FAA Part 141-compliant simulator training. The second phase transitioned to in-aircraft flight instruction, delivered on a daily basis and supplemented by oral lessons conducted with an instructor and a student peer. This stage continued until students completed their first solo flight. The third and final phase focused on cross-country flight operations and end-of-course checkride preparation. Flight activities during this phase occurred daily or at a minimum frequency of three sessions per week, depending on student progress and aircraft availability.

VR Flight Simulation Curriculum and System

Three VR instructional domains, ATC communication, preflight inspection, and advanced flight control, were strategically selected to align with key skill categories outlined in the FAA Private Pilot Airman Certification Standards (ACS; FAA 2023). Specifically, ATC communication and preflight procedures correspond directly to discrete ACS task areas under Sections I and II, while advanced flight control encompasses multiple performance elements related to takeoff, landing, and stall recovery (FAA, 2023). These domains were chosen because they represent foundational procedural and decision-making components of early flight training that require strong spatial awareness, situational judgment, and repetitive practice to master. The VR-integrated training sessions were organized into daily modules aligned with the FAA's Private Pilot ACS (FAA, 2023). Students were expected to complete each assigned module on schedule, with any missed sessions required to be made up within the same week. Modules could also be repeated as needed to reinforce learning and ensure proficiency before advancing to subsequent phases of instruction.

Training was delivered through the university's VR-integrated flight simulator system, which combined desktop-based and headset-based simulation using commercially available VR software built on the X-Plane platform and custom-developed three-dimensional inspection modules. The hardware configuration included PC-based workstations equipped with head-mounted displays, motion-tracked controllers, and integrated ATC voice simulation, providing both interactive and procedural fidelity while maintaining scalability for group instruction (Refer to Figures 1, 2, 3). To ensure consistency, all specifications, task selections, and training conditions were standardized across participants. The VR training was offered at no additional per-hour cost beyond standard tuition fees, and instructional support was provided by trained staff within the simulation laboratory. Attendance was emphasized as a key component of program success, and continued access to supplemental training opportunities was contingent upon consistent participation and engagement.

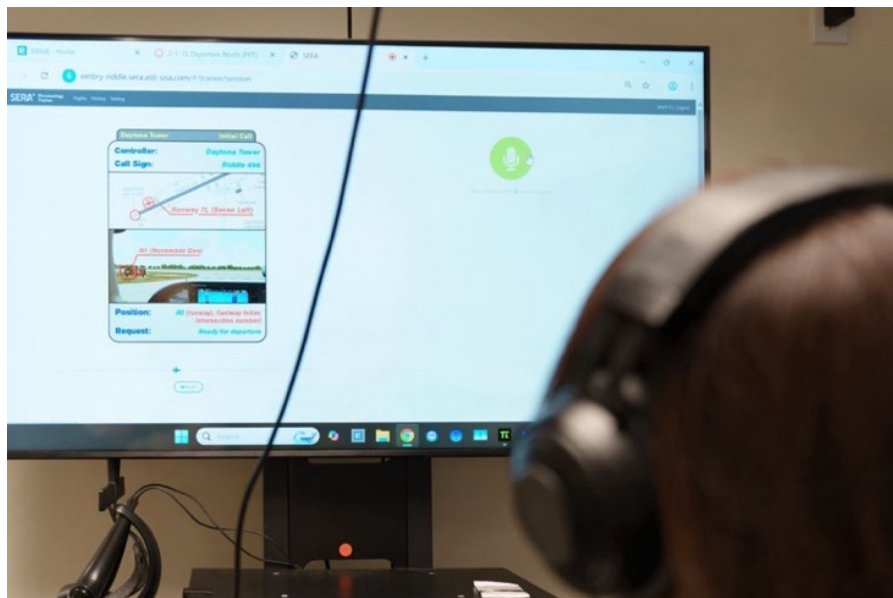
The VR flight simulation system was calibrated to replicate the specific aircraft model used later in the flight training program. This configuration featured realistic operational scenarios incorporating dynamic weather conditions and airport environments to enhance environmental realism and situational awareness. The system accommodated users with or without corrective eyewear and featured aircraft-representative controls, including throttle, mixture, and flap settings, with optional interaction through a mouse-based interface.

Figure 1
Pre-Flight Immersion Laboratory Simulator Setup



VR-Based ATC Communications Training. The ATC communication component of the VR-based training was scenario-based and designed in collaboration with aviation English experts. The full communication sequence from taxi clearance through departure from controlled airspace was simulated in each training module. A noise-canceling headset and integrated microphone captured student responses, which were automatically evaluated for alignment with standard ATC phraseology (Refer to Figure 2). This repeated exposure to realistic communication tasks aimed to improve student confidence and proficiency prior to initial flight operations.

Figure 2
ATC Communications Scenario within VR-Based Training Module



VR-Based Preflight Inspection Training. The preflight laboratory module utilized VR headsets and handheld controllers to simulate the preflight inspection process. One controller displayed and navigated the procedural checklist, while the other enabled physical interaction with aircraft components in the virtual environment (Refer to Figure 3). Procedures were modeled after industry-standard preflight protocols, and contextual hints were available to support independent student learning. This module enabled students to develop familiarity with inspection procedures in a controlled, risk-free environment that supported experiential learning and procedural accuracy.

Figure 3

Preflight Inspection Scenario within VR-Based Training Module



Review of Relevant Literature

The rapid advancement of VR technology has enabled new possibilities across industries, particularly in education and training. By enabling immersive, interactive experiences in controlled environments, VR technology is a powerful tool for enhancing learning, simulating complex scenarios, and delivering more personalized hands-on practice (Crogman et al., 2025; Dodevska et al., 2025). This literature review examines the practical applications and educational benefits of VR technology, with a focus on its growing role in the industry and flight training programs.

Applications of VR Technology

Research consistently highlights VR's positive effects on learning retention, student engagement, and accessibility, particularly in complex fields such as medical training, technical education, and psychological therapy (Elendu et al., 2024; Ifanova et al., 2023). For example, VR has been used to simulate real-world scenarios for medical procedures, military exercises, and complex assembly tasks, allowing learners to gain hands-on experience without the risks or costs of physical equipment (Ifanova et al., 2023). These simulations help bridge the gap between theoretical knowledge and practical application. VR also plays a critical role in expanding access to high-cost tools and technologies by providing realistic virtual alternatives, making advanced training more widely available (Elendu et al., 2024).

VR's ability to simulate complex, hard-to-access environments offers significant advantages for students by enabling practical, risk-free learning experiences and helping to overcome logistical barriers to traditional instruction (Virtual Reality Society, n.d.; Shin, 2002; Suria et al., 2023). For instance, desktop-based VR platforms have been used effectively in web-based science education, allowing students to explore geophysical and astronomical concepts through interactive, self-paced modules (Shin, 2002). Beyond education, VR has also shown promise in therapeutic settings, such as exposure therapy for anxiety and phobias, demonstrating its versatility as both a learning tool and a means of supporting mental well-being (Suria et al., 2023).

These applications highlight VR's potential to enhance conceptual understanding and student engagement through exploratory, hands-on learning. Collectively, these studies highlight VR as a tool for bridging cognitive, affective, and psychomotor learning domains. Across disciplines, VR-based learning may better promote engagement and retention by enabling learners to interact with content dynamically, which supports deeper conceptual understanding. These outcomes suggest that the instructional design of VR experiences, rather than the technology alone, may be the primary determinant of learning effectiveness (Makransky et al., 2019; Radianti et al., 2020). However, despite these benefits, widespread adoption still faces challenges, including high hardware costs, the need for faculty training, and difficulties integrating VR into existing curricula (Ifanova et al., 2023). As technology becomes more accessible and affordable, broader adoption in educational settings is likely to increase.

Educational Benefits and Theory of VR-Based Immersion Training

The educational benefits of VR-based training stem from its ability to replicate scenarios that are otherwise inaccessible due to logistical, safety, or financial constraints. VR technology enables opportunities to interact with simulated environments, such as distant geographies, historical events, or scientific phenomena, in ways that enrich traditional educational methods (Marougkas et al., 2023). Students can engage directly with content in a hands-on manner, which is particularly beneficial for visual and kinesthetic learners (Luberger, 2025). Additionally, VR's capability to transform abstract data into interactive, three-dimensional formats enhances student comprehension of complex systems, such as planetary motion or molecular structures (Virtual Reality Society, n.d.).

The theoretical foundation supporting VR-based training can be drawn from *Experiential Learning Theory* (Kolb, 1984) and *Constructivist Learning Theory* (Piaget, 1980). Both frameworks emphasize the role of active participation and reflection in constructing knowledge. Virtual reality environments embody these principles by immersing learners in interactive contexts where they can observe, perform, and refine tasks in real time (Lehrman, 2025). Through feedback loops and repetitive exposure, VR enables deeper cognitive processing and promotes skill mastery, making it particularly suited for the complex, procedural nature of flight training (Thomas et al., 2023).

Another emerging area of interest involves VR's influence on long-term knowledge retention, particularly within accelerated training environments. Makransky et al. (2019) found that immersive simulations enhanced memory retention by promoting cognitive engagement and contextual encoding. Similarly, Dela Peña (2025) observed that VR-based repetition in aviation maintenance training led to stronger recall and skill transfer after delays compared to traditional methods. In time-compressed flight programs, this suggests that VR may help mitigate knowledge decay by reinforcing procedural memory through interactive, scenario-based repetition.

VR Applications in Flight Training

In the aviation field, the potential of VR to supplement and enhance flight training has gained significant attention. Given the complexity, cost, and safety considerations of flight instruction, VR and extended reality offer an efficient alternative or supplement to traditional training environments (Marron et al., 2024; Somerville et al., 2025). By simulating realistic flight conditions, flight deck layouts, and emergency procedures, VR allows student pilots to develop technical and decision-making skills in a controlled, low-risk setting (Guthridge & Clinton-Lisell, 2023).

Applications in Primary (Ab-Initio) Flight Training

While much of the current literature focuses on commercial and airline training environments, comparatively few studies examine VR use in ab-initio or private pilot instruction. Lawrynczyk (2018) demonstrated that VR-based procedural training reduced time-to-proficiency during pre-solo phases, while Lewis and Livingston (2018) reported improvements in students'

confidence and systems knowledge but minimal change in overall flight hours. These findings suggest that the advantages of VR-based learning may be most evident in cognitive and procedural learning rather than direct reductions in training time. More targeted research is needed to determine how VR integration at the primary level influences measurable outcomes such as solo readiness and checkride pass rates.

Integration in Commercial and Airline Training

Recent airline industry adoption of VR-integrated training supports this shift. Alaska Airlines, for instance, implemented VR-based training modules in initial Boeing 737 ground training, replacing static diagrams with interactive, immersive instruction (Goodwillie, 2022). Such initiatives enhance pilot confidence and familiarity with aircraft systems before entering the cockpit (Thomas et al., 2023). VR's effectiveness extends beyond airline training to maintenance education, aircraft design, and procedural standardization across aviation roles (Fussell & Truong, 2020; Jensen & Konradsen, 2018).

Comparing Low-Fidelity VR and Certified Simulators

Studies comparing low-fidelity, non-certified VR systems with certified flight training devices (FTDs) provide valuable insight into the appropriate application of each technology. Jensen and Konradsen (2018) noted that while non-certified VR tools enhance procedural familiarity and situational awareness, they lack the motion and instrument realism critical for high-fidelity simulation. Fussell and Truong (2020) emphasized that VR functions best as a complementary tool, allowing students to rehearse tasks before engaging in FTD sessions. These findings underscore that VR should augment rather than replace certified simulators, reinforcing skill transfer through repeated exposure and contextual practice.

Advantages of VR-Based Immersive Learning in Flight Training

VR-based training offers key advantages in aviation education by providing instant feedback and personalized learning paths, allowing students to quickly correct errors and better understand aircraft systems and cockpit operations (Fussell & Truong, 2020). This real-time feedback loop is essential for mastering the complexities of flight, as it enables learners to refine skills through repetition and gain insight into the consequences of their actions. Multiple studies support the effectiveness of VR in teaching complex aviation tasks. Fussell and Truong (2020) emphasized how VR improves comprehension of aircraft systems and cockpit procedures. Jensen and Konradsen (2018) found that immersive VR environments enhance learning by fostering spatial awareness and procedural memory, both critical for pilot performance. Similarly, Marron et al. (2024) found that VR-based flight training strengthens cognitive and psychomotor skills, leading to improved situational awareness and responsiveness under pressure. These studies suggest that VR-based immersive learning can bridge theoretical knowledge and practical application, creating a more holistic and effective training environment that better mirrors real-world flight dynamics.

Summary

VR technology presents a transformative opportunity for both education and aviation training by offering immersive, adaptable, and scalable environments for skill development. In educational contexts, VR enhances access to complex systems, accommodates diverse learning styles, and fosters engagement with abstract concepts. In aviation, VR serves as a valuable supplement to traditional pilot training, allowing students to safely practice high-risk scenarios, reduce training costs, and build proficiency through repeated exposure and immediate feedback.

Growing interest and early success stories suggest a shifting trend toward greater adoption of VR technology. Continued research and testing are essential for evaluating the long-term impacts of VR-integrated flight training and supporting its broader integration into existing regulatory frameworks, such as FAA-approved curricula for primary flight instruction. As educational institutions and aviation programs seek innovative, cost-effective strategies to improve training outcomes, VR emerges as a potential solution. Realizing its full potential, however, will require sustained research, infrastructure investment, and institutional willingness to adapt. With appropriate implementation, the literature suggests that VR can significantly enhance the quality and efficiency of pilot training, ultimately contributing to safer and more effective aviation practice.

Despite the demonstrated benefits of VR in education and professional training, its integration into civilian flight training programs remains limited. Studies by Lawrynczyk (2018) and Lewis and Livingston (2018) reveal a persistent gap between VR's potential and its practical implementation within the aviation training sector. Key obstacles include organizational resistance to pedagogical change, substantial initial investment costs, and the absence of standardized VR instructional frameworks aligned with regulatory requirements (Akinradewo et al., 2025). While previous research consistently supports VR's effectiveness in enhancing engagement, procedural understanding, and cognitive skill development, empirical evidence on its long-term impact within structured flight training environments remains insufficient. Specifically, few studies have examined quantifiable outcomes such as training efficiency, student performance, and certification success rates. Synthesizing findings across disciplines and training application indicate consensus on VR's capacity to enrich learning experiences, yet uncertainty persists regarding its measurable effects on pilot proficiency and regulatory compliance. This inconsistency may stem from methodological variability, differences in simulator fidelity, learner populations, and assessment criteria, which underscores the need for systematic, data-driven research comparing VR-enhanced and conventional pilot training within standardized curriculums.

This study aimed to address this research gap by testing the following hypotheses:

H₀₁: There is no significant difference in oral hours between pilots trained with traditional training methods and those trained with VR training method.

H₀₂: There is no significant difference in simulation hours between pilots trained with traditional training methods and those trained with VR training method.

H₀₃: There is no significant difference in flight hours between pilots trained with traditional training methods and those trained with VR training method.

H₀4: There is no significant association between the type of training and the oral check-ride pass rates.

H₀5: There is no significant association between the type of training and the flight check-ride pass rates.

H₀6: There is no significant association between the type of training and the total check-ride pass rates.

Methodology

This study utilized a quasi-experimental design to compare pilot training outcomes between two independent groups: one group trained using a VR-enhanced curriculum and the other using traditional training methods. Existing data from an internal learning management system that tracked detailed metrics on oral instruction, simulator usage, flight hours, and check-ride performance were analyzed. Independent-samples *t*-tests were conducted to compare average training hours between the two groups, while chi-square tests were used to assess the relationship between training type and check-ride pass rates. All statistical analyses were performed using IBM Statistical Package for Social Sciences (SPSS) software to evaluate the impact of VR integration on training efficiency and student pilot performance.

Participants

The study population consisted of students enrolled in a large, university-based, FAA Part 141 flight training program who completed the Private Pilot course and obtained the rating. The sample included 159 students who received training through traditional flight instruction methods between late 2020 and mid-2021, and 421 students who participated in the VR-integrated flight training program implemented through the PILOT initiative from mid-2021 to mid-2024, as previously described in the introduction.

For the traditional training cohort (trained between late 2020 and mid 2021), data were collected from students who completed the private pilot course under a previous iteration of the flight school's FAA-approved Training Course Outline (TCO) that did not include VR-integrated components. The VR-integrated training cohort (trained between mid-2021 and mid-2024) comprised students who completed the course under the FAA-approved VR-integrated TCO implemented in mid-2021 up to when this research was conducted in mid-2024. The only modification between the two TCO curricula involved a reordering of modules to incorporate VR-integrated training activities. All other elements, including total course hours, instructional content, aircraft types, instructor assignments, admission standards, and assessment procedures, remained consistent across both cohorts.

Data Collection

Data for this study were obtained from an internal flight department student learning and training management system, which provided comprehensive and reliable records on key metrics such as total flight hours and checkride outcomes for students enrolled in the Private Pilot course. The collected dataset was anonymized to ensure participant confidentiality and was accessed with departmental approval, ensuring its ethical use and relevance to the study. To

ensure consistency, only students who completed the full course under a single training method were included in the analysis.

Instrument Reliability/Validity

Both instrument reliability and validity were ensured throughout the study through the use of the internal flight department student learning and training management system that systematically tracked key flight training metrics. Reliability was maintained through precise recording of Hobbs time, automatically calculated when simulation or aircraft devices are activated, and manually verified by dispatch staff during aircraft or simulator ramp-in and ramp-out procedures. Oral instruction time was logged based on mutual agreement between the instructor and student, with any discrepancies requiring documentation and approval from dispatch personnel or supervisory staff. Validity was supported by the system's detailed capture of training activities, including simulator and aircraft use as well as instructor-led instruction time, ensuring that the data accurately reflects intended constructs. Verification protocols, such as confirmation of oral contact time and reconciliation of Hobbs time discrepancies, further ensured data accuracy and integrity.

Treatment of the Data

Check-ride pass rates were coded for statistical purposes, with a pass coded as one and a failure as 0. Descriptive statistics were used to summarize the data, focusing on central tendency (mean, median, mode), variability (standard deviation, variance), and distribution (range, interquartile range, frequency distributions, and histograms). For hypothesis testing, the null hypothesis stated that no significant difference existed in training outcomes between the VR-integrated PILOT program and traditional flight training methods. Independent-samples *t*-tests were conducted to compare mean training hours between groups, while chi-square tests were used to examine the association between training type and checkride pass rates. Statistical significance was assessed at an alpha level of 0.05.

Results

This section presents the analysis comparing training outcomes between students trained using a traditional flight training program (Traditional Training Group) and those who trained through a VR-integrated flight training program (VR Training Group) to obtain a Private Pilot rating. The metrics compared were oral instruction time, simulator time, and total flight time, with independent *t*-tests used to assess differences between the groups. Chi-square tests were also conducted to examine the association between training methods and checkride pass rates. Box plots and histograms were used to visualize these findings for visual data interpretation.

Descriptive Statistics

To provide a comprehensive overview of the sample groups before hypothesis testing, the descriptive statistics for both the traditional training group and the VR training group were first analyzed. This section focused on key measures such as mean, standard deviation, and range for oral instruction time, simulator time, total flight time, and checkride pass rates.

In terms of oral instruction time, the traditional training group took an average of 47.42 hours with a standard deviation of 15.05, ranging from 30 to 70 hours to complete the Private Pilot course. In contrast, the VR training group demonstrated a higher mean of 74.48 hours and a larger standard deviation of 16.47, with values spanning from 55 to 100 hours to complete the Private Pilot course, indicating greater variability. For simulator time, the traditional group took an average of 16.83 hours and a standard deviation of 5.11, with a range between 10 and 25 hours. The results of the VR training group had a similar mean of 16.66 hours but with a smaller standard deviation of 3.34, reflecting a range from 12 to 22 hours and less variability compared to the traditional training group.

Total flight training time to complete the Private Pilot course exhibited notable differences between the two groups. The traditional training group had a mean of 115.98 hours with a higher standard deviation of 32.19, demonstrating significant variation among students, with flight hours ranging from 85 to 150. Meanwhile, the VR training group showed a lower mean of 99.60 hours and a standard deviation of 25.78, indicating a range of 75 to 130 hours and a relatively more consistent distribution.

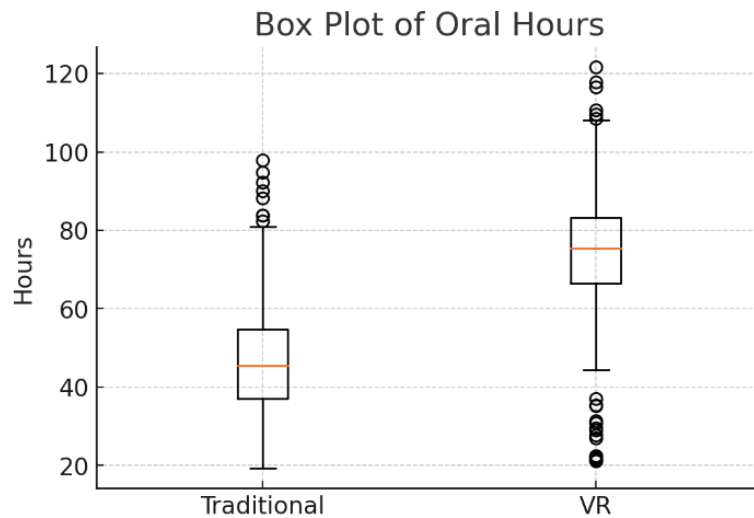
When examining checkride pass rates, the traditional training group had an oral pass rate of 80.51%, a flight pass rate of 65.41%, and a total pass rate of 53.46%. The VR training group presented a slight improvement in oral pass rates at 84.56%, while the flight pass rate was similar at 65.08%, and the total pass rate showed a marginal increase to 55.34%. These descriptive statistics highlight the initial differences and distributions in training and performance metrics between the two training methods.

Hypothesis Testing

Oral Instruction Time Comparison

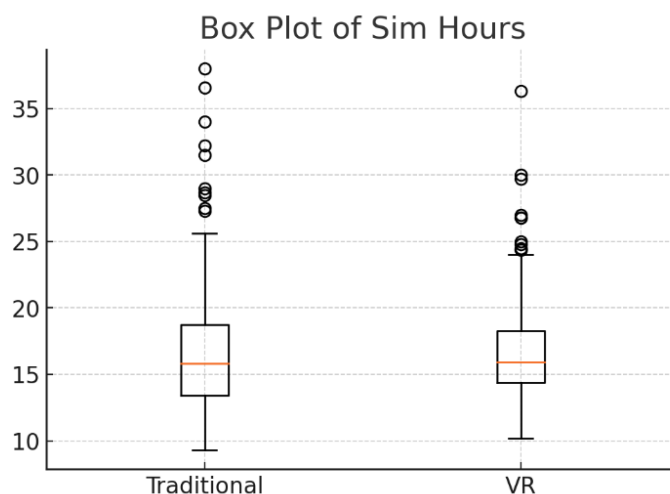
An analysis was conducted to compare the oral instruction time required to complete the Private Pilot course between the traditional training group and the VR training group. Levene's test indicated unequal variances; therefore, an independent t-test was conducted without assuming equal variances. The VR training group required a significantly higher mean oral instruction time (Hours; $M = 74.48$, $SD = 16.47$) compared to the traditional training group (Hours; $M = 47.42$, $SD = 15.05$), with a t -statistic of -18.06 and a p -value of less than .0001. The null hypothesis was rejected, confirming a significant difference in oral instruction time between the two groups. A box plot (Figure 1) illustrated that the VR group consistently required higher and more variable oral hours.

Figure 1
Box Plot of Oral Instruction Time (Hours)

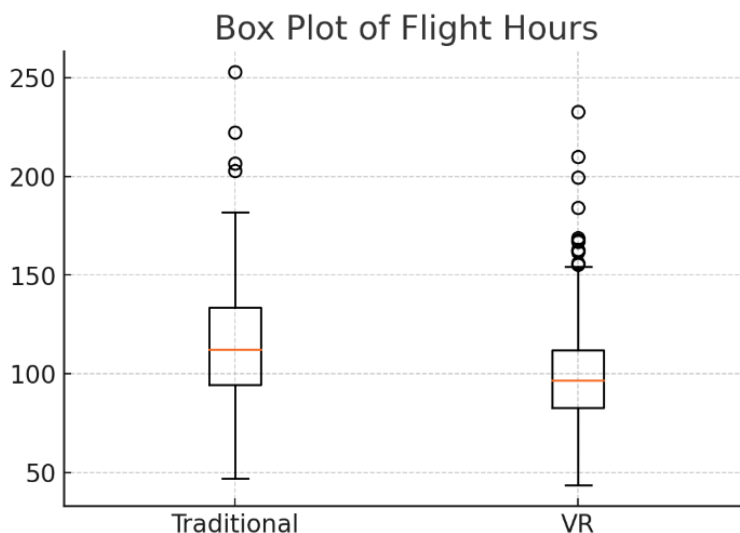


Simulator Time Comparison

An analysis was conducted to compare the simulator time required to complete the Private Pilot course between the traditional training group and the VR training group. Levene's test confirmed equal variances; therefore, an independent t -test was performed assuming equal variances. The mean simulation hours for the traditional group (Hours; $M = 16.83$, $SD = 5.11$) and the VR Group (Hours; $M = 16.66$, $SD = 3.34$) were similar, with a t -statistic of 0.46 and a p -value of 0.64. Since the p -value was greater than 0.05, the null hypothesis was retained, indicating no significant difference in simulation hours between the two groups. A box plot (Figure 2) confirmed these similar distributions.

Figure 2*Box Plot of Simulator Time (Hours)***Total Flight Training Time Comparison**

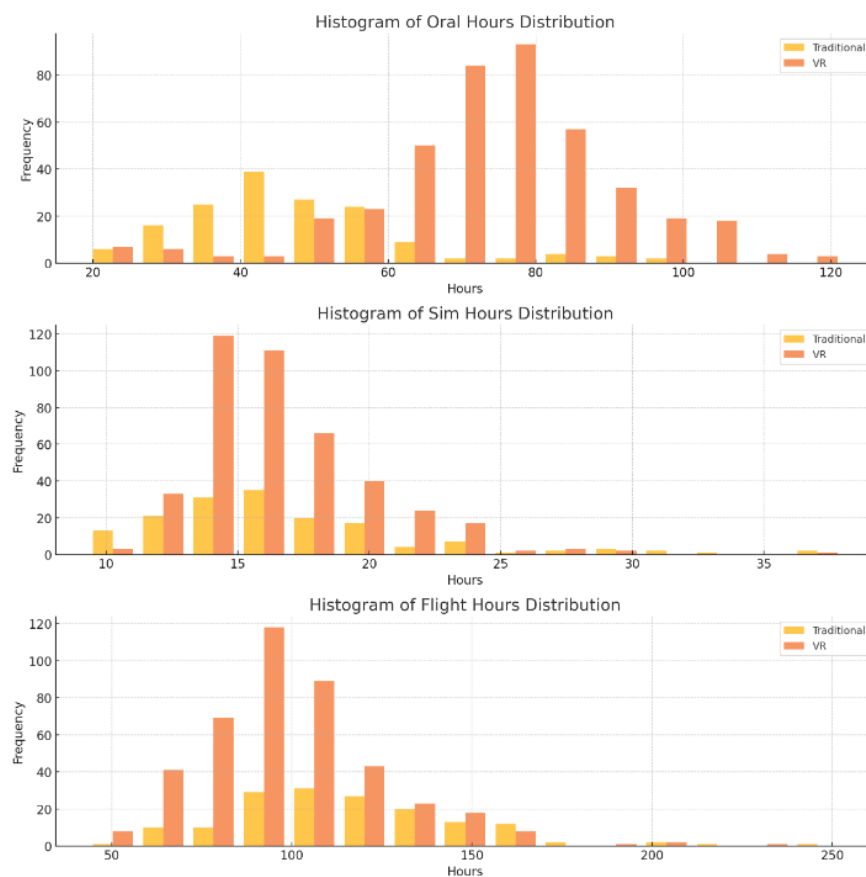
An analysis was conducted to compare the total flight time required to complete the Private Pilot course between the traditional training group and the VR training group. Levene's test indicated unequal variances; therefore, an independent *t*-test was performed without assuming equal variances. The traditional training group had significantly higher mean total flight hours (Hours; $M = 115.98$, $SD = 32.19$) compared to the VR training group (Hours; $M = 99.60$, $SD = 25.78$), with a *t*-statistic of 6.35 and a *p*-value of $4.24e-10$. The null hypothesis was rejected, indicating a significant difference in flight hours between the two groups. A box plot (Figure 3) further illustrates that the traditional training group consistently required higher total flight hours to complete the Private Pilot course.

Figure 3*Box Plot of Total Flight Time (Hours)*

Overall Training Comparison

Figure 4 presents histograms illustrating the frequency distributions of oral instruction time, simulator time, and total flight time required to complete the Private Pilot course for both the traditional and VR training groups. These visualizations clearly highlight key differences between the groups. The VR training Group required significantly higher oral instruction time, a comparable simulator, and notably lower total flight time to complete the course than the traditional training group. This comparison highlights the shift in training emphasis and performance introduced by the VR-integrated curriculum.

Figure 4
Histogram of Oral Instruction/Simulator/Total Flight Time (Hours) Distribution



Relationships Between the Type of Training and Checkride Pass Rates

The relationship between checkride pass rates and the type of training (traditional training group compared to VR training group) was analyzed using the Chi-square test for independence.

Relationship Between the Type of Training and Checkride Oral Pass Rates

A chi-square test was conducted to assess the relationship between training type (Traditional vs. VR) and oral pass rates. The pass rate for the traditional training group was 80.51%, and for the VR training group, it was 84.56%. The chi-square value was 1.391, with a p -value greater than 0.05, meaning the null hypothesis was retained. This result indicated that there was no significant association between training type and oral pass rates, suggesting that the type of training did not significantly affect students' checkride oral pass rates.

Relationship Between the Type of Training and Checkride Flight Pass Rates

A chi-square test was conducted to assess the association between training type (Traditional vs. VR) and flight pass rates. The pass rate for the traditional training group was 65.41%, and for the VR training group, it was 65.08%. The chi-square value was 0.003, with a p -value greater than 0.05, meaning the null hypothesis was retained. This result indicated no significant association between training type and flight pass rates, suggesting that the type of training did not significantly affect students' checkride flight pass rates.

Relationship Between the Type of Training and the Overall Checkride Pass Rates

A chi-square test was conducted to assess the association between training type (Traditional vs. VR) and overall checkride pass rates. The checkride pass rate for the traditional training group was 53.46%, and for the VR group, it was 55.34%. The chi-square value was 0.168, with a p -value greater than 0.05, meaning the null hypothesis was retained. This result indicated no significant association between training type and overall flight pass rates, suggesting that the type of training did not significantly impact students' overall checkride pass rates.

Summary

Overall, measurable differences were identified between the VR-integrated and traditional training groups across multiple performance indicators. Students trained using the VR-integrated curriculum required fewer average flight and simulator hours to complete their course requirements compared to those in the traditional group. Differences in oral instruction hours were less pronounced, indicating that theoretical and ground instruction time remained relatively consistent across cohorts. In terms of performance outcomes, the VR group demonstrated slightly higher oral and flight checkride pass rates, suggesting potential benefits in knowledge retention and procedural proficiency. While these results indicate that VR integration may enhance training efficiency and performance, further analysis in the discussion section explores possible confounding variables and contextual factors influencing these differences.

Discussion

The findings of this study highlight both the practical benefits and implementation challenges associated with VR in flight training. The results suggest positive and promising student flight training outcomes in utilizing VR-integrated curriculums, particularly in reducing

the number of required total flight time while maintaining checkride pass rates comparable to those of traditional training methods. These findings align with previous research indicating that VR can effectively supplement traditional educational methods by reinforcing practice of procedural knowledge and enhancing situational awareness (Tene et al., 2024; Zhan et al., 2024).

However, an increase in oral instruction time was observed in the VR training group, likely stemming from the PILOT program curriculum structure, which front-loads theoretical content. In contrast, traditional flight training programs often distribute oral instruction more evenly throughout the course. To mitigate this content delivery imbalance of the VR-integrated flight training course, CFIs could assign supplemental materials during canceled or rescheduled flight activities and integrate review exercises into pre-flight preparation briefings to support ongoing student knowledge reinforcement and reduce content redundancy.

The intensive structure of the VR training model features compressed ground school phases and extended simulation blocks. While such condensed formats may lead to short-term gains in skill acquisition and reduced flight course completion times, they may potentially hinder long-term student skill/knowledge retention. This concern aligns with prior research indicating that densely packed instructional timelines in aviation training may hinder knowledge retention and contradict established best practices in educational design. (Ambrose et al., 2010; Dinçer, 2023; Pashler et al., 2007). A more effective approach may involve gradually introducing complex elements such as ATC communication and preflight procedures throughout the flight training course instead of front-loading it through VR-integrated training. Integrating and combining additional essential flight procedures into VR practice modules could also help reduce the total simulator hours required by minimizing content repetition.

Limitations of the Study

While the findings indicate meaningful advantages of VR-integrated flight training, some limitations should be considered when interpreting the results. Because this study used archival data from the university's flight department management system, control over contextual variables such as instructor differences, aircraft availability, and weather-related delays was limited. Instructor experience, teaching style, or scheduling flexibility may have influenced the pace and quality of instruction. Likewise, fluctuations in aircraft maintenance or scheduling could have affected student progression, introducing variability beyond the instructional method itself.

As a quasi-experimental design, group assignment was not randomized, which increases the potential for confounding factors. Although both cohorts followed the same FAA Part 141 curriculum, differences in cohort size, instructional context, and institutional procedures may have influenced outcomes. The VR-integrated group, trained between mid-2021 and mid-2024, may have also benefited from newer instructional resources with regard to VR training.

Directions for Future Study

Although the reduced total flight hours required to complete the flight course for the VR training group suggest improved training efficiency, substantial opportunities remain to optimize

the VR-integrated flight curriculum in future studies. For example, targeted feedback from students and CFIs could be collected to identify current inefficiencies in curriculum design and content delivery. This iterative approach to curriculum improvement, based on user experience, can enhance learner engagement and improve training outcomes. Qualitative studies incorporating student and CFI perspectives could provide a deeper understanding of the perceived value, technology acceptance, limitations, and usability of VR-integrated training, guiding future curriculum design and further integration of technology into aviation education.

Future research should explore the long-term impacts of VR-integrated flight training on student/pilot performance, operational decision-making, and career progression. A longitudinal study comparing graduates of traditional and VR-integrated flight training programs could provide valuable insights into the real-world preparedness and safety performance of pilots from each training method. Additionally, replicating this study across a broader range of flight schools (i.e., comparing multiple Part-141 collegiate flight training programs) and training environments (i.e., Part 141 vs. Part 61 flight training institutions) would improve the generalizability of the findings.

Conclusion

This study demonstrated the potential of VR to enhance the efficiency and effectiveness of flight training by reducing the total flight time required to complete a flight rating/course while maintaining essential pilot competencies. The immersive, hands-on nature of VR simulation offers a complement to traditional training approaches, particularly when thoughtfully integrated into the curriculum. While VR-integrated training can introduce new challenges, such as increased oral instruction time, these can be addressed through strategic curriculum design and ongoing instructional refinement. As flight training continues to evolve, it is crucial to adapt innovative teaching methods that leverage the strengths of emerging technologies while maintaining a focus on both theoretical understanding and practical skill development. Although this study was conducted within a single institutional context, the findings highlight the broader value of continuous assessment and curriculum innovation. Future research should explore the long-term performance of VR-trained pilots and examine the effectiveness of such programs across different training environments beyond aviation.

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