Work in Progress: A Second Comparative Study of the Impact of Virtual Reality in Aerospace Education

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Student Paper

A Second Comparative Study of the Impact of Virtual Reality in Aerospace Education

Introduction

Virtual reality (VR) is an advanced technology that immerses users in computer-generated environments that they can interact with in a realistic and engaging manner. Traditional VR systems include a head-mounted display (HMD) headset that tracks the user's position, as well as controllers for input. Though most commonly used in entertainment and gaming [1], VR technology has significant applications in the aerospace industry as a means of boosting productivity and in education as an interactive platform for learning. However, the overlap between the two– VR for aerospace education– is a niche field. By creating controlled virtual environments, VR can transform knowledge acquisition and practical skill development in a risk-free setting.

The primary advantages of VR lie in its ability to simulate scenarios that are dangerous, impossible, counterproductive, and/or expensive, according to a framework proposed by Bailenson [2]. This aligns closely with the needs of aerospace engineering education, where many relevant systems (e.g. rockets during launch, extraterrestrial spacecraft operations, and flying aircraft) are inherently risky, challenging to observe directly, and/or costly to replicate in the real world. Instead, experiences of such systems in action can be simulated in VR. With a realistic and immersive simulation, VR can enhance conceptual understanding and provide unique firsthand experiences not subject to the aforementioned real-world constraints.

Literature Review

Use in Industry

Virtual reality has become a valuable tool in the aerospace industry and is used in a variety of applications. Early aerospace VR pioneers have been using the technology since the 80's; one such pioneer is NASA, who used large VR rigs for astronaut training [3]. Another long-standing example is use for pilot training, in which aviators can simulate flights from a digital cockpit on the ground [4]. Modern advancements have expanded applications beyond these examples. For instance, VR can be used for microgravity training to potentially reduce space motion sickness caused by the feeling of weightlessness [5]. Engineers also utilize VR for engine design, allowing designers to both visualize and optimize components for turbomachinery [6]. Additionally, VR is being explored as a method for teleoperations in aerospace parts fabrication– that is, parts manufacturing from a remote location [7]. These examples are but few of many that highlight VR's potential to increase efficiency, safety, and innovation in the aerospace industry.

Use in Education

Immersive VR has seen a variety of uses in K-12 education [8–12] and university-level applications, including topics such as physics [13], chemistry [14, 15], architecture [16, 17], and most extensively, medicine [10, 14, 18, 19]. These implementations not only enhance student engagement and comprehension but also offer interactive, experiential opportunities that traditional methods struggle to efficiently replicate. As an added bonus, institutions that integrate VR courses into their curricula often gain a competitive edge, distinguishing themselves through innovative approaches to teaching and learning [20].

Popular pedagogical theories associated with VR simulations are primarily based on constructivist ideology [21, 22]. The most frequently cited theory is experiential learning theory, which posits that effective learning occurs when individuals engage in a cycle of experience, reflection, and application [23]. Additional theories that align with VR's immersive properties include situated learning theory, which emphasizes learning within authentic contexts [24], and discovery learning theory, which suggests that learners gain a deeper understanding by drawing their own conclusions with minimal guidance [25]. While less commonly cited, other theories benefiting from VR include embodied learning, which connects physical actions to cognitive processes [9], and social constructivist theory, which highlights collaborative learning within virtual environments [26]. Adherence to these theories provides a strong framework for understanding VR's potential to transform education.

Use in Higher Aerospace Education

In higher education, several research studies have attempted to use VR technology to teach aerospace concepts. While examples exist (primarily based on experiential learning foundations), they are relatively sparse in the literature, and application tends to be limited to single experiments rather than continuous, repeated use. Examples of use include VR simulations for visualizing aircraft coordinate systems for flight dynamics [27], interacting with turbofan assembly and engine structure [28], and serving as an introduction to turbomachinery and fluid flow [29]. Despite the promising applications outlined in the previous subsection, the integration of VR into full courses remains uncommon at the university level. The problem is two-fold: VR is rarely implemented, and impacts on students are not documented comprehensively.

This paper examines the exploratory Aeroverse course, which seeks to address the aforementioned literature gap by providing a structured, ongoing implementation of VR-based learning for aerospace education. Through this approach, Aeroverse aims to demonstrate the value of VR as a core component of a curriculum rather than a one-time experiment.

Research Questions

This study builds off of findings from the 2024 Aeroverse course, which is documented extensively in [30]. The purpose remains the same, with a focus on virtual reality: we aim to integrate VR modules into the existing aerospace engineering curriculum at the Massachusetts Institute of Technology to enhance learning, and the goal is to assess whether VR can affect grade performance, changes in confidence in ability to achieve learning objectives, and enjoyment of learning. We hypothesize that VR will positively enhance all three of these learning outcomes.

For the second iteration of this course, we propose an additional hypothesis: students will perform the same as last year's VR users. The rationale for this hypothesis is that, given that the content of the course has not changed significantly, additional data from VR users should corroborate the trends observed in the previous iteration. Nonetheless, the data collected from the 2025 course will increase the sample size to confirm or challenge trends.

Method

Course Design

Aeroverse is an experimental three week-long course featuring a total of seven classes. Though the content is targeted to undergraduates interested in aerospace, there is no registration restriction on age or major, and no mandatory prerequisite courses. The course is for-credit and graded on a pass/fail basis; academic standing was calculated based on a series of summative, formative, and reflective assessments. Students prepare for each class with a pre-reading assignment, pre-reading quiz, and pre-class reflection in which they rate their current ability to meet a set of learning objectives that differ by topic. Each class begins with an hour-long lecture that covers material relevant to the following lab activity. The two-hour lab is comprised of the activity itself and an accompanying worksheet. Simulation access is restricted to prevent students from accessing the modules in advance. After class, students submit a post-class assessment and post-class reflection, the latter of which is to assess the change in confidence from meeting the set of learning objectives. The course structure is summarized in Figure 1 below.

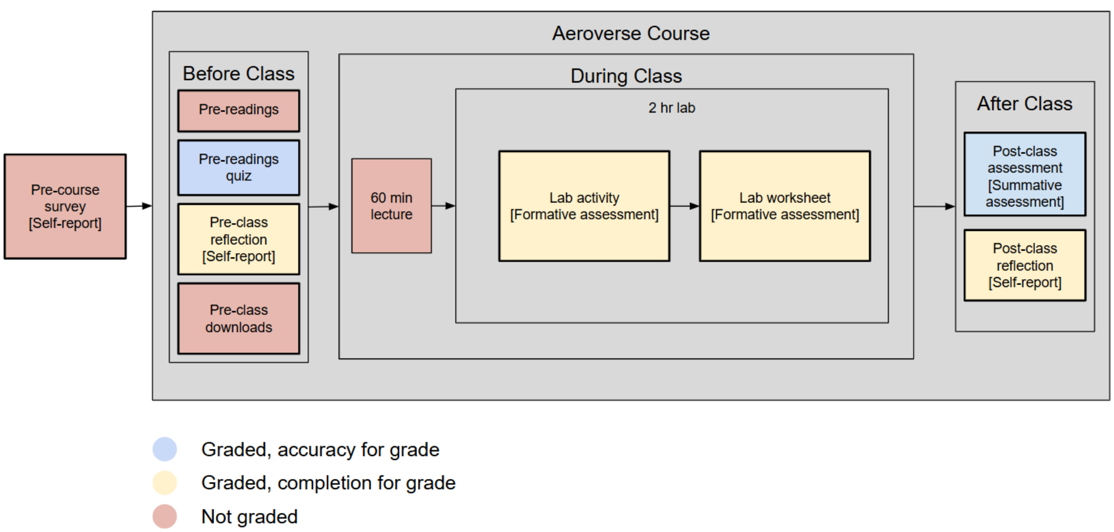


Figure 1: Course logistics and assignments before, during, and after each class.

In the 2024 version of the course, students were divided into VR and non-VR groups for comparative assessment. However, due to limited enrollment in 2025, the decision was made to have no non-VR condition. As such, this year's labs were fully VR activities, and the non-VR materials were reserved for circumstantial use.

A relevant change to the new course is that three students were given Meta Quest 3S devices– the most recent device variant at the time of publication– while the remaining students were given

Meta Quest 2 headsets. Though the intent was to keep as many independent variables the same from the previous year, the Meta Quest 2 has been discontinued as of September 2024 and could not be ordered for Aeroverse 2025 [31]. Nonetheless, the same digital content was accessible to all students with no extra accommodations necessary.

Student Enrollment

Students were given a pre-course survey for demographic data purposes. Of the 8 students, five were undergraduates and one was a graduate student, most of whom are aerospace majors. Two alumni with no aerospace backgrounds were also invited to participate. The majority had experienced VR "once or twice but not regularly" or never at all, and none owned a VR headset. Appendix A displays demographic data and other relevant metrics such as prior headset use.

Course Content

Some of the course-level learning objectives were determined to be more efficiently addressed through traditional means as opposed to being included in VR. This decision was made on a case-by-case basis for each module based on complexity, total simulation duration, and development time. Therefore, gaps in the lab activities were supplemented by the preceding lectures. The lectures provided complementary information, including prerequisite context, to prepare students before using the VR headsets.

For the lab activities, a mix of existing simulations and custom developments were used. For the custom modules A and C, feedback from the previous year was implemented to make the simulations more user-friendly, though the educational content remained unchanged. Descriptions of the contents of each VR module can be found in Table 1 and are documented more thoroughly in [30]. Modules were grouped according to theme, with one theme focused on air and the other two on space. The names of the themes have been updated to reflect the addition of the newest module, Module E: Assemble and Launch a Rocket.

The suggestion to include another module to the course was based on several factors, including: to expand the course to cover additional relevant topics in aerospace engineering, to build upon lessons learned from previous simulation development, and to experiment with new types of interactions. In particular, Module E supports hand-tracking inputs (with an option to switch to controllers) and features a hands-on assembly scene in which players piece together a miniature version of a SpaceX Falcon 9 launch vehicle. This module in particular was designed to be a shorter experience with an average completion time of around 20 minutes.

VR content was mostly centered around situational learning, guided discovery, and experiential learning theories. For example, realistic virtual settings were chosen to place students in a cockpit, on Mars, in the ISS, and at a launch pad. Students were able to inspect and interact with aerospace systems at a 1:1 scale. The expectation is that environmental realism adds to the learner's ability to draw connections between the simulation and the real world. In Modules A, C, E, F, and G, players have the freedom to explore certain parts or areas of interest and discover more about them at their leisure. For ease of use, interactable objects were clearly identified with in-game indicators. Finally, students had the experience of controlling or operating large aerospace systems such as airplanes, rovers, robotic arms, and rockets.

Table 1: Course content for the 2025 Aeroverse class.

Theme	Module Nickname	Simulation Type	Description
Aircraft Week	Module A: Explore a Jet Plane	Custom module	Learn about the basics of flight, the components of an airplane, the layout of a glass and analog cockpit, and the organization of an airport
	Module B: Fly a Jet Plane	Microsoft Flight Simulator, VR version	Complete two sample flights: a landing of a Cessna 172, and a flight in adverse weather using a Cessna Citation CJ4
Mars Week	Module C: Explore Mars with a Remote-Controlled Vehicle	Custom module	Learn about the subsystems of the Curiosity rover, drive it around Mars, and control its arm to drill for rock samples
	Module D: Explore Mars with an Autonomous Vehicle	Custom module	Complete a coding exercise focused on stereo vision, cost map construction, and path planning with the Curiosity rover and watch the code execute
Orbit Week	Module E: Assemble and Launch a Rocket	Custom module	Learn about the layout of a launch pad, the subsystems of a Falcon 9 rocket, and the stages of flight for a launch vehicle
	Module F: Humans in Space	Mission: ISS scavenger hunt	Complete a guided scavenger hunt to explore human systems aboard the ISS through a series of videos and go on a space walk
	Module G: Human-Machine Interactions	Mission: ISS scavenger hunt	Complete a guided scavenger hunt to explore human-machine interactions aboard the ISS through a series of videos and operate the Canadarm2

Results and Discussion

Quantitative data was collected from the post-module quizzes, while qualitative data came from the pre- and post-module reflections. To determine whether the results from VR users this year had discrete effects over non-VR users, the results from this year's class are compared to the results collected from last year's class. First, a summary of the prior year's VR and non-VR performance is presented. Then, a comparison is made between the current VR and the previous VR and non-VR results.

Summary of previous results from 2024 Aeroverse

To provide a control group for comparison, the 2024 Aeroverse course split the 29 enrolled students into two groups, which were then assigned to VR and non-VR conditions. Depending on the module, there were 14-15 VR users, and 14-15 non-VR users who underwent a traditional lab activity instead. Groups rotated condition assignment so that every student had three VR labs and three non-VR labs, but the educational content within each lab was as identical as possible, regardless of condition. Table 2 describes the activities associated with each condition for the six modules. Recall that Module E: Assemble and Launch a Rocket is a new addition to the 2025 course and is therefore not mentioned here. The module naming convention has been updated to reflect the changes in 2025 for consistency; in particular, the order of the last two modules was switched in 2025 due to scheduling conflicts of the guest speaker.

Table 2: Description of the course setup from the 2024 Aeroverse trial.

Theme	Module Nickname	VR Activity	Non-VR Activity
Aircraft Week	Module A: Explore a Jet Plane	Custom module	Lecture
	Module B: Fly a Jet Plane	Microsoft Flight Simulator, VR version	Microsoft Flight Simulator, desktop version with flight stick
Spacecraft Week	Module C: Explore Mars with a Remote-Controlled Vehicle	Custom module	Interactive slideshow
	Module D: Explore Mars with an Autonomous Vehicle	Custom module	Desktop simulator
Astronaut Week	Module G: Human-Machine Interactions	Mission: ISS scavenger hunt	Slideshow with videos
	Module F: Humans in Space	Mission: ISS scavenger hunt	Slideshow with videos

The following learning outcomes were analyzed in the 2024 study: grade performance, difference in confidence in achieving learning objectives, and enjoyability. Grade performance was derived directly from the post-module quiz, while change in confidence and enjoyability was determined from the pre- and post-module reflections. The data distribution from these learning outcomes– split between groups– is repeated in the following subsection.

Statistical tests to determine the significance of the collected results were performed. However, in the previously published results, the computed p-values from the Kruskal-Wallis test were incorrectly reported as one-sided (halved). By definition, one-sided p-values are not defined for unordered alternative data used in the Kruskal-Wallis test; p-values from this test are inherently two-sided [32]. This statistical error has been corrected in this paper, and p-values from all tests are reported as two-sided. Table 5 in Appendix B displays the full corrected test results. Additional statistical analyses were performed to determine whether prior VR experience or academic level had an effect on learning in [30], but are not discussed here.

The performed statistical tests show that, for all modules, there was no significant difference in grade performance between VR and non-VR students. There was also no significant difference found for change in confidence in any module. Similarly, there was no significant difference for enjoyability for any module, with the exception of Module A. A Kruskal-Wallis test showed a significant difference in median rating for enjoyability for this module, with students rating the VR experience higher than the non-VR activity (extended lecture).

2025 VR performance vs. 2024 VR and 2024 Non-VR performance

The questions in all pre-module and post-module assessments remained unchanged in the 2025 course. Therefore, comparisons can be made directly between years.

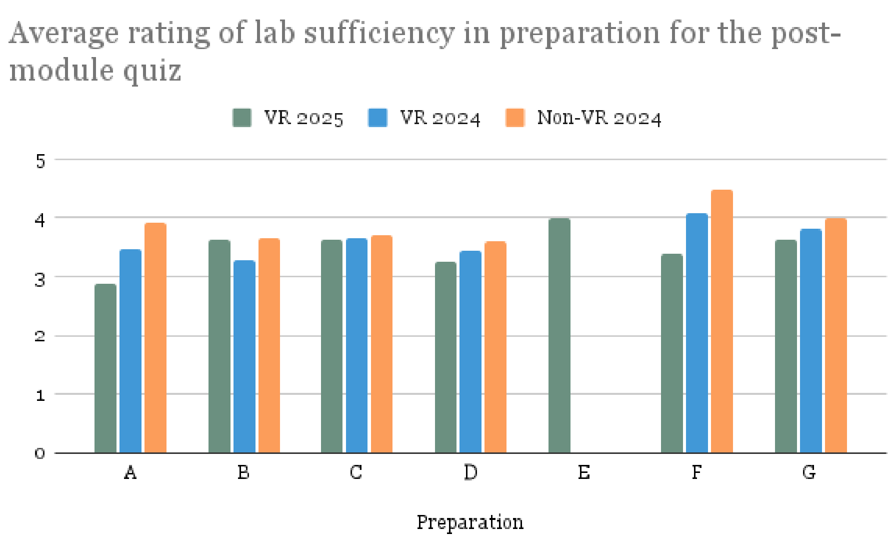


Figure 2: Student ratings among all groups for lab sufficiency in preparation for the post-module quiz. Scale ranges from 1- Highly Insufficient to 5- Highly Sufficient.

In the post-module reflection, students were asked how sufficient they found the lab to be in preparation for the post-module quiz. Similar to the 2024 data, included in Figure 2 above, VR students in the 2025 class ranked the lab preparation sufficiency lower than the 2024 non-VR students. Students again noted in feedback that pausing the simulation and removing the headset to take notes was cumbersome. However, the students who used the Meta Quest 3S did not share the same complaints. As opposed to the Meta Quest 2, the 3S includes the "action button" which allows users to activate the device's passthrough feature. Passthrough uses the headset's cameras to livestream the user's surroundings to the device, enabling users to see around them without taking the headset off. A student with the 3S noted this extra convenience during the lab sessions. As an aside, high-quality passthrough is expected to be a standard feature on future devices.

Also in the post-module reflection, students were asked to rate how well they enjoyed the lab session. Rankings for enjoyability were similar to the VR users in 2024, again with about half of the labs having a higher average rating over the non-VR users' ratings. These trends can be seen in Figure 3.

Figure 3: Averages of student responses from a scale of 1- Not at all to 5- Yes, very much.

A noticeable increase in perceived enjoyment can be seen from the 2024 VR to 2025 VR data for Module C. In response to critique from the previous students, the introduction to Module C was broken up into mini-scenes rather than one long, continuous scene. The educational content of the introduction was not modified, but the update allowed users more control over the progression of the scene. This aligns with the idea of user agency– how much control over the environment a user has– which is a key aspect of VR and may attribute to the higher rankings, post-update [9]. In general, higher agency contributes to immersion and thus can lead to a more enjoyable experience overall.

Though Module E has no non-VR data to compare against, the data from 2025 shows that the average enjoyability ranking for this module tied for first place against the flight simulator and Explore Mars with a Remote-Controlled Vehicle (Modules B and C, respectively). Module E was the latest simulation developed for the AeroAstro department and built upon the previous modules by incorporating additional features such as hand-tracking. With additional time dedicated to its development, Module E had more refined visuals. Survey responses indicated that students particularly appreciated the gamified aspects in this simulation. Students in general enjoyed time with the flight simulator, but echoed feedback from last year in that the VR controls were finicky and either too sensitive or not sensitive enough.

In the pre- and post-module reflections, students rated their confidence in meeting a set of learning objectives before and after the class. The rankings were given on a 3-point scale from "1- Not achieved," "2- Barely achieved," or "3- Fully or almost fully." For each module, average confidence among all students and all objectives was computed before and after the class. The difference in average confidence is recorded in Figure 4. Note that the difference varies based on the previous knowledge of the students; students with extensive prior knowledge may exhibit a lower change in confidence after the class, which affects the final averaged scores. Nonetheless, all changes are greater than zero, indicating an effective course overall.

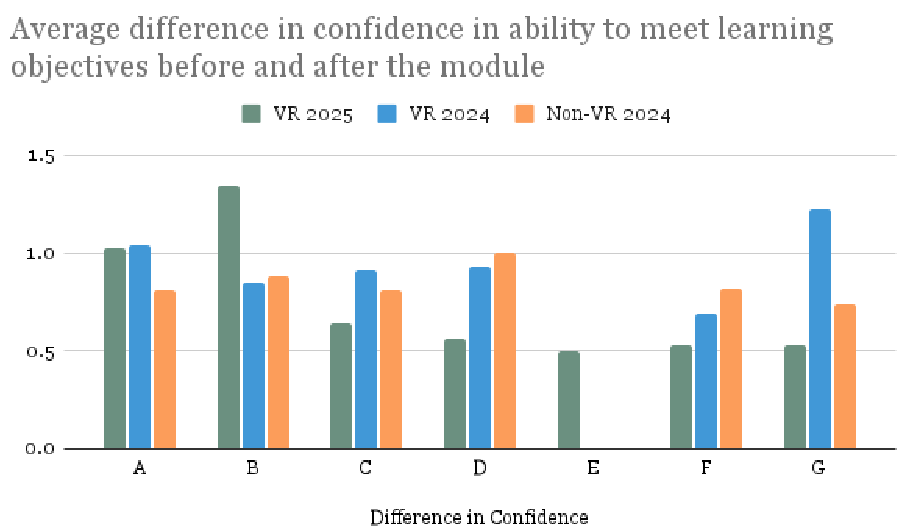


Figure 4: Difference between pre- and post-module average confidence levels.

At the end of the course, students were asked whether they preferred to learn the course material with or without VR on a scale from "1- Strongly preferred without VR" to "5- Strongly preferred with VR." The response distribution is shown in Figure 5. The average response from the 2025 students was higher than 3, showing a general preference for more VR; however, not all students preferred to learn with VR. This disagreement highlights the need to provide students with alternative methods of learning if VR is incorporated into the lesson plan; a non-VR alternative lesson can accommodate students' preferences and learning styles.

In terms of summative assessment performance, the data collected from the post-class quizzes show that the grade averages are roughly equal across groups for all modules, except Module D. The full descriptive statistics from the post-class quizzes are compared in Table 3.

Module D was the most difficult section of the course, a sentiment that was repeated for both years that Aeroverse was offered. Unlike the other modules, which require minimal prior knowledge, this module focuses on autonomous navigation and assumes a foundational understanding of coding. In 2025, some students with limited coding backgrounds struggled with completing this module. Nonetheless, the means of all other groups reflect an A-B average grade.

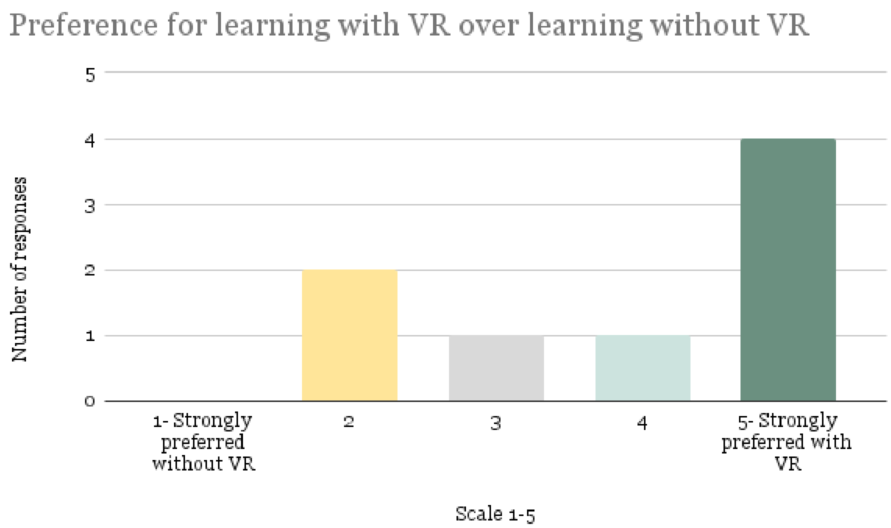


Figure 5: Student response to ”Based on your experience with the Aeroverse class so far, what is your current your preference for learning with VR over learning without VR?”

Table 3: Post-class quiz grade distribution for each module by group.

Module	Group	Mean	Min	1st Quart	3rd Quart	Max
	2025 VR	0.81	0.46	0.78	0.90	1.00
	2024 VR	0.84	0.68	0.81	0.89	0.96
A	2024 Non-VR	0.83	0.64	0.79	0.86	1.00
	2025 VR	0.81	0.54	0.70	0.94	1.00
	2024 VR	0.84	0.64	0.79	0.89	0.96
B	2024 Non-VR	0.84	0.64	0.80	0.88	0.93
	2025 VR	0.95	0.79	0.94	1.00	1.00
	2024 VR	0.95	0.88	0.92	0.98	1.00
C	2024 Non-VR	0.91	0.57	0.93	0.97	1.00
	2025 VR	0.76	0.63	0.73	0.81	0.83
	2024 VR	0.91	0.82	0.87	0.95	1.00
D	2024 Non-VR	0.90	0.69	0.89	0.94	0.98
	2025 VR	0.88	0.67	0.81	1.00	1.00
	2024 VR	0.82	0.46	0.79	0.90	1.00
F	2024 Non-VR	0.88	0.79	0.84	0.92	0.96
	2025 VR	0.87	0.50	0.81	1.00	1.00
	2024 VR	0.89	0.80	0.86	0.92	0.94
G	2024 Non-VR	0.91	0.84	0.87	0.95	0.99

Statistical Analysis

In order to determine if the response data distributions among all three groups (2025 VR, 2024 VR, and 2024 Non-VR) are statistically similar or not, one-way analysis of variance (ANOVA) and Kruskal-Wallis tests were performed. A one-way ANOVA test compares the means between three or more groups of data to determine if there is a significant difference among any group. As such, this test is appropriate for examining the grades and change in average confidence data to see if any group had a different mean result when compared to the others. A Kruskal-Wallis test, on the other hand, is the nonparametric version of the one-way ANOVA suitable for ordinal data such as the enjoyability responses. If a significant difference is found, post-hoc tests can be applied after either test for further investigation. Full parameters of each test are presented in Table 6 in Appendix C; only final results are discussed in this section.

The statistical outcome of the ANOVA test on the grades data shows that, for all modules except D, there is no significant difference in means among grade data. All students performed similarly in the course with respect to the summative assessment after each class. The exception to this pattern occurs in the Module D data– the p-value for this test was $p < 0.05$, and thus a significant difference in means between groups exists. A Bonferroni post-hoc test, tabulated in Table 7 in Appendix C, shows that the difference in means lies between the 2025 VR students and the other two groups. As observed in the raw data in Table 3, the 2025 VR students performed below average in comparison to all 2024 students. The content and assessment remained the same for Module D between years. Therefore, it is posited that the smaller sample size coupled with the non-aerospace background of some of the students contributed to the contrast in responses.

When considering effects on change in average confidence, the ANOVA tests support the previous findings and additionally conclude that there is insufficient evidence to show that the means of the three groups are significantly different for any module. In short, the VR condition has no significant impact on difference in confidence.

The results from the Kruskal-Wallis enjoyability test further support the outcomes from the previous course. There is no difference in median enjoyability rankings for every module with the same exception in Module A. A Dunn's pairwise post-hoc test was applied to then determine between which of the three groups the difference in median(s) lie. From the post-hoc test results reported in Table 8 in Appendix C, it is clear that both the 2025 VR and 2024 VR groups rated their enjoyability significantly higher than the 2024 Non-VR group, but retain similar medians between themselves. Therefore, the conclusion is drawn that, in the context of Module A, VR users ranked their enjoyment more favorably than non-VR users, and there is no difference among VR users between years.

Cybersickness

One cannot discuss virtual reality without mentioning its primary drawback: cybersickness, also known as VR motion sickness. Cybersickness shares many similarities with motion sickness– such as malaise and nausea– but also affects the ocular senses in the form of eye strain and eye fatigue [33, 34]. Cybersickness can negatively affect a user's experience, and is the most cited complaint among users who have purchased a VR device [35]. During Aeroverse, students were asked to self-report "any adverse affects of any kind or magnitude" experienced during the lab; the definition of cybersickness in this study is particularly lax and includes all mentions of slight eye strain or dizziness. Results from the second iteration of the course are shown in Figure 6.

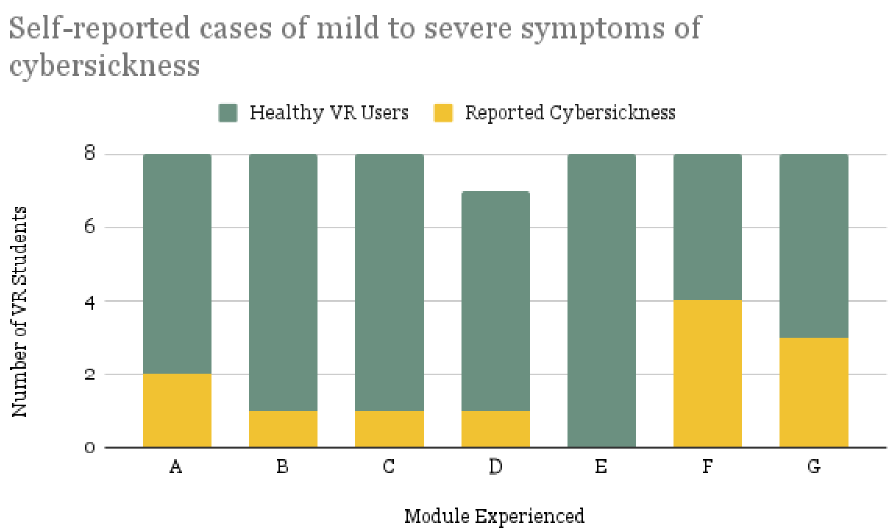


Figure 6: Self-reported cases of cybersickness by module in 2025.

Similar to the previous results, the highest number of cases came from Modules F and G, which used Mission: ISS, a free application that simulates microgravity. Notably, no cases were reported for Module E. Though visual optimization may have contributed, it is more likely due to the fact that Module E was considerably shorter than the other lab activities ($\sim$20 minutes to complete, as opposed to 60-90 minutes).

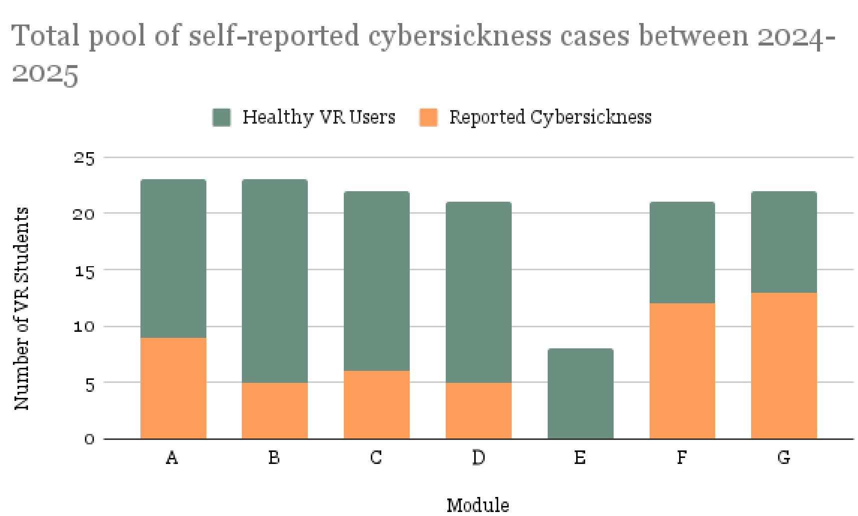


Figure 7: All self-reported cases of cybersickness from 2024-2025 by module.

A traditional independent samples t-test was performed to compare the mean grade scores of the two groups– cybersick and healthy VR users– to determine if the population means are significantly different. However, since some groups had a sample size of only $N = 1$, a t-test could not be performed on the 2025 cybersickness data alone. Instead, the data in Figure 6 has been added to the 2024 cybersickness data to form a cumulative pool, outlined in Figure 7 above. A t-test was then performed, shown in Table 4, which ultimately revealed no significant difference for any module in terms of grade performance. Again, this affirms the findings from [30]: cybersickness has no significant impact on students' grades.

Table 4: Statistical results from the Student's t-test applied to the cybersickness data.

Module A			**Module B**			**Module C**		
	Healthy	*Cybersick*		*Healthy*	*Cybersick*		*Healthy*	*Cybersick*
Mean	0.83	0.83	Mean	0.82	0.87	Mean	0.95	0.95
Variance	0.02	0.01	Variance	0.01	0.01	Variance	0.00	0.00
Observations	14	9	Observations	18	5	Observations	16	6
df	21		df	21		df	20	
T Stat.	-0.085		T Stat.	0.78		T Stat.	0.064	
p-value	0.93		p-value	0.44		p-value	0.95	
Module D			**Module F**			**Module G**		
	Healthy	*Cybersick*		*Healthy*	*Cybersick*		*Healthy*	*Cybersick*
Mean	0.85	0.87	Mean	0.87	0.90	Mean	0.82	0.85
Variance	0.01	0.01	Variance	0.01	0.00	Variance	0.03	0.02
Observations	16	5	Observations	9	12	Observations	9	13
df	19		df	19		df	20	
T Stat.	0.381		T Stat.	0.61		T Stat.	0.371	
p-value	0.71		p-value	0.55		p-value	0.71	

Conclusion and Future Work

These findings wholly agree with the previous results found in [30], with one exception. It can be concluded then that, for this particular course setup, the inclusion of VR over non-VR activities shows little improvement in the following learning outcomes: grades, difference in average confidence, and enjoyability. The only significant deviations were seen in the Module A enjoyability data– all VR students enjoyed their lab significantly over the non-VR extended lecture– and the Module D grade performance– 2025 VR students received lower scores than 2024 students.

Though the findings from this study show limited significant improvement for students who use VR, the findings simultaneously show no consistent *decrease* in the same learning outcomes as well, given that all statistical tests are two-sided. One conclusion to be drawn is that, for these particular non-VR offerings, VR student performance was comparable. However, these results may change for alternative non-VR offerings. Recall that the non-VR lab activities were designed to be as similar in educational content as possible, but still be engaging enough so as to not dissuade classroom participation. The non-VR labs are somewhat untraditional in the context of an aerospace engineering course, as they involve desktop simulators and interactive slideshows; refer to Table 2. In short, while the non-VR options in this study may *individually* resemble traditional teaching methods, the non-VR condition does not replicate a conventional course curriculum overall. Results may change for alternative non-VR offerings that more closely mirror a traditional course curriculum, particularly one that is lecture-based. The significant result found for Module A suggests that, had all non-VR activities been replaced by lectures, the outcomes of this experiment may be vastly different.

Consider, then, an alternative interpretation of these findings. The non-VR activities were deliberately designed as a cohesive alternative to the VR experience. The lack of difference in enjoyment between the two groups suggests that it is indeed possible to create a non-VR learning experience that is equally enjoyable. This has important implications for educators, particularly given that not all students respond positively to VR, i.e. in the case of cybersickness. It was observed that users did experience some form of cybersickness throughout the course, but that cybersickness had no significant effect on grade performance. Still, creating carefully designed non-VR alternatives can provide accessibility and maintain engagement without relying exclusively on immersive technologies.

Because student performance remained consistent across subsequent years in almost all cases, this indicates that VR-based instruction is repeatable. Such insight is particularly valuable for instructors considering the adoption of immersive technologies but concerned about potential drawbacks. Knowing that VR can be implemented repeatedly without negatively impacting learning outcomes provides a strong case for further exploration and refinement. Finally, since students expressed preference to learn with VR, instructors may view this positive reception as an additional factor when deciding whether to integrate immersive experiences into their teaching.

The work done thus far for the Aeroverse course has a variety of applications. Insights gained from creating VR content will guide the development of additional modules, including those using augmented reality. Given that no significant disadvantage has been found in consistently using these modules, future efforts will also focus on integrating them into other existing courses at the Massachusetts Institute of Technology, both at the undergraduate and graduate level. To contribute to the existing pool of educational VR content, the modules will be made open-source and accessible to anyone with a compatible headset after a series of final refinements. By continuing to share results and create new resources, this work aims to support the wider adoption of immersive technologies in education and inspire future advancements in the field.

References

[1] D. Cvetković, *Virtual Reality and Its Application in Education*. Rijeka: IntechOpen, 2021.

[2] J. Bailenson, *Experience on demand: what virtual reality is, how it works, and what it can do*. W. W. Norton& Company, Inc, 2018.

[3] J. Hale, "Applied virtual reality in aerospace," in *Wescon/96*, pp. 547–550, IEEE, 1996.

[4] T. Jung and J. Dalton, eds., *XR Case Studies: Using Augmented Reality and Virtual Reality Technology in Business*. Management for Professionals, Springer International Publishing, 2021.

[5] C. D. Rojas Ferrer, H. Shishido, I. Kitahara, and Y. Kameda, "Visual exploratory activity under microgravity conditions in VR: An exploratory study during a parabolic flight," in

2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR), pp. 1136–1137, IEEE, 2019.

[6] S. Tadeja, P. Seshadri, and P. Kristensson, "AeroVR: An immersive visualisation system for aerospace design and digital twinning in virtual reality," *The Aeronautical Journal*, vol. 124, no. 1280, pp. 1615–1635, 2020.

[7] E. Matsas, G.-C. Vosniakos, and D. Batras, "Modelling simple human-robot collaborative manufacturing tasks in interactive virtual environments," in *Proceedings of the 2016 Virtual Reality International Conference*, pp. 1–4, ACM, 2016.

[8] M. Bower and M. S. Jong, "Immersive virtual reality in education," *British Journal of Educational Technology*, vol. 51, no. 6, pp. 1981–1990, 2020.

[9] M. C. Johnson-Glenberg, "Immersive VR and education: Embodied design principles that include gesture and hand controls," *Frontiers in Robotics and AI*, vol. 5, p. 81, 2018.

[10] M. A. M. AlGerafi, Y. Zhou, M. Oubibi, and T. T. Wijaya, "Unlocking the potential: A comprehensive evaluation of augmented reality and virtual reality in education," *Electronics*, vol. 12, no. 18, p. 3953, 2023.

[11] E. Southgate, *Virtual Reality in Curriculum and Pedagogy: Evidence from Secondary Classrooms*. Routledge, 1 ed., 2020.

[12] G. B. Petersen, S. Klingenberg, R. E. Mayer, and G. Makransky, "The virtual field trip: Investigating how to optimize immersive virtual learning in climate change education," *British Journal of Educational Technology*, 2020.

[13] X. Yu, K. Li, J. Li, B. Wang, and X. Zhang, "Design of an VR-based immersive physics experiment teaching platform," in *2021 2nd International Conference on Information Science and Education (ICISE-IE)*, pp. 1102–1106, IEEE, 2021.

[14] C. L. Hemme, R. Carley, A. Norton, M. Ghumman, H. Nguyen, R. Ivone, J. U. Menon, J. Shen, M. Bertin, R. King, E. Leibovitz, R. Bergstrom, and B. Cho, "Developing virtual and augmented reality applications for science, technology, engineering and math education," *BioTechniques*, vol. 75, no. 1, pp. 11–20, 2023.

[15] H. S. Qorbani, A. Arya, N. Nowlan, and M. Abdinejad, "ScienceVR: A virtual reality framework for STEM education, simulation and assessment," in *2021 IEEE International Conference on Artificial Intelligence and Virtual Reality (AIVR)*, pp. 267–275, IEEE, 2021.

[16] A. Z. Sampaio, M. M. Ferreira, D. P. Rosário, and O. P. Martins, "3d and VR models in civil engineering education: Construction, rehabilitation and maintenance," *Automation in Construction*, vol. 19, no. 7, pp. 819–828, 2010.

[17] N.-C. Tai, "Applications of augmented reality and virtual reality on computer-assisted teaching for analytical sketching of architectural scene and construction," *Journal of Asian Architecture and Building Engineering*, vol. 22, no. 3, pp. 1664–1681, 2023.

[18] K. Hanson and B. E. Shelton, "Design and development of virtual reality: Analysis of

challenges faced by educators," *Journal of Educational Technology& Society*, vol. 11, pp. 118–131, 2008.

[19] A. Cabrera-Duffaut, A. M. Pinto-Llorente, and A. Iglesias-Rodríguez, "Immersive learning platforms: analyzing virtual reality contribution to competence development in higher education—a systematic literature review," *Frontiers in Education*, vol. 9, 2024.

[20] M. Resnick and G. Morgan, "Best practices for virtual reality in higher education," tech. rep., Gartner, 2017.

[21] E. Johnston, G. Olivas, P. Steele, C. Smith, and L. Bailey, "Exploring pedagogical foundations of existing virtual reality educational applications: A content analysis study," *Journal of Educational Technology Systems*, vol. 46, no. 4, pp. 414–439, 2018.

[22] C. Fowler, "Virtual reality and learning: Where is the pedagogy?," *British Journal of Educational Technology*, vol. 46, no. 2, pp. 412–422, 2015.

[23] L. Lehane, "Experiential Learning– David A. Kolb," in *Science Education in Theory and Practice: An Introductory Guide to Learning Theory* (B. Akpan and T. Kennedy, eds.), pp. 241–257, Springer, 2020.

[24] G. Cakmakci, M. Aydeniz, A. Brown, and J. Makokha, "Situated cognition and cognitive apprenticeship learning," in *Science Education in Theory and Practice: An Introductory Guide to Learning Theory* (B. Akpan and T. Kennedy, eds.), pp. 293–310, Springer, 2020.

[25] Y. Ramma, A. Bholoa, and M. Watts, "Guided Discovery–Robert Gagne," in *Science Education in Theory and Practice: An Introductory Guide to Learning Theory* (B. Akpan and T. Kennedy, eds.), pp. 191–208, Springer, 2020.

[26] A. Scavarelli, A. Arya, and R. J. Teather, "Virtual reality and augmented reality in social learning spaces: a literature review," *Virtual Reality*, vol. 25, no. 1, pp. 257–277, 2021.

[27] L. Giunta, H. Wright, S. Chandra Shekar, and S. Gururajan, "Student paper: Developing an extensive virtual reality environment for learning aerospace concepts," in *2022 ASEE Annual Conference & Exposition Proceedings*, p. 41814, ASEE Conferences, 2022.

[28] Y. Xie, Y. Zhang, and Y. Cai, "Virtual reality engine disassembly simulation with natural hand-based interaction," in *VR, Simulations and Serious Games for Education* (Y. Cai, W. Van Joolingen, and Z. Walker, eds.), pp. 121–128, Springer Singapore, 2019. Series Title: Gaming Media and Social Effects.

[29] C. A. Aji and M. J. Khan, "The impact of immersive virtual reality on undergraduate STEM students," in *2023 ASEE Annual Conference & Exposition Proceedings*, p. 44460, ASEE Conferences, 2023.

[30] M. Johnson, R. Lavi, O. De Weck, P. Hajela, L. Carlone, S. Hu, M. Abate, Z. Awwad, and Y. Chang, "A comparative study of the impact of virtual reality on student learning and satisfaction in aerospace education," in *2024 ASEE Annual Conference & Exposition Proceedings*, p. 46426, ASEE Conferences, 2024.

[31] A. Perry, "Meta discontinues the quest 2 and quest pro after revealing quest 3s." Accessed: April 4, 2025. [Online]. Available: https://mashable.com/article/meta-quest-2-discontinued-connect-2024.

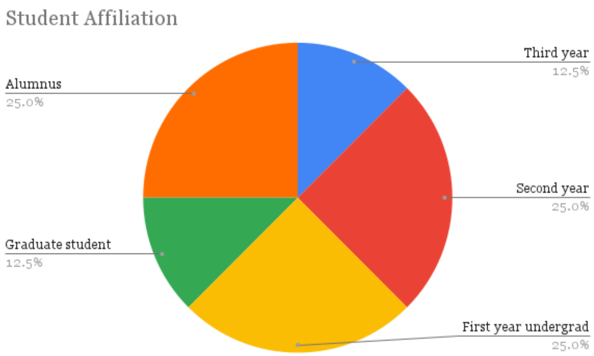
[32] C. R. Mehta and N. R. Patel, "Ibm spss exact tests," 2013. Accessed: Mar. 10, 2025. [Online]. Available: https://www.ibm.com/docs/en/SSLVMB_27.0.0/pdf/en/IBM_SPSS_Exact_Tests.pdf.

[33] R. Doerner, W. Broll, P. Grimm, and B. Jung, eds., *Virtual and Augmented Reality (VR/AR): Foundations and Methods of Extended Realities (XR)*. Springer International Publishing, 2022.

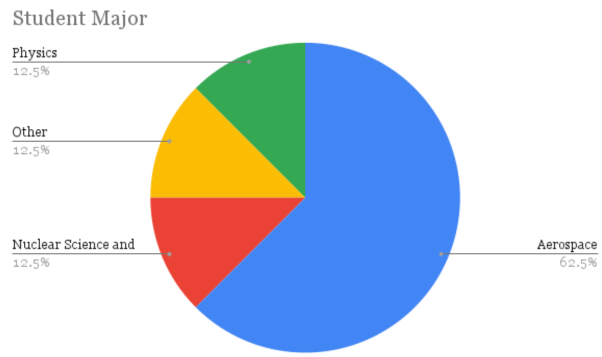
[34] O. Hein, P. Rauschnabel, M. Hassib, and F. Alt, "Sick in the car, sick in VR? understanding how real-world susceptibility to dizziness, nausea, and eye strain influences VR motion sickness," in *Human-Computer Interaction – INTERACT 2023*, vol. 14143, pp. 552–573, Springer Nature Switzerland, 2023. Series Title: Lecture Notes in Computer Science.

[35] F. Navaratnam-Blair, K. Wagstaff, G. Miller, M. Cumberbatch, and C. Rethore, "Beyond reality," 2022.

Appendix A

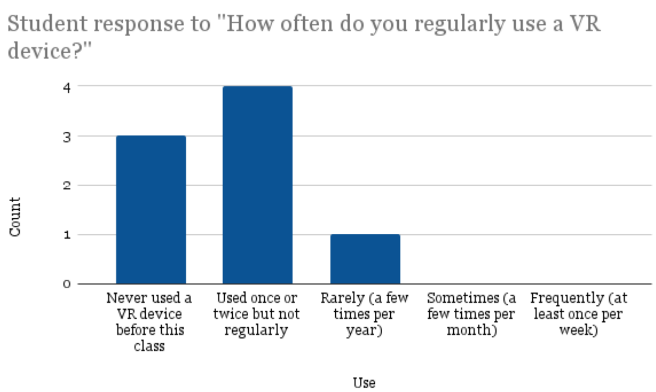


(a)

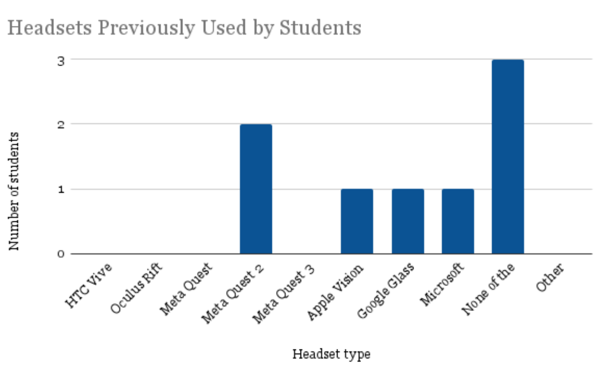


(b)

Figure 8: (a) Student breakdown by year. Two alumni were allowed to join the course as a participant, who were able to complete all assignments. (b) Student breakdown by major.



(a)



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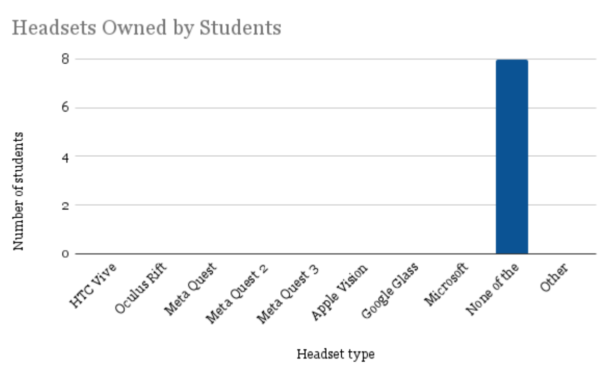

(c)

Figure 9: (a) Students rated their regular use of VR of any type. (b) Students recorded experience with any previous VR device by type. (c) Students listed which headsets they own.

Appendix B

Table 5: Updated statistical results from the 2024 course when comparing VR and non-VR groups.

t-Test: Grades								
Module A			**Module B- Grades**			**Module C- Grades**		
	VR	*Non-VR*		*VR*	*Non-VR*		*VR*	*Non-VR*
Mean	0.840	0.829	Mean	0.843	0.835	Mean	0.949	0.913
Variance	0.007	0.008	Variance	0.008	0.006	Variance	0.001	0.013
Observations	15	14	Observations	15	14	Observations	14	15
df	27		df	27		df	27	
t Stat	0.328		t Stat	0.250		t Stat	1.143	
P (two-tail)	0.745		P (two-tail)	0.804		P (two-tail)	0.263	
Module D			**Module F- Grades**			**Module G- Grades**		
	VR	*Non-VR*		*VR*	*Non-VR*		*VR*	*Non-VR*
Mean	0.909	0.901	Mean	0.888	0.914	Mean	0.824	0.877
Variance	0.003	0.006	Variance	0.002	0.002	Variance	0.025	0.003
Observations	14	15	Observations	14	15	Observations	15	14
df	27		df	27		df	27	
t Stat	0.322		t Stat	-1.531		t Stat	-1.197	
P (two-tail)	0.750		P (two-tail)	0.137		P (two-tail)	0.242	
t-Test: Difference in Average Confidence								
Module A			**Module B**			**Module C**		
	VR	*Non-VR*		*VR*	*Non-VR*		*VR*	*Non-VR*
Mean	1.040	0.814	Mean	0.821	0.875	Mean	0.908	0.754
Variance	0.361	0.520	Variance	0.158	0.603	Variance	0.739	0.336
Observations	15	14	Observations	14	14	Observations	14	14
df	27		df	26		df	26	
t Stat	0.918		t Stat	-0.230		t Stat	0.554	
P (two-tail)	0.367		P (two-tail)	0.820		P (two-tail)	0.584	
Module D			**Module F**			**Module G**		
	VR	*Non-VR*		*VR*	*Non-VR*		*VR*	*Non-VR*
Mean	0.929	1.250	Mean	0.691	0.822	Mean	1.222	0.737
Variance	0.437	0.250	Variance	0.914	0.474	Variance	0.329	0.686
Observations	14	15	Observations	14	15	Observations	15	14
df	27		df	27		df	27	
t Stat	-1.484		t Stat	-0.427		t Stat	1.843	
P (two-tail)	0.150		P (two-tail)	0.673		P (two-tail)	0.076	
Kruskal-Wallis: Enjoyability								
Module A			**Module B**			**Module C**		
	VR	*Non-VR*		*VR*	*Non-VR*		*VR*	*Non-VR*
Median	4	3	Median	5	5	Median	4	3
Total N	29		Total N	28		Total N	28	
Test Statistic	13.369		Test Statistic	3.363		Test Statistic	1.57	
df	1		df	1		df	1	
Asymptotic Sig.	$<$ **0.05**		Asymptotic Sig.	0.067		Asymptotic Sig.	0.21	
Module D			**Module F**			**Module G**		
	VR	*Non-VR*		*VR*	*Non-VR*		*VR*	*Non-VR*
Median	3.5	4	Median	5	4	Median	4	4.5
Total N	29		Total N	29		Total N	29	
Test Statistic	0.67		Test Statistic	0.347		Test Statistic	0.055	
df	1		df	1		df	1	
Asymptotic Sig.	0.413		Asymptotic Sig.	0.556		Asymptotic Sig.	0.814	

Appendix C

Table 6: Statistical results from the 2024-2025 data sets comparing all VR and non-VR groups.

ANOVA: Grades

Module A				**Module B**				**Module C**			
	2025 VR	*2024 VR*	*2025 Non-VR*		*2025 VR*	*2024 VR*	*2025 Non-VR*		*2025 VR*	*2024 VR*	*2025 Non-VR*
Mean	0.813	0.840	0.829	Mean	0.813	0.843	0.835	Mean	0.954	0.949	0.913
df btw. Groups		2		df btw. Groups		2		df btw. Groups		2	
df w/in Groups		34		df w/in Groups		34		df w/in Groups		34	
F-statistic		0.163		F-statistic		0.226		F-statistic		0.927	
Significance		0.850		Significance		0.799		Significance		0.406	
Module D				**Module F**				**Module G**			
	2025 VR	*2024 VR*	*2025 Non-VR*		*2025 VR*	*2024 VR*	*2025 Non-VR*		*2025 VR*	*2024 VR*	*2025 Non-VR*
Mean	0.756	0.909	0.901	Mean	0.881	0.824	0.877	Mean	0.870	0.888	0.914
df btw. Groups		2		df btw. Groups		2		df btw. Groups		2	
df w/in Groups		34		df w/in Groups		34		df w/in Groups		34	
F-statistic		13.942		F-statistic		0.892		F-statistic		0.697	
Significance		**<0.001**		Significance		0.419		Significance		0.505	

ANOVA: Difference in Average Confidence

Module A				**Module B**				**Module C**			
	2025 VR	*2024 VR*	*2025 Non-VR*		*2025 VR*	*2024 VR*	*2025 Non-VR*		*2025 VR*	*2024 VR*	*2025 Non-VR*
Mean	1.025	1.040	0.814	Mean	1.344	0.821	0.875	Mean	0.641	0.908	0.754
df btw. Groups		2		df btw. Groups		2		df btw. Groups		2	
df w/in Groups		34		df w/in Groups		16.488		df w/in Groups		33	
F-statistic		0.446		F-statistic		2.041		F-statistic		0.388	
Significance		0.644		Significance		0.146		Significance		0.681	
Module D				**Module F**				**Module G**			
	2025 VR	*2024 VR*	*2025 Non-VR*		*2025 VR*	*2024 VR*	*2025 Non-VR*		*2025 VR*	*2024 VR*	*2025 Non-VR*
Mean	1.071	0.929	1.250	Mean	0.709	0.691	0.822	Mean	0.709	1.222	0.737
df btw. Groups		2		df btw. Groups		2		df btw. Groups		2	
df w/in Groups		33		df w/in Groups		34		df w/in Groups		34	
F-statistic		1.125		F-statistic		0.105		F-statistic		2.226	
Significance		0.337		Significance		0.901		Significance		0.123	

Kruskal-Wallis: Enjoyability

Module A				**Module B**				**Module C**			
	2025 VR	*2024 VR*	*2025 Non-VR*		*2025 VR*	*2024 VR*	*2025 Non-VR*		*2025 VR*	*2024 VR*	*2025 Non-VR*
Median	4	4	3	Median	5	5	5	Median	5	4	3
Total N	37			Total N	36			Total N	37		
Test Stat.	15.578			Test Stat.	3.233			Test Stat.	5.567		
df	2			df	2			df	2		
Asymp. Sig.	<0.001			Asymp. Sig.	0.199			Asymp. Sig.	0.062		
Module D				**Module F**				**Module G**			
	2025 VR	*2024 VR*	*2025 Non-VR*		*2025 VR*	*2024 VR*	*2025 Non-VR*		*2025 VR*	*2024 VR*	*2025 Non-VR*
Median	4	3.5	4	Median	4.5	5	4	Median	4.5	4	4.5
Total N	36			Total N	37			Total N	37		
Test Stat.	2.357			Test Stat.	0.371			Test Stat.	0.071		
df	2			df	2			df	2		
Asymp. Sig.	0.308			Asymp. Sig.	0.831			Asymp. Sig.	0.965		

Table 7: Bonferroni post-hoc results from the ANOVA test applied to Module D grades data.

Pairs	**Mean Difference**	**Std. Error**	**Sig.**
2025 VR & 2024 Non-VR	-0.14495	0.03068	**<.001**
2024 VR & 2024 Non-VR	0.0079	0.02491	1
2025 VR & 2024 VR	-0.15286	0.03103	**<.001**

Table 8: Dunn's pairwise post-hoc results from the Kruskal-Wallis Enjoyability test for Module A. Asymptotic significance levels have been adjusted by the Bonferroni correction.

Pairs	**Test Statistic**	**Asymp. Sig.**	**Adjusted Sig.**
2024 Non-VR & 2025 VR	13.473	0.003	**0.009**
2024 Non-VR & 2024 VR	13.869	0.003	**0.001**
2025 VR & 2024 VR	-0.396	0.93	1