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Effectiveness of Virtual Reality Simulations for Civilian, Ab Initio Pilot Training

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Introduction

Interdisciplinary researchers across the world are now assessing virtual reality's (VR) usability and efficacy for education and training processes in education, medical training, industrial applications, marketing, and more (Jerald, 2016). Developers in the aviation industry have applied VR simulations to the design, manufacturing, and maintenance of aircraft, as well as maintenance personnel training (Fussell & Truong, 2020; Jensen & Konradsen, 2018). The United States Army, Air Force, and Navy have successfully implemented inexpensive, yet advanced, VR simulations in training aviators (Hawkins, 2019; Lewis & Livingston, 2018).

Multiple studies demonstrate VR's effectiveness in learning complex tasks, despite VR's slow adoption in civilian aviation education (Fussell & Truong, 2020; Jensen & Konradsen, 2018; Lawrynczyk, 2018; Lewis & Livingston, 2018; Zhao et al., 2021). Lawrynczyk's (2018) research used perceived cognitive load and physiological measures to determine if fully immersive VR could be a viable replacement for traditional flight simulators. In a critical finding, Lawrynczyk indicated that training in a VR environment replicates real-world mental and physical flight stress while 2D simulators do not. Student pilots typically prefer to learn through hands-on activities and practice, wherein complex mental models can be formed and tested (Gao et al., 2013). There is a long history of research on augmented reality (AR), mixed reality (MR), and VR in the field of aviation for developing cognitive and psychomotor skills, emerging with Caudell and Mizell's study on AR in the early 1990s (as cited in Schaffernak et al., 2020). Results of many studies show that these technologies, especially when combined with games, can improve the content or content delivery for pilot training (Lawrynczyk, 2018; Lewis & Livingston, 2018; Schaffernak et al., 2020). The most widely accepted proof of efficacy for a new form of instruction, such as VR, is improving students' performance on established assessments (Greenwald et al., 2018). While 2D simulators are known to be effective training devices for aviators, as of 2021, VR is still an unproven innovation for *civilian* pilot training because there have not been any studies directly comparing the training transfer, training efficiencies, or differences in academic performance between VR and 2D simulation (Judy, 2018; L. Brown, personal communication, November 7, 2019). In contrast, there have been several studies of training transfer and efficiency for medical education (Zhao et al., 2021).

Purpose of the Study and Research Questions

The primary objective of this quasi-experimental pilot study was to determine whether a more contemporary approach to teaching and training civilian pilot students through VR simulation would yield higher academic performance compared to traditional 2D training. For this study, VR flight simulations are defined as those occurring in the virtual environment while wearing a Head Mounted Device (HMD), and 2D simulations are those occurring at a desktop console with a flat-screen display. The VR environment includes views of the virtual flight controls such as the yoke, along with a 360-degree view of both inside the cockpit and out the windows. The 2D simulation display is also capable of panning 360 with both inside and outside views using the mouse and space bar, but it is limited to the surface space available on the desktop computer screen. In both cases, the simulator base was stationary.

The research focused solely upon the first phase of flight training—the pre-solo phase. The knowledge and skill demonstration before a student's initial solo is an important qualifier for the complex and demanding profession of aviation (Judy, 2018). Student pilot academic performance in pre-solo training represents an important milestone of skill synthesis, and it is an important indicator of requisite knowledge, skills, attitudes, and natural ability (Judy, 2018). The findings of this research will be valuable to future researchers in the field of aviation education.

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Differences in academic performance identified in this study will lead to more research on this topic for all levels of pilot training.

Research Question: Is there a difference in academic performance between the VR and 2D groups?

Hypothesis: There will be a significant difference in academic performance between those who train with VR simulations and those who use 2D simulations.

Methodology

Research Design and Sample

The pilot study occurred in the fall 2020 semester at a private university in the United States. A quasi-experimental, small *n* design was used due to constraints of the university environment. The subjects self-enrolled into one of two available courses, but they did not know when they enrolled in the experimental course that there would be two distinct treatments between the course sections. The Institutional Review Board (IRB) at Embry-Riddle Aeronautical University, where this study was conducted, concluded that this study fell under the "curriculum/course improvement" category and did not require formal IRB review or approval. Participants signed an informed consent document and agreed to provide de-identified data after the course conclusion. Instructors for both groups taught the course material per the approved Master Course Outline (MCO) and were not informed of the purpose of the study, nor the data collection or analysis measures being taken for either group. The researchers chose this technique to avoid the potential for instructor bias; knowing the goals of the study may have caused them to modify their teaching methods.

The population for this research study was ab initio civilian pilot students at a Federal Aviation Administration (FAA) 14 Code of Federal Regulations (CFR) Part 141 institution. The convenience sample of students used in the study were those who had self-enrolled in an experimental course offered as a three-credit elective: Aeronautical Science (AS) 195J, “Virtual Private Pilot Operations.” The course was offered to all eligible AS freshman students, although registration for the course was opened late due to limitations caused by the pandemic lockdown. The courses initially had enrollments of 11 and 12. The final sample was reduced to sections of 8 and 9 participants due to attrition, COVID-19-related suspensions and quarantine, or removal from the course for failing to complete coursework. The sampling framework and sample size were appropriate for a small *n* design pilot study (Smith & Little, 2018; Yin, 2018).

Instrumentation

Alienware gaming computers equipped with Lockheed Martin’s Prepar3D Version 4 with a high-fidelity model of the Textron Cessna 172S (C-172) were the training medium, as the participants utilize the C-172 in flight training. The instrumentation for the hands-on portion of the study involved the use of two software programs and one hardware system: a set of Computer Based Training (CBT) modules and a Prepar3D Flight Simulator, which linked to an HTC Vive Pro VR HMD for participants in the VR group. The simulations and CBTs displayed airport terrain data from the surrounding local area, except for some of the emergency procedures simulations, which included mountainous terrain data.

Participants accessed learning materials and CBT modules through their section’s Canvas Learning Management System (LMS). Canvas is an online program designed for academic courseware, grading, and communication among instructors and students. The learning materials included videos, lectures, and readings. Each CBT module covered an overarching concept that included specific maneuvers and basic flight skills required by the FAA Airman Certification Standards to achieve a private pilot certificate. The seven modules consisted of “Fundamentals,”

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"Flight Maneuvers," "Airport Operations," "Local Airspace," "Emergency Procedures," "Advanced Flight Skills," and "Check Rides."

Study Procedures

The participants enrolled in one of two separate sections of the experimental course, AS 195J. When the enrollment period ended, section AS195J.01 ("Section .01") was assigned to the 2D group, and section AS 195J.02 ("Section .02") was assigned to be the VR group. Each section fulfilled the same CBT modules requirements, which encompassed videos, lectures, and readings, along with the same classroom instruction, followed by two distinct modes of simulation delivery. Section .01 learned maneuvers in simulations on desktop gaming computers in the classroom. Section .02 participants completed the same simulations in a designated VR lab utilizing the HMD. Both groups received the same instruction when in person and via the Canvas LMS and were trained with identical CBT and simulation modules with the same Lockheed Martin Prepar3D software and Alienware gaming computers.

Utilizing the university's approved training course outline for the experimental course, participants were directed to complete specific lessons from the modules covering a maneuver or set of similar maneuvers after receiving ground training on the subject. Participants then took a quiz in Canvas to ensure understanding of each maneuver. Quizzes were reviewed the next class period, and then the next maneuver, or set of maneuvers, was taught.

Data Collection and Analysis

Academic performance data was collected in the Canvas LMS. Performance in each section was measured by assessing participants' understanding of a maneuver learned in the lesson module with short post-module quizzes. Descriptive statistics were collected for the final score of each lesson module, which was a summation of associated quizzes, course assignments, and simulation completion scores. A questionnaire assessed the perceived benefits of using the various course materials and asked the participants to identify the type of course material they preferred for training. Several optional, open-ended items allowed the participants to provide qualitative feedback: “Please tell us what you'd improve about the… simulations you completed. Be as detailed as possible! This will help us design a better product for your training in the future”; “Consider which [learning material] option you prefer and do not prefer. Can you elaborate on why?”; and “Please add any additional comments here. We value your feedback.”

Paired samples *t*-tests were used to compare the ratings of materials. The nonparametric Mann-Whitney U test was used to compare lesson scores (e.g., per module) and final scores between groups, due to the small sample size and lack of random assignment to groups. Demographic data was limited to section enrollment, gender, and age. Researchers administered post-semester questionnaires to gather both qualitative and quantitative data: the response regarding perceived benefits included perceptions of the course, preference for learning material type, and general feedback. Participants received $20/hour for the post-semester questionnaire.

Results

The participants were ab initio student pilots, ranging in age from 18 to 24, with a reported total time of 16.1 hours in a Cessna-172 and a total of 2.5 hours in an unspecified FAA-certified training device across the sections. Section .01 (n = 8) and Section .02 (n = 9) each had one female student. The data was checked for normality and shape similarity to ensure the Mann-Whitney U test could be used and that assumptions were met.

Midway through the course and upon completion, the participants were asked to give feedback to gauge their perception of the course and preferences for the learning materials. The structure of an undergraduate semester includes a segment of work before and a segment after

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midterm grades are given, so the timing of these feedback sessions mirrored other types of instructor and course feedback. The participants ranked the benefit of using CBT modules for private pilot training on a scale of 1 (least beneficial) to 10 (most beneficial). The perceived benefits of Section .01 of CBT (encompassing videos, lectures, and readings; $M = 8.88$, $SD = 1.25$) was compared to the perceived benefits of the simulation modules ($M = 9.13$, $SD = 0.99$) using a paired-samples *t*-test; it was not significantly different, $t(7) = 0.80$, $p = 0.45$. The perceived benefits of Section .02 of CBT ($M = 8.44$, $SD = 1.24$) was compared to the perceived benefits of the simulation modules ($M = 9.22$, $SD = 1.09$) using a paired-samples *t*-test; it was not significantly different, $t(8) = 1.94$, $p = 0.09$. The perceived benefits were also compared between the Sections. There was no difference in perception of benefits of the CBT materials (Mann–Whitney U = 29.00, $n_1 = 8$, median = 9.00, $n_2 = 9$, median = 8.00, Z = -0.73, $p = 0.47$ two-tailed) and the simulation modules (Mann–Whitney U = 33.50, $n_1 = 8$, median = 9.50, $n_2 = 9$, median = 10.00, Z = -0.26, $p = 0.79$ two-tailed).

Academic performance, as measured by module scores and final scores (final grading), was compared between the groups. Overall, academic performance was higher in Section .02 (96.81%, $SD = 7.86$) than in Section .01 (89.48%, $SD = 11.07$), although significance testing was insignificant. The shapes of the distributions of lesson module scores were compared using an Independent Samples Mann-Whitney U test to ensure similarity between the groups. Only the distribution of the CBT Modules and Simulations Final Score data were not the same ($p = 0.015$). Further examination of the descriptive statistics of the data revealed that participants in Section .01 had more consistent scores ($M = 99.77$, SD = 0.64, median = 100.00) than Section .02 ($M = 96.01$, SD = 6.70, median = 99.45). The Mann-Whitney U test was also used to compare lesson scores between the Sections. There was no difference between module final scores except for the CBT Modules and Simulations Final Score (Mann-Whitney U = 11.00, n_1 = 8, median = 100.00, mean rank = 12.13; n_2 = 9, median = 99.45, mean rank = 6.22, Z = -2.61, p = 0.009 two-tailed) due to the difference in shape. The hypothesis was only partially supported.

The participants were also asked what they would improve about the CBTs and simulations. Table 1 summarizes the feedback in four overarching categories. All of the eight Section .01 participants and six of the nine participants in Section .02 mentioned specific software malfunctions or used the terms "glitch" or "bug"/"buggy" in their feedback. Three participants in Section .02 stated that the glitches distracted from learning zero times, one time, or every time (11.11% of the respective option). Seven participants (41.18%; 3 from Section .01 or 37.50%, and 4 from Section .02 or 44.44%) reported that glitches caused a distraction 1 to 3 times. Another seven participants (5 from Section .01 or 62.50%; 2 from Section .02 or 22.22%) stated that glitches were a distraction more than 3 times. Despite the issue of the glitches, which were more inconvenient than detrimental to learning, the scores and ratings were deemed acceptable because the solution was to restart the simulation. The learning process itself was not negatively impacted, as demonstrated by the academic performance and composite feedback of the participants. Participants in both sections noted that progress was not always recognized, which may have been an indication of a program malfunction, and that assessments would be marked "half wrong," as a failure, or as incomplete. In turn, the issue meant that the instructor had to review the assignments and change the grades manually, which led one participant to indicate a lack of grading transparency and two to express frustration. Three participants indicated that changing the hardware (i.e., yoke, rudder pedals in Section .01; "less blurry lenses;" or removing rudder pedals in Section .02) would improve the learning experience. About half of the participants in both sections indicated that the simulations enhanced their

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understanding of the concepts, aided hands-on learning, and, as one participant reported, “helped give me a head start in my flight training!”

Table 1

Summary of Participant Feedback

Summary of Qualitative Feedback	Responses from Section .01 (*n*, %)	Responses from Section .02 (*n*, %)	Total (*n*, %)
Software issues	8, 100%	6, 66.67%	14, 82.35%
Hardware issue	1, 12.50%	2, 22.22%	3, 17.65%
Recommendation for improvement (e.g., student can progress the simulation, more “save check points”)	4, 50%	4, 44.44%	8, 47.06%
Indication of enjoyment and/or benefit	4, 50%	6, 66.67%	10, 58.82%

Participants in Section .02 were also asked additional, VR-related questions. When asked about cybersickness while completing the VR simulations, two participants mentioned feeling cybersickness 1 to 3 times, but only one participant indicated that it was a distraction, and then only during a single occurrence. The participants did not elaborate on the cybersickness in the open-ended feedback portion of the questionnaire nor to their instructor.

At the end of the course, both sections were asked about their preference of using learning materials most and least frequently, detailed in Table 2. Three participants in Section .01 explained that the simulations were preferred as they helped with the understanding of the maneuver and foundation concepts, enhanced learning, gave better visualizations of the maneuvers, and provided hands-on learning and a chance to apply what they were taught. One participant indicated that some simulations were too long. Feedback on the CBT videos revealed that the videos were too long (n = 1) or were “unnecessary” (n = 1), while one participant stated they were better than the readings because they provided visual instruction. Direct feedback on the reading materials was split between boring (n = 1) and beneficial (n = 1).

Participants in Section .02 gave feedback as well but were more likely to weigh the pros and cons of the different learning materials. Three participants indicated that in-person instruction, simulations, and videos were all very important; one summarized the advantage of having different materials as "The videos helps [sic] cover what was coming up. Simulations was [sic] a good representation. The in person [sic] class clarified any questions I had." One participant, who described themselves as a visual learner, did not prefer the reading materials; however, another participant preferred the medium for quick information access, note-taking, and mental visualization of the procedure. One participant indicated that the videos "recycled over" the same information and made note-taking difficult, but another admitted that although videos were the least favorite, they were still important. In-person instruction was criticized for being held too late in the evening (n = 1), and for covering too much information that was relayed in ground school as opposed to focusing on mastering maneuvers (n = 1). Finally, the simulations made the class stand out from other courses (n = 1) and, as one participant stated, they were most beneficial for learning, reinforcing concepts, and practicing the procedures, and they were "able [to] translate what [they] learned in the sims and videos to actually flying the real plane" even though the VR did not replicate the "feel" of flight in an aircraft. A breakdown of learning material preferences is shown in Table 2.

Table 2

Participant Preferences for Learning Materials

MOST Preferred	Responses from Section .01 (*n*, %)	Responses from Section .02 (*n*, %)	Total (*n*, %)
Readings	1, 14.29%	1, 14.29%	2, 14.29%
CBT videos	0	0	0
Simulator training	5, 71.43%	6, 85.71%	11, 78.57%
In-person instruction	1, 14.29%	0	1, 7.14%
LEAST Preferred			
Readings	0	0	0
CBT videos	7, 100%	4, 57.14%	11, 78.57%
Simulator training	0	0	0
In-person instruction	0	3, 42.86%	3, 21.43%

Note. One participant in Section .01 and two participants in Section .02 did not respond with their preferences. Percentages are based on 7 responses per section, for a total of 14.

Discussion

The results indicate that participants who learned flight maneuvers in the 2D simulations had statistically significantly higher CBT Modules and Simulations scores than participants who learned using VR simulations. This finding may have been due to the difference in data distribution as opposed to learning in the medium (2D or VR) itself; the grading and scoring system with the simulation software needs further review, as the complete or incomplete score, which required instructor review, is lacking in accuracy and reliability. The small sample size warrants more research to determine the impact of 2D and VR simulation on learning and performing flight maneuvers. However, there was no significant difference between the final scores of the sections which may indicate that learning in the VR environment did not hinder student mastery.

Other researchers have found similar results, noting that skill mastery in both aviation and medicine may be a result of generational or even gender-related learning preferences, which have trended in recent years towards less didactic and lecture-based, and more hands-on (Schaffernak et al., 2020; Zhao et al., 2021). This research study supported these findings, as both sections reported a preference for using the simulations over the other learning materials. Aviation students tend to prefer hands-on learning, trust in procedures that they have learned and practiced, and rely on their experience and observations to create mental models (Gao et al., 2013; Schaffernak et al., 2020). The data collected makes it clear that VR simulation programs for aviation education should be examined in greater depth in follow-on studies for efficiency, training transfer to the aircraft, and safety before implementation at a larger scale. The Zhao et al. (2021) meta-analysis of training efficiency for VR, compared to traditional pedagogy in the medical education field, serves as a great example for future aviation researchers to follow.

Enhanced academic performance on a VR simulation or quiz is not necessarily the end goal of aviation or medicine, but an indicator that students are absorbing concepts more fully than the traditional lecture. The goal for surgeons or pilots is the safe and skillful performance of their jobs. Comparisons of quiz pass rates tell only part of the story, and so assessments for skill transfer must be developed and studied to ensure there is no negative transfer of training from VR into the real world (Zhao et al., 2021).

Recommendations

The small sample size of the pilot study, and lack of random assignment, limited the statistical analyses and comparisons between groups. A larger sample size would allow for randomization of the groups, as well as correlations, regressions, and parametric statistical testing between groups, among other things. More research is required to understand how learning flight maneuvers in an immersive virtual environment (i.e., VR) impacts academic performance and skill mastery as compared to a less immersive (i.e., 2D) environment. An additional study is planned to assess the usability of the 2D and VR simulations using data collected at the end of the course (Fussell & Hight, 2021). This will provide insight into the perceived workload, learning efficiency, enjoyment, and other aspects associated with the usability of simulations for training. The results of the combined studies will provide a better understanding of how to use VR simulations to improve learning outcomes for future students.

This pilot study is intended to lead a series of longitudinal studies designed to determine the extent to which VR simulations can partially replace hands-on flying or more costly FAA-certified simulators. Efficiencies discovered through the Army's recent helicopter VR training class, and in the USAF's Pilot Training Next (PTN) program may translate into the university setting, but further research is required to ascertain exactly how to replicate these efficiencies

(Huber, 2019; Lewis & Livingston, 2018). This project may set the stage for many similar experiments in VR training for pilots. Future studies comparing VR simulations with traditional pedagogical approaches in the classroom may prove valuable for making efficiency improvements and adjustments to formal flight training syllabi (Haritos & Fussell, 2018).

Limitations and Delimitations

The largest limitation of this study was the sample size. The original pilot study, involving 22 participants, was in the data collection process during the spring semester of 2020, when the university shut down due to the COVID-19 pandemic. Registration and subsequent retention of students in the AS 195J course for the fall 2020 semester were lower than anticipated. Simulator equipment posed some limitations, as Section .01 was equipped with joysticks that lack the design and feel of the C-172 aircraft controls. In Section .02, the controls were more accurate to the actual aircraft design, but they included an extraneous propeller lever and a lever-type throttle quadrant instead of the push/pull design of the C-172. The researchers determined, based on prior studies, that the “real feel” of the controls was not as critical to the 2D group as to the VR group, where immersion, presence, and interaction are essential characteristics of VR technologies (Radianti et al., 2020).

Delimitations in this study include the choice to narrow the population and sample to include only inexperienced, civilian pilot students at one university. The main objectives and scope of this pilot study dictated that this quasi-experiment focused only on the variables under the control of the researchers. This study did not include student performance during actual flight operations at any time because of numerous uncontrollable variables.

Conclusion

In the case of this quasi-experimental pilot study, there is evidence of subjective benefits of both 2D and VR simulations for ab initio pilot training. Based on the results of this and many other recent studies, leaders in aviation education should seriously consider increasing research and development support related to VR innovations. Though the results here are not revolutionary because of the limitations, this study does confirm that VR is worthy of further research.

The study showed that the immersive simulation environment did not hamper learning and may have impacted academic performance. Future studies comparing academic performance in 2D and VR should include demonstrations of flight maneuvers directly after performing simulations in either 2D or VR. This type of simulation-to-flight experiment would provide both additional means of comparing the two mediums and additional testing of the efficacy of immersive VR for pilot training. Conducting future studies in more rigid conditions, with larger and more diverse samples of students, will provide greater internal validity to this pilot study. This initial study also revealed that the economic investment into VR stations did not detract from the learning of flight maneuvers during simulations.

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