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A study of the virtual reality cybersickness impacts and improvement strategy towards the overall undergraduate students' virtual learning experience

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Abstract

Purpose – Virtual reality (VR) technologies have expanded their application domains towards education with pedagogical benefits including fully immersive learning environment and in-depth user engagement through scenario-based virtual simulations. Motion sickness (MS), however, has become one of the long-standing key challenges of the VR utilisation, even in gaming industries. Thus, this paper aims to present a preliminary study on understanding the VR MS, referred as cybersickness, in the teaching and learning (T&L) context at the University of Nottingham Ningbo China.

Design/methodology/approach – A VR-based virtual classroom content was developed and tested for 60 undergraduate students having equal access to the same VR equipment. A two-step data collection, comprising qualitative and quantitative measures, was conducted for the participants. The aspects of how gender influences the cybersickness severity and how academic background affects the learning experience were investigated and analysed using analysis of variance F-test statistical approach.

Findings – The results demonstrated approximately 47% of the participants had experienced cybersickness, where 64% of them were females. With confidence level of 95% ($a = 5\%$), the obtained p-value and F-statistical value for the respective gender and study discipline categories against the cybersickness symptoms confirmed the significance level between the two compared variables. Moreover, it is worth highlighting that the virtual movement speed, perspective angle and visual properties of the virtual environment were selected as the top three factors that caused the cybersickness.

The study is conducted by the V-ROOM project team, which is led by the first author of this paper. All materials such as research data, figures and tables are produced by the V-ROOM project team. The project is funded by the University of Nottingham Ningbo China, under the V-ROOM strategy budget code.

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Originality/value – The study is hoped to provide valuable pointers to current and future VR developers in minimising the cybersickness symptoms that would enable an effective T&L environment in higher education.

Keywords Higher education, Simulation, Experiential learning, Blended learning, Digital learning, Virtual and augment reality, V-ROOM, Virtual reality, Cybersickness, Motion sickness, Teaching and learning, Education technology, Pedagogy innovation

Paper type Research paper

1. Introduction

The general description of motion sickness (MS) is recognised as a common syndrome that typically occurs due to the mismatch between perceived and expected motion (Takov and Tadi, 2021). Nooij *et al.* (2021) added a statement that MS could also be induced by the belief that motion is happening, although in reality, no motion is detected in the actual experience. MS usually manifests differently on different individuals for various reasons, although many reported overlapping symptoms such as nausea, headache, stomach awareness, disorientation, vomiting and more (Golding, 2016; Takov and Tadi, 2021).

According to Lackner (2014), MS can be instigated by three types of motion: physical, visual and virtual. Physical motion refers to the motion that resulted from real-life movements such as the swaying motion on a ship or when riding a rollercoaster. Visual motion is the motion that is "perceived" when looking at an otherwise stationary environment, such as when viewing an optical illusion. MS caused by visual motion typically occurs when what is perceived visually does not correspond to the physical stimulation, such as when riding a car where a person would sit in a stationary position while the perceived scenery in the surrounding environmental view would pass rapidly. Virtual motion, as the name suggests, occurs in a virtual environment and is similar to the visual motion. Often, the virtual motion MS also takes place when there is a mismatch between the perceived motion and the actual motion felt by the individual exposed to the virtual environment.

In recent years, visual and virtual MS (collectively designated as visually induced MS or VIMS) are increasingly reported along with the rapid development of visual and virtual technologies, such as the three-dimensional (3D) motion picture in cinemas (Flanagan *et al.*, 2004; Solimini, 2013) and virtual reality (VR) technologies (Chang *et al.*, 2020). In the context of using VR, an immersive VR is defined as a VR content in which the user has a sense of being present and is able to interact with the virtual environment (Hamilton, *et al.*, 2021). In other words, the VR users would be fully immersed in the created virtual world or environment. Following the rising use of VR technologies in daily life, apart from gaming, and the emergence of affordable low-cost VR equipment, VR cybersickness (VRC) continues to be one of the most common side effects of using VR. There is thus an increasing need to better understand the effects and impacts of MS in VR. Thus, it is important to first understand the relationship of different factors that potentially cause or trigger the occurrence VRMS in numerous applications.

1.1 Motion sickness

VRMS, also known as cybersickness or virtual reality sickness, is a subset of MS that is often linked to the use or immersion in the created VR environments (Chang *et al.*, 2020; Yildirim, 2019). People who experienced VRMS typically reported similar symptoms compared to that of traditional MS (Chang *et al.*, 2020; McCauley and Sharkey, 1992; Yildirim, 2019).

One notable study by Gavgani *et al.* (2018) has tried to compare between VRMS and "classical" MS. The study had concluded that "cybersickness and classic MS are clinically identical, at least in their advanced stages" (Gavgani *et al.*, 2018, p. 1679) based on the similarity of symptoms and autonomic changes between VRMS and traditional MS in the same group of volunteer participants.

The occurrence of VRMS could be explained through the sensory conflict theory, i.e. the mismatch between visual stimuli and the vestibular senses (Ng *et al.*, 2020). As the name of the theory suggests, this theory presumes that VRMS would occur whenever the different sensory systems present conflicting sensory information. When VR users are immersed in virtual environments, what they observe are created virtually and usually do not correspond to their physical situation or position, thus causing different feedbacks between what the eyes see and what they experienced physiologically. This theory has remained as the most accepted and cited theory explaining the cause of cybersickness (Keshavarz *et al.*, 2014; Palmisano *et al.*, 2020).

VRMS has been reported to occur in one form or the other by the majority of VR users. Several studies done by other researchers have concluded that more than 80% of participants of a VR experience reported some form of VRMS (Clifton and Palmisano, 2019; Risi and Palmisano, 2019; Teixeira and Palmisano, 2021). Stanney *et al.* (2020) also believed that MS or cybersickness is one of the key factors that might become an obstacle when mass adoption of XR (extended reality) technology is considered, including for VR. Thus, it is important that the effects of VRMS be minimised or mitigated.

1.2 Virtual reality cybersickness in various applications

As VR technologies are being continuously developed and studied, its application amongst a plethora of discipline has also increased, especially in the field of higher education (HE), video games, medicine/health care and the social sciences, such as history (Cipresso *et al.*, 2018; Radianti *et al.*, 2020; Yildirim, 2019).

In the context of VRC presence in the field of health care, Servotte *et al.* (2020) conducted a study specifically amongst a group of predominantly undergraduate health-care students and postgraduates with no special trainings. The study used a specially made VR simulation that was developed following medical emergencies scenarios that were designed by health-care professionals. Servotte *et al.* found that a high sense of presence during VR immersion is associated with low level of cybersickness, albeit discomfort caused by VR was still observed. To add on, a study by Taylor and Layland (2019) tried to investigate different forms of virtual simulations and its prevalence in inducing VRC in the context of health care. Amongst the simulations were "360-degree video, manikin, standardised patient, and video case study" (Taylor and Layland, 2019, p. 171). It was found that participants are not more likely to get MS from VR-based simulation than from other type of simulations, thus justifying the use of VR in health care.

The presence of VRC in video games, another field involving VR technologies and VRC, has also been widely investigated. Most video games incorporate elements of digital graphics, storytelling and user immersion to deliver a compelling narrative and gameplay that draw players to play it. VR video games, which offer fully immersive virtual environments, are of no exception to cause cybersickness. However, Weech *et al.* (2020) have interestingly found that VRC is negatively correlated to the sense of presence in VR games. To put it simply, an enriched narrative/story allows for players to be more immersed and present in the game, which in turn reduces the effect of cybersickness.

Having investigated at how common the MS and VRC symptoms appeared in the use of digital to virtual environment in various applications, the current work focuses on a specific implementation in the context of HE to observe students reaction towards this, i.e., when a VR-based classroom is used in their teaching and learning (T&L) conduct. To briefly review at the potentials of using VR-based virtual classroom (V-ROOM), previous research has shown how students' perceptions of using VR in the HE classrooms vary from one to another; however, it is evident that their responses towards educational VR are generally positive (Hagge, 2020; Baxter and Hainey, 2019; Alfalah, 2018; Domingo and Bradley, 2018). The study conducted by Oiwake *et al.* (2018) also demonstrated similar responses from the students when exposed to three types of classes (real-world classes, remote classes and VR classes), where it was suggested that VR classrooms could increase students' motivation, and VR scored the highest in terms of relevance and satisfaction parameters.

Having looked at the many pedagogical advantages of VR in education in contrast to the VRC side effects that occur as a compromise, hence, a pilot study was conducted to investigate whether the cybersickness effects are linked to the utilisation of VR devices. If so, the symptoms that are associated with VRC will also be identified in the T&L activity applications. In this paper, the presence of VRC symptoms in the use of a VR-based classroom, and how these symptoms are related to the students' background will be particularly investigated. Causes of the VRC symptoms, when present, will also be studied according to the students' receptive level of severity and commonness during the VR experience of the virtual classroom. The following sections will present and analyse the data obtained from the pilot study survey, starting from how the study was designed and conducted (Section 2), statistical process of the survey data analysis (Section 3), review of potential mitigation strategies in dealing with the VRC (Section 4), and what can be concluded from the results including future work of this study (Section 5).

2. Methodologies

This V-ROOM pilot study aims to provide a preliminary understanding of the VRC effects of using a VR-based classroom in the T&L area for undergraduate students. Feedbacks from the students would be studied and surveyed based on their VR experiential journey. The study has been reviewed and approved by the University Research Ethics Subcommittee according to the ethical review processes of University of Nottingham Ningbo China (UNNC). These processes, as shown in Figure 1, are governed by the University's Code of Research Conduct and Research Ethics.

In comparison to previous studies in the similar areas of VRC and/or VRMS, contributions of the current study are highlighted below:

- The pilot study uses the developed V-ROOM mobile APP which comprises the use of different virtual classrooms set for the purpose of T&L activities. This is offered as an alternative scenario to being in the actual physical classrooms. The embedded VR contents, i.e. learning activity and tasks such as quizzes, presentation slides and video, are designed to be aligned with the utilisation of learning resources in the classroom. Nonetheless, the VRC investigation using a V-ROOM was not widely studied by previous researchers.
- As the focus of the pilot study looks at how VR is used in the HE context, students become one of the primary end-users of the proposed V-ROOM. Therefore, the participants invited in the pilot sessions are university undergraduate students, ranging from 18 to 23 years old, who are directly involved in the learning process. Previous researches, however, mainly explored the cybersickness effects from broader range of participants' backgrounds such as age and profession, even when they were within educational settings.

Through these specific arrangements, the participants will experience the virtual environment as themselves, "a student", without the necessity of a role-play scenario. The study results are thus expected to provide as accurate data representation as possible of the user experience, which is the student experience, to align with the bigger aim of the V-ROOM project, i.e. analysing the usability of V-ROOM for teaching purposes. If proven as a viable pedagogical approach, pending further research and analysis, VR scene could be suggested as a more regular option used for T&L delivery in the future. It is however noted that this paper will only present the preliminary investigation results of the VRC presence and suggest plausible strategy to reduce the VRC impacts. The following sections will present detailed execution of the pilot study.

2.1 Participants

A total of 60 healthy participants from various study disciplines were selected to participate in the study following a volunteer sampling method. Amongst these participants, 33 came from study disciplines of the Social Sciences, and 27 from the Natural Sciences. Table 1 below summarises the demography of the participants based on their gender and study disciplines. It was worthwhile noting that from this pool of participants, 68.3% of the participants have had previous experience with the use of VR technologies and equipment.

Each participant was informed that their participation in the study was entirely voluntary and that they were able to withdraw from the study at any time. Information

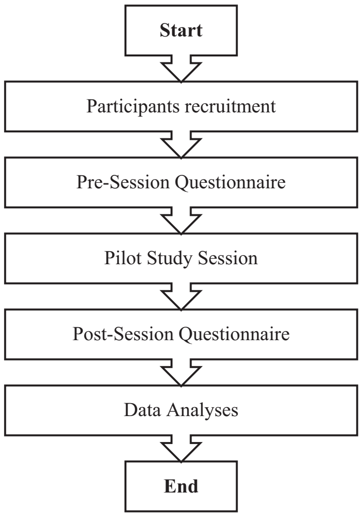

Figure 1. Flowchart of the V-ROOM research methodology

Study disciplines	Male	Female	Total *n*
Natural Sciences	14	13	**27**
Social Sciences	13	20	**33**
Total *n*	**27**	**33**	**60**

Table 1. Participants' demography (disciplines and gender)

regarding each participant was kept confidential in accordance with the data storage requirements outlined in the University's Code of Research Conduct.

2.2 Questionnaire

Prior to the start of the study, a pre-session questionnaire has been sent to the registered participants to collect information about their prior VR experience and knowledge, including if they have ever used VR equipment and experienced MS in the past.

After the pilot study session, participants were asked to fill out a post-session questionnaire to obtain information about their VR experience and if they developed any MS symptoms. Based on the responses, participants who experienced VRC were then asked to rate the severity of their symptoms on a scale from 0 to 5, where 0 means the particular symptom did not manifest and 5 means the symptom was very severe. Additionally, the participants were also asked to identify the possible factor that may have induced the VRC. The post-session questionnaire comprises below multiple-choice, rating-based scale and open-ended information:

Did you experience any motion sickness symptoms throughout the V-ROOM explorative journey? *(Yes/No)*

If the answer is "*yes*", how long approximately after using the VR equipment did you start experiencing motion sickness? *(an open-ended question)*

Please tick all the relevant motion sickness symptoms occurred in your journey and rate its severity level using Likert scale. Score 1 is the least severity, while score 5 is the highest severity. The available options are: *headache, fatigue, eye strain, loss of balance, nausea, dizziness, sweating, disorientation, general discomfort, stomach awareness/ache, vomiting* and *"other"* (a blank space to fill-in).

Which of the following is the likely cause of motion sickness? The available options are: *bright colours/light, speed of the movement, angle of the movement, lag/latency, graphic quality* and *"other"* (a blank space to fill-in).

After the survey was completed by the participants, we also conducted a follow-up interview to the student participants who experienced any VRC symptoms in the first instance for collecting more detailed feedbacks regarding points (iii) and (iv) asked in the post-session questionnaire. Their participation in the interview was also voluntary.

2.3 Pilot study design

Participants who volunteered to participate in the study were asked to select a pre-defined date and time slots to attend the V-ROOM pilot study. The pilot study spanned over the course of three weeks with two sessions allocated for each week, subject to the availability of the V-ROOM team personnel and participants. Prior to the study, the pre-session registration questionnaire was disseminated to the volunteers via an email message alongside the time booking slots.

The pilot study sessions were all conducted in the same controlled environment and approximately same environmental conditions to minimise data discrepancy between sessions. During the study sessions, participants were equipped with a mobile VR headset and an audio listening device. A mobile phone with the V-ROOM application installed was provided for each mobile VR headset. The relevant specifications for each mobile phone used are outlined in Table 2.

Specification	Device A	Device B	Device C
Screen display			
Type	AMOLED, 120 Hz	IPS LCD, 60 Hz	IPS LCD, 120 Hz
Size	6.9 inch	6.3 inch	6.67 inch
Resolution	1440 × 3088 pixels (~496 ppi density)	1080 × 2340 pixels (~409 ppi density)	1080 × 2400 pixels (~395 ppi density)
Platform			
Operating system	Android 10	Android 10	Android 10
Chipset	Qualcomm SM8250 Snapgradon 865+ (7 nm+)	Qualcomm SDM675 Snapdragon 675 (11 nm)	Mediatek MT6889Z Dimensity 1000+ (7 nm)
CPU	Octa-core (1 × 3.0 GHz Kryo 585 and 3 × 2.42 GHz Kryo 585 and 4 × 1.8 GHz Kryo 585)	Octa-core (2 × 2.0 GHz Kryo 460 Gold and 6 × 1.7 GHz Kryo 460 Silver)	Octa-core (4 × 2.6 GHz Cortex-A77 and 4 × 2.0 GHz Cortex-A55)
GPU	Adreno 650	Adreno 612	Mali-G77 MC9

Table 2.
Mobile phone specifications outline

Before the start of each session, participants were required to attend a briefing about the aims of the study, usage of the devices to be equipped and health and safety advisory. Participants were ensured to be familiar with the devices prior to the immersive VR experience, e.g. one clickable button on the top-right of the mobile VR headset can be used to interact with the user interface in the virtual environment. When the participants were ready to undergo the V-ROOM experience, as shown in Figure 2, the team personnel assisted in equipping the VR headsets. Participants were also made aware of the possibility of VRC, which is a common occurrence that many people experienced during the use of VR equipment. Participants who developed unbearable reactions towards VRC during the session were allowed to either stop the V-ROOM experiential journey or resume the study after a short rest period.

The V-ROOM experiential journey APP provided participants with an objective-oriented exploration of three types of classroom designs, where each classroom has a unique feature that participants could try. Each of these rooms vary in terms of colour and interior designs, exposing participants to different aspects of visual design in a virtual environment. Content of the V-ROOM experiential journey, including actions that were expected from the participants, is summarised in Table 3.

From exploring the APP, it was expected that the participants would gain a complete experience of basic interactions with the virtual object and/or environment. Hence, various learning tasks were integrated as part of the experience with exposure to different sets of environment. This experiential journey provided each participant with a series of "objectives" that they needed to follow. Once an objective was cleared, which was purposefully placed in each venue listed in Table 3, they were then able to continue to the next objective. The objectives were designed such that participants were guided through all of the rooms to test the available features. VRC were expected from a portion of the participants, since several of the features and aspects of the VR environment were known to induce VRC, such as bright colours, sensory mismatch and levitation.

Figure 2.
Participant was equipped with the mobile VR headsets, courtesy of V-ROOM

Each session lasted, on average, about 10–12 min per participants or until the participant decided to end the session due to VRC. The participants were then allowed to rest before asking them to fill the post-study questionnaire. V-ROOM team personnel were always present to assist the participants at any time during the pilot study session on a one-to-one ratio basis; that is one participant was supervised by one personnel. Data from the questionnaires were then compiled and analysed by using the analysis of variance (ANOVA) *F*-test statistical analysis method whose results will be discussed in the following sections.

Virtual venue/room	Expected action/outcome	Possible movement
Lobby	Reading and listening to general instructions on the board	Head/body rotation, walk
Lounge	Viewing photo and slides	Head/body rotation, walk, button/UI click
Classroom 1	Watching a video	Head/body rotation, walk, button/UI click
Classroom 2	Throwing and aiming an object at a certain target in the class	Head/body rotation, walk, button/UI click, object grab/touch, object throw
Classroom 3	Completing a simple multiple choice quiz	Head/body rotation, walk, button/UI click, object grab/touch
A mini garden and an elevator	Exploring the mini garden and going to upper floor	Head/body rotation, walk, button/UI click, levitation
Upper floor room	Collecting the trophy	Head/body rotation, walk, button/UI click, object grab/touch

Table 3.
V-ROOM experiential journey contents

2.4 Statistical method for data analyses

The ANOVA method was selected as the method to analyse the data that had been obtained from the study. The method was selected to investigate whether the two compared variables, i.e., gender vs VRC and study discipline vs VRC, have statistical significance. The "significance" in the ANOVA test is hereby defined whether the variance between the two variables is significantly different from each other. In other words, the study investigates the influence of differences in gender and study discipline on the presence of VRC symptoms in the context of using a VR-based classroom for learning purpose.

This method uses two hypotheses, namely, the null hypothesis (*H0*) and the alternate hypothesis (*H1*), to determine whether there is a statistically significance relationship between two variables (Larson, 2008; Pandis, 2015), e.g. gender and VRC presence. Confidence level of 95% is used in this study, which means alpha (α) is 0.05. The results of an ANOVA would either be accepting or rejecting *H0*. When *H0* is rejected, when *p*-value is smaller than the confidence level or when *F-statistic* value falls above F-critical (*F-crit*), it is said that there is a statistical significance in the data. If *H0* is accepted – thus rejecting the alternative hypothesis – it indicates that there is not enough evidence in the data to justify that there exists a statistical significance in the compared sets of data.

For the ANOVA hypothesis test, five more variables need to be introduced for the purpose of results presentation in Section 3, as follows:

- *SS* denotes the "sum-of-squares", a measure of variation from the mean value of a set of data, computed by summing over the squares of the deviations from the mean.
- *df* denotes the "degrees of freedom".
- *MS* denotes the "mean squares", which is computed by dividing the sum of squares over the given degrees of freedom.
- *F-statistic value* is calculated by dividing an *MS* over another *MS* value.
- *P-value* is the probability value of observing and comparing *F*-statistic value, which is obtained from the study, with the value of *F*-critical, hence, to determine whether to reject or accept the null hypothesis.

3. Results and analysis

3.1 Overview

Through the completion of the pre- and post-session questionnaires, it was identified that almost 50% of the study participants (28 out of 60 students) experienced VRC of varying severity. Out of 28, 16 of them had used a VR headset and experienced VRC, mostly in games, prior to coming to the V-ROOM pilot study session. Background of the participants who experienced VRC during the V-ROOM experiential journey is provided Figure 3. Based on the study disciplines these participants came from, 15 and 13 participants were from the Social Sciences and Natural Sciences, respectively.

It could also be seen from Figure 3 that in both study disciplines, female participants were more susceptible to VRC than their male counterparts, i.e. 73% females enrolled in the Social Sciences and 54% in the Natural Sciences. During the study, it was noted that all participants successfully completed the V-ROOM experiential journey session despite some having experienced VRC.

3.2 Virtual reality cybersickness symptoms

The participants who experienced VRC during the pilot study were asked to rate their experience of each particular symptom on a scale of 0–5. Figure 4 illustrates the frequency of each symptom on participants. The graph also shows the distribution of each symptom on each gender. It is interesting to see that the most frequent VRC symptoms experienced by the participants were dizziness (25 participants) and discomfort (24 participants), followed by loss of balance and disorientation (19 participants, respectively). Meanwhile, the study also confirmed that female participants were at a higher risk in experiencing VRC than male participants.

Prior to analysing how significant demography of the participants affects the reaction towards VRC, the symptoms that were present were categorised based on the severity and commonness during a VRC experience. The results were then compared to one study conducted by Leung and Hon (2019), which provided an understanding on the pathophysiology and management of MS, as presented in Table 4. Symbol-coding was used to represent both the degree of severity and commonness and are explained in the legend below the table.

Based on the generated comparison, it could be seen that for most cases, the severities of the symptoms were similarly categorised, except in the cases of eye strain and sweating,

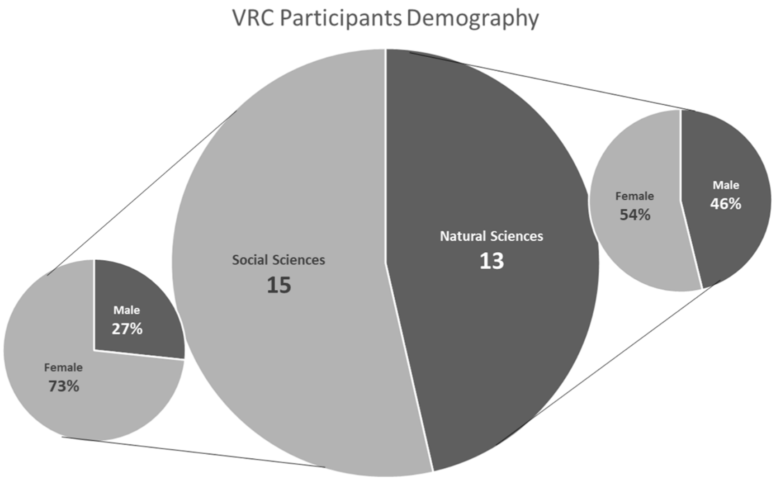

Figure 3.
Demography of the participants who experienced VRC during the V-ROOM study

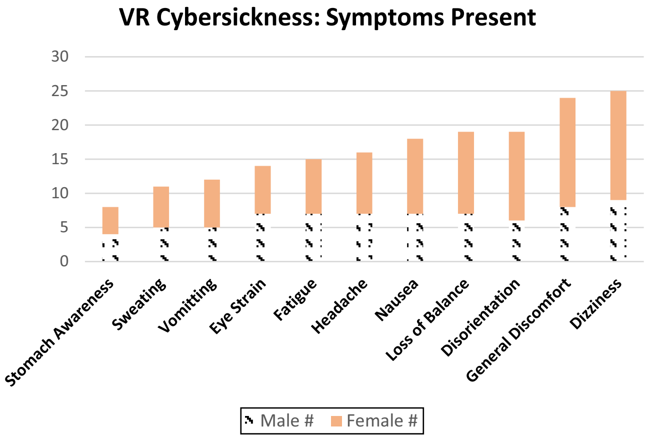

Figure 4.
VRC symptoms experienced by the V-ROOM study participants

Table 4.
Comparison of severity and commonness of VRC symptoms between literature data and data obtained in the study

	Literature*		Current study: V-ROOM	
Symptoms	***Severity***	***Commonness***	***Severity***	***Commonness*****
General discomfort	●	★★★★★	●	★★★★★
Fatigue	●	★★★★	●	★★★★
Nausea	■	★★★★★	■	★★★★
Eye strain	■	★★★★★	●	★★★
Dizziness	■	★★★★★	■	★★★★★
Headache	▲	★★★★★	▲	★★★★
Disorientation	▲	★★★★	▲	★★★★
Sweating	▲	★★★	■	★★★
Vomiting	▲	★★★	▲	★★★
Loss of balance	-***	-***	▲	★★★★
Stomach awareness	-***	-***	■	★★
Legends for severity:			Legends for commonness:	
●	Low-impact		★	Least common
■	Medium-impact		★★★★★	Most common
▲	High-impact			

Notes: *The data from literature in the table are summarised from the literature. ** Commonness threshold was determined based on the number of participants who experienced VRC. *** These symptoms were not present or described as a part of other symptoms in the literature

which were, respectively, low and medium impact in contrast to the medium and high impact that were described in the literature. Additionally, two of the symptoms that were observed in the study were not discussed in the literature and thus were not compared.

Looking at the commonness aspect of the symptoms, there is a consensus between the literature and the study that general discomfort and dizziness are very common amongst people who experienced VRC. One notable symptom that differs greatly between the literature and the study was the eye strain, where in the study, participants reported only low impact and it was not as commonly observed as the other symptoms. To summarise, the severity levels of the VRC symptoms used in this study analysis are categorised as follows:

- Low impact: fatigue, eye strain and general discomfort;

- Medium impact: sweating, nausea, dizziness and stomach awareness; and
- High impact: headache, loss of balance, disorientation and vomiting.

3.3 Virtual reality cybersickness versus gender

To understand whether gender manifests a certain significance towards VRC in the context of using the developed VR-based classroom, a one-way ANOVA was used to analyse the data obtained from the study. For this, each of the VRC severity category was analysed against gender, i.e. female and male, as shown in Table 5. The null hypothesis suggests that there is no evidence for gender and VRC symptoms to be statistically different.

The results showed that for all three categories, the *F-statistic* values are significantly higher than the *F-critical* values, respectively, from low to high impact: 38.927, 49.599 and 44.901 against 4.019, 4.019 and 4.019, which denotes that gender of the participants has a degree of significance when compared against VRC symptoms during the VR experience. In addition, this was further emphasised by the p-values, respectively, 7.035×10^{-8}, 3.512×10^{-9} and 1.26×10^{-8}, which are all below the value of α (0.05). This confirms the acceptance of an alternative hypothesis *H1* which states that there is a statistical significance between gender and the occurrence of VRC, therefore rejecting the null hypothesis *H0*.

This finding is also supported by a study (Chattha and Shah, 2018) which has found that female participants have a greater chance of being afflicted by MS while using VR. Another study by Chattha *et al.* (2020) further confirmed that gender is one of the statistically significant factors that plays a key role in the occurrence of VRC.

3.4 Virtual reality cybersickness versus study disciplines

The relationship between study disciplines, divided into Natural Sciences and Social Sciences, and VRC symptoms is demonstrated in Table 6. The significance of these two sets of data is clearly demonstrated by having the F-statistic values (i.e. 41.86, 52.16 and 47.53) larger than the F-critical value (i.e. 4.02) for all VRC symptoms' severity levels, i.e. low, medium and high impact. When calculating the total amount of Likert scale responses from the participants, it is also worth noticing that the medium-impact VRC received the largest responses from the study participants, indicating the most common symptoms experienced by the participants; its value was higher by 10.5% and 28.1% than those of high- and low-impact VRC symptoms, respectively. To support these results, it is also evident that the obtained p-values were of infinitesimal numbers, very close to zero, and were much smaller than 0.05. These statistical findings led to the rejection of null hypothesis, meaning the two sets of data, study disciplines and VRC symptoms, differed significantly from each other.

3.5 Potential causes of virtual reality cybersickness

To further investigate potential causes of VRC, participants were asked to select the factors that they believed might have contributed to the occurrence of VRC. In this study, the factors that are being reviewed were the speed of movements, angle of movements, lag, graphics quality and bright colours/lights.

3.5.1 Speed of movements. In most VR experiences, player movements, also known as locomotion, is an important aspect because it provides a way for users to move around in the virtual environment. The types of locomotion may vary depending on the VR experience. The locomotion method that this study used was gaze-controlled walking. Some feedbacks from the study participants regarding this are "slower speed is better for me", and "I genuinely think that the movement can be slower down a bit for a better experience in VR."

Source of variation	SS	df	MS	F	P-value	F crit
Gender vs low-impact VRC						
Between groups	196.875	1	196.875	38.927	7.035×10^{-8}	4.019
Within groups	273.107	54	5.058			
Total	469.982	55				
Gender vs medium-impact VRC						
Between groups	418.018	1	418.018	49.599	3.512×10^{-9}	4.019
Within groups	455.107	54	8.428			
Total	873.125	55				
Gender vs high-impact VRC						
Between groups	325.446	1	325.446	44.901	1.26×10^{-8}	4.019
Within groups	391.393	54	7.248			
Total	716.839	55				

Table 5. One-way ANOVA of gender versus VRC symptoms with various severity levels: low impact; medium impact; and high impact

Source of variation	SS	df	MS	F	P-value	F crit
Study discipline vs low-impact VRC						
Between groups	212.161	1	212.161	41.8618	2.98088×10^{-8}	4.019541
Within groups	273.679	54	5.068122			
Total	485.839	55				
Study discipline vs medium-impact VRC						
Between groups	440.1607	1	440.1607	52.16106	1.79437×10^{-9}	4.019541
Within groups	455.6786	54	8.438492			
Total	895.8393	55				
Study discipline vs high-impact VRC						
Between groups	345.0179	1	345.0179	47.5323	6.11562×10^{-9}	4.019541
Within groups	391.9643	54	7.258598			
Total	736.9821	55				

Table 6. One-way ANOVA of study discipline versus VRC symptoms with various severity levels: low impact; medium impact; and high impact

3.5.2 Angle of movements. As the locomotion method in this study relied on the participants moving their head and eyes to gaze as the control, any movements that occurred would be accompanied by a change in the gaze angle. As noted by Gavgani *et al.* (2018), the action of tilting one's head does contribute to the possible manifestation of MS. From the interview, several students explained that head movement was not a good choice for the user to move around in virtual environment, e.g. "using my head to see a different perspective of the surroundings was not as pleasant as in reality. It was not comfortable. I hope this can be changed."

3.5.3 Lag. Lag, or more formally known as motion-to-photon latency, is one of the causes of MS in most computer-related systems, including in VR (Stauffert *et al.*, 2020). Lag in this study is defined as the delay between the participant's head movement and the virtual changes that correspond to the head movement.

3.5.4 Graphic quality. Graphic quality generally refers to the visually significant aspects that are present in the VR environment. As Burningham *et al.* (2002) have noted, any image that is shown or produced on a display or printer could be evaluated in terms of quality by their viewers. Thus, this study asked participants to evaluate the graphic quality of the VR environment and whether it contributed to the manifestation of VRC. Some students who experienced the VRC in the study agreed that graphic quality contributed to how they feel as they were immersed in the virtual world such as:

> The visual graphics can be improved so make my eyes feel more comfortable when exploring the virtual classroom.

> How about reducing the pixel size of the screen? Perhaps, we can also use a mobile phone with better resolution.

3.5.5 Bright colours/lights. The use of bright colours or lights may also be a factor for VRC to occur. A study by Bonato *et al.* (2004) concluded that chromaticity may affect how stationary environment is being perceived as and may be a contributing factor to MS. In addition, another study by Vasylevska *et al.* (2019) has noted that the brightness of a head-mounted display (HMD) may also contribute to cybersickness, although inconclusive at the time and requires further investigation. This is in-line with the qualitative comments provided by a few students who experienced VRC during the V-ROOM experiential journey such as:

> Beautiful decorations on the wall were nice, but I think the brightness of the light and colour was too strong.

> I feel sick I think because the light is too bright for me. Maybe, the light could be adjustable in the virtual classroom.

As reported by the participants in the study, the possible causes of VRC have been documented and illustrated in Figure 5 above, with 20 participants, each, reporting that speed of movements and angle of movements were a major cause of their VRC, followed by 12 participants who reported graphics quality, 5 reported bright colours/lights, and lag being the least likely to cause VRC with only 4 participants reporting it. Additionally, three other possible factors have been identified by three participants, namely, "user control experience"; "levitation"; and "[use of] mixed colours". In terms of the differences of possible causes of VRC amongst male and female, it was observed that a higher proportion of female participants believed that all of the factors, with an exception of "lag", was the cause(s) of their VRC (shown in Table 7).

Some participants were asked about their use of the V-ROOM APP and their experience of VRC during the study. One participant commented that "the motion can be better", while another agrees that "[sic] the movement can be less dizzy". It is interesting to note that when asked about what they believe could alleviate their VRC, two student participants were aware of how using different VR headsets could contribute to their overall experience, i.e.:

> [use] high tech equipment to prevent sickness like dizziness and other uncomfortable symptoms.

and

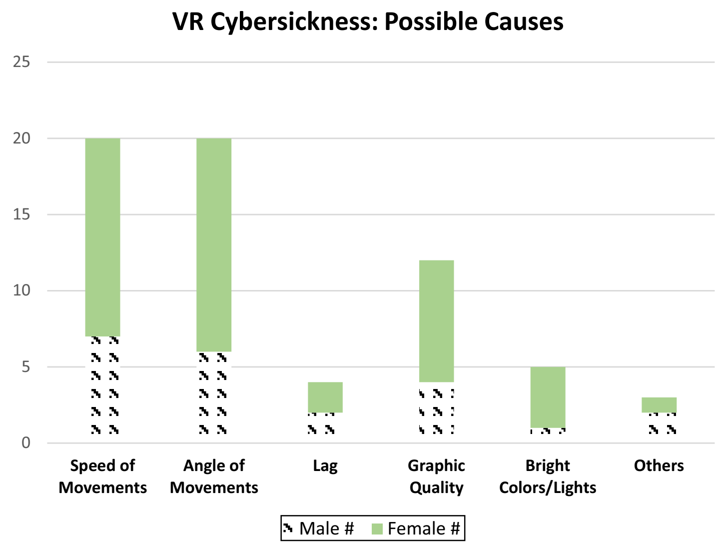

Figure 5. Feedback from the participants regarding potential causes of VRC

Table 7. Possible causes of VRC and the proportions of male and female participants who reported that particular cause

Possible causes	Male(%)	Female(%)
Speed of movements	70	72
Angle of movements	60	78
Lag	20	11
Graphic quality	40	44
Bright colours/lights	10	22
Others	20	6

> Use better devices (For example Oculus Quest 2 is an excellent but also cost-friendly option), or another which does not rely upon mobile phone capacity.

which also imply that appropriate hardware selections may be one of the possible solutions to reducing the occurrence of VRC. Further evidence is required whether or not using different types of currently available VR headsets in the commercial market could resolve the VRC problems. For example, according to the experiments conducted by Yildirim (2020), Oculus Rift CV1® and HTC Vive® would induce similar severity of cybersickness when worn for VR experience, at a higher level than viewing the content in the non-VR desktop display setup.

4. Potential mitigation strategy

Numerous studies have been done to explore the possible methods of reducing the VRC effect while immersed in a virtual environment; each method comes with its own limitations. Stanney *et al.* (1998) had proposed the research and development (R&D) agenda for resolving cybersickness under four categories, i.e. basic knowledge, technology, evaluation and applications. In their report, the four highest priorities were given to:

(1) creating powerful, lightweight and untethered devices (“technology”);

(2) reducing visual latencies ("technology");
(3) standardising subjective and objective measurement of aftereffects ("evaluation"); and
(4) developing an understanding of the magnitude of cybersickness problems and their implication to job or career performance ("evaluation").

Meanwhile, creating peripheral devices for senses beyond vision and audition as well as determining the relationship between presence, cybersickness and adverse psychological aftereffects became the lowest priority of the action items which were under the categories of "technology" and "basic knowledge", respectively (Stanney *et al.*, 1998). These factors and their priority weightings, however, have to be revisited and updated as the technology on its own has evolved over the past decades. Some of the updates towards the R&D agenda have been reported in (Stanney *et al.*, 2020), e.g. where the relationship between cybersickness, presence and adverse psychological aftereffects was stated to have been investigated, although they are still rather complicated to be concluded.

In addition to these, Farmani and Teather (2020) investigated the use of rotation snapping technique to reduce cybersickness, where snapping was defined as using more discrete movements. Throughout their experiments, snapping was only activated when cybersickness was likely to occur in which could be determined by looking at the rotation speed of the participants. Meanwhile, the cybersickness experience was measured by using the well-known simulator sickness questionnaire (SSQ) which was first introduced by (Kennedy *et al.*, 1993). It was concluded by Farmani and Teather that the rotation speed of 25 degree per second as the appropriate threshold to enable the rotation snapping procedure during the VR experience. However, there exists some compromises in the utilisation of snapping technique, two of which are the user performance and realism aspect of the immersive experience.

There are also other cybersickness questionnaires, namely, Cybersickness Questionnaire and Virtual Reality Sickness Questionnaire which have been claimed by Sevinc and Ilker (2020) to perform better validity indicators compared to SSQ. They however added that further evaluation is still required to confirm this finding. Then, Shi *et al.* (2021) have tried to compare three VRMS mitigation techniques: FOV Reduction, DOF Blur and Rest Frame. Breakdown of these terminologies is provided below. Unlike in the V-ROOM pilot study where a virtual classroom scenario was tested, Shi's study used a racing game where participants were asked to steer a car in a virtual environment while immersed using an HMD VR device. The result is summarised as follows:

- FOV Reduction: Reducing the user's field of view (FOV) resulted in a reduced incidence of sensory conflict at the cost of losing some information displayed on the screen.
- DOF Blur: Blurring objects that falls outside a set visual depth distance resulted in lowering of vergence-accommodation conflict, i.e. the mismatch of the distance of a 3D object and the distance needed for focusing on the object. However, blurring may increase discomfort and affect performance.
- Rest Frame: Adding a point of reference in a fixed position in the virtual environment that users can use as a gauge. This method helps users to focus their gaze and reduce sensory mismatch. However, the added rest frame is always present on screen and may block the view.

It was noted in the recent study by Shi *et al.* that all three methods were able to mitigate the VRMS to a certain extent; however, it is also worth noting that each of them has their drawbacks. The FOV Reduction and DOF Blur both have the tendency of causing loss of information from the scene, while using Rest Frame might be difficult as if the reference object is too small it will be insignificant and if it is too large, it may block parts of the scene.

Wang *et al.* (2020) on the other hand proposed that a possible way to improve the methods above is by including the use of non-invasive monitoring device, such as electroencephalography probes, to monitor and analyse users' discomfort level. This method, however, also comes with its own shortcomings. The use of monitoring sensors on top of VR HMD equipment may result in inaccurate physiological data. The collection and usage of these data have been reported to be problematic as using sensors may yield very large amount of data, which presents the challenge of analysing them (Davis *et al.*, 2014).

Having obtained both qualitative and quantitative feedbacks from the study participants who had explored V-ROOM, several technical actions can be proposed when designing and developing a V-ROOM which are summarised in Table 8. The priority given in this table is determined upon the number of votes from the study participants on each VR property, aligning the percentages shown in Table 7. "High" priority indicates a larger proportion of the study participants voted that the associated VR property was the main cause of VRC, whereas "medium" and "low" priorities indicate the relatively moderate to small proportions of participants voted the category for the same reason. Further investigation is however still required to confirm the effectiveness of the proposed actions, especially teaching scenarios are not just based on a single content, i.e. different subject disciplines would need different types of activities – which learning activity or content that would best convey the subject to the students and achieve the module learning outcomes, as well as how VR usage can enhance their learning experience are part of the considerations.

5. Conclusion and future work

Pilot study conducted by the V-ROOM team focused on investigating the cybersickness effects of using a V-ROOM, has been completed. The aims are threefold:

(1) identification and qualitative analysis of the VRC symptoms;

(2) statistical significance analysis of students' demography, i.e. gender and study discipline, when compared against the occurrence of VRC symptoms; and

(3) understanding the potential causes that strongly contribute to VRC and providing suggestions to mitigate the VRC effects.

Responses received through the given questionnaire demonstrated that 46.7% participants, university UG students at UNNC, were affected by VRC symptoms when immersing themselves in the developed VR-based classroom. Based on the severity and commonness levels of VRC classification proposed in this study, medium-impact VRC received the highest number of responses from the study participants. This category includes sweating, nausea, dizziness and stomach awareness. When assessed individually, out of 11 VRC symptoms considered, dizziness was the most frequent symptom experienced by the participants. It is also worth mentioning that around 53.6% participants who experienced VRC came from the Social Sciences study discipline, a slightly higher percentage compared to participants with Natural Sciences background. In both cases, female participants were particularly found to be more prone to experiencing VRC. One-way ANOVA results obtained from this study suggest that both gender and study disciplines offer statistical significances against

VR properties	Priority	Proposed actions by V-ROOM
Movement speed	High	• The speed of basic movement, e.g. when walking in a virtual environment, can be lower relative to the actual walking speed • For a virtual classroom scenario, there could be two options being made available for the user (students and teachers) to move, i.e. "to walk" and "to run."
Movement angle	High	• The angle of movement and navigation cannot solely rely upon the head movement as it may trigger confused and/or sickness feelings. Hence, using VR headsets associated with a joystick or controller is recommended, and/or providing the users with a large area to explore and walk around in reality throughout their VR experience
Graphics quality, design and lighting	Medium	• If a mobile VR is used, selecting mobile phones with higher and more stable performance is recommended, such as with better graphics and image resolution. • Even though there were complaints about the mobile phone capacity, it is also worth considering that the models and decorations used in the virtual classroom to be better rendered. An effective mesh simplification, for example, can also be used to enhance the graphics of the 3D models in general
Hardware	Low	• For generating a fully immersive VR experience in the virtual classroom, a mobile VR is not sufficient to capture the interactions between the users and the virtual objects or environment. An exception for using mobile VR devices is when the content is less complicated, i.e. when interaction is not required. Generally, a mobile VR only offers one interaction (clickable) button on the top surface of the VR headset. A joystick or a mouse can be used to help in the navigation. The V-ROOM project team would also explore the use of other commercially available VR headsets, including desktop VR and standalone VR equipment and make comparisons upon them. Obviously, using a desktop VR is more recommended to achieve a total experience, both immersive and interactive, particularly in a more complex virtual learning environment

Table 8. Technical suggestions to improve the quality of the VR-based virtual classroom

the presence of VRC when a VR-based classroom is used by the university students in the T&L context. It is therefore worth considering the two factors, such as when developing a virtual environment for the students equipped with VR technologies.

At present, there are four aspects to be considered as plausible VRC mitigation strategies in the context of using V-ROOMs for undergraduate students; they are movement speed, movement angle, graphics quality, design and lighting, as well as hardware selection. Movement speed and angle were nominated by the study participants to be the top two causes of the VRC symptoms occurred during their VR experiential journey, with around 60%–78% responses were, respectively, collected for each cause.

Further investigation of the V-ROOM project would include the exploration of whether the presence of VRC influences the learning experience and performance of these students in comparison to those who do not experience VRC, alongside other factors that might correlate to VRC. Moreover, future pilot sessions would include several action points to follow-up:

- having a larger sample size in the pilot study sessions;
- exploring the use of other commercially available VR headsets, whether they are a standalone VR, a mobile VR or a desktop VR, and conducting a comparative analysis for these devices;
- investigating the impacts of altering the technical parameters of the VR features such as the movement speed and angle on the VR scene and user experience, and other potential ways on minimising the VRC effects; and
- identification of the types of user–environment virtual interactions that would and would not cause VRC.

The authors believe that these action points would help not only the VR developers but also educators in the navigation of how immersive technology, including VR, can be effectively used as a learning tool. By understanding the preliminary results of the presence of VRC symptoms and potential causes of VRC from this study, especially in the HE sector applications, it is hoped that the key findings can be used as a guideline for designing and developing an effective virtual learning environment.

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