Colour in virtual classrooms: effects of colour schemes and interior elements on students' preference and attention

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The design of virtual learning environments is becoming increasingly crucial to enhancing learning outcomes. This study investigates the impact of diverse colour schemes and configurations on the subjective and cognitive responses of virtual reality (VR) classroom users. Three colour schemes were examined: achromatic, desaturated and saturated. These were applied to different interior elements, including walls/ceilings, furniture and floors, resulting in six unique configurations per scheme. By implementing a 3 (colour schemes) x 6 (colour configurations) within-subjects design, we gathered subjective evaluations including willingness-to-stay, immersion and cybersickness. College students' task performance metrics, such as speed and accuracy, were also recorded. The results revealed that colour schemes did not significantly impact participants' willingness-to-stay and immersion. In contrast, colour configurations influenced all subjective measurements significantly. Regarding the attention task, there were no discernible effects. Configurations involving neutral walls/ceilings, dark furniture and light floors were most preferred. Among different interior elements, the wall/ceiling colour exerted the most substantial influence on responses. Specifically, neutral and dark colours were preferred over bright hues for walls and ceilings. This study underscores the need for careful colour selection when designing virtual learning environments and provides valuable insights into how interior colour configurations in VR classrooms can impact student preferences.

Keywords: virtual classroom; colour scheme; interior element; preference

1 Introduction

A virtual classroom is a digital learning environment that utilises virtual reality (VR) technology to create a simulated classroom experience, allowing students to participate in educational activities remotely (Parker & Martin, 2010). Using a head-mounted display (HMD), a virtual classroom can simulate an environment that closely resembles a physical classroom (Li et al., 2021; Hasenbein et al., 2022). Moreover, it offers greater control over environmental variables than physical classrooms, providing an opportunity for more personalised and effective student learning experiences. Welldesigned virtual learning environments have the potential to enhance students' learning outcomes by improving their preferences, attention and engagement.

Colour plays a crucial role in the design of VR environments and has a significant influence on the cognitive abilities of students. According to Xia et al. (2022), a well-planned colour experience in VR can increase positive user engagement and cognitive performance. This finding emphasises the significance of thoughtful application of colour stimuli in the design of effective virtual environments. Despite this, there is still a paucity of research on colour stimulation in these environments. Prior studies have primarily concentrated on the influence of singular colours, particularly wall colour (Cha et al., 2020; Llinares et al., 2021), while the effects of combining multiple colours have been largely overlooked. Interior designers usually employ a combination of colours as opposed to a singular one. Interestingly, even within a single colour scheme, diverse colour configurations can emerge based on the application of these colours to distinct interior elements. For instance, in a palette containing three colours—white, grey and black—a colour configuration might include white walls, grey furniture and a black floor. An alternative configuration might feature grey walls, black furniture and a white floor using the same palette. Thus, a single three-colour scheme can lead to up to six distinct configurations. Despite these possibilities, studies exploring colour applications across various interior elements are limited. While Cho and Suh (2020) investigated the impact of colour scheme and configuration on a commercial retail space using images, there are no equivalent studies in the context of virtual classrooms.

Therefore, this study investigates the influence of colour schemes and configurations on subjective and cognitive responses in a virtual classroom. To achieve the objectives of this study, the following research questions have been formulated:

1. What is the impact of colour schemes and configurations on subjective and cognitive responses in a virtual classroom?
2. To what extent do individual interior elements contribute to the subjective and cognitive responses in a virtual classroom?
3. What are the colour preferences for the identified interior elements concerning subjective and cognitive responses in a virtual classroom?

2 Materials and methods

This study used VR technology to create a virtual classroom with varying colour schemes and configurations. We collected subjective evaluations and task performance data from college students. Following a 3 × 6 within-subjects design, we examined two different features: colour scheme and colour configuration.

2.1 Colour selection

To ensure a comprehensive analysis, the colour scheme was classified into two categories: achromatic and chromatic. The chromatic colour scheme was further subdivided into desaturated and saturated schemes, resulting in a total of three colour schemes: achromatic, desaturated and saturated. Each colour scheme consisted of three colours with different tones: light, neutral and dark.

The first colour scheme, achromatic, is the conventional colour setting used in physical classrooms. Despite its widespread use in educational settings (Niero & Premier, 2010), the achromatic colour scheme was found to be less effective and more distracting (Birren, 1983). Therefore, we included the achromatic colour scheme to determine its impact when implemented in virtual classrooms. The second colour scheme, desaturated, was selected based on Pile's recommendation (1997) for creating an attentive learning environment. The colour scheme includes desaturated yellow, green and brown colours. For the third colour scheme, saturated, we increased the saturation of the second colour scheme to its maximum, i.e., 100. According to Al-Ayash et al. (2016), learning performance was significantly higher under saturated colour conditions. Table 1 displays the HSB colour specifications of the chosen colour schemes.

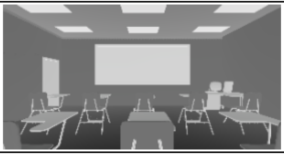
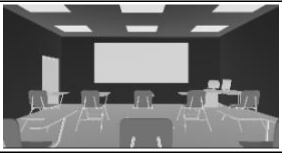
Table 1. The specifications of each colour scheme (H: Hue; S: Saturation; B: Brightness)

Colour Scheme	**Specifications**	**Tone**		
		Light	**Neutral**	**Dark**
Achromatic	H	0	0	0
	S	0	0	0
	B	100	50	0
	Colour Swatch			
Desaturated	H	51	85	30
	S	35	29	47
	B	63	18	20
	Colour Swatch			
Saturated	H	51	85	30
	S	100	100	100
	B	63	18	20
	Colour Swatch			

In terms of interior elements, we focused on three components: walls/ceilings, furniture (chairs) and floors. Each interior element was painted with different colours, resulting in a total of six distinct colour configurations. Table 2 displays the scenes used in our experiment.

Table 2. Experimental scenes: three colour schemes and six colour configurations

Colour Configuration	**Colour Scheme**		
	Achromatic	**Desaturated**	**Saturated**
1			
2			
3			

4			
5			
6			

2.2 Environmental simulation set-ups

The virtual classroom was designed to represent a typical university lecture room to ensure that the virtual environment would be consistent with a typical classroom experience. In order to improve the sense of presence, directional ambient sounds were maintained in all processes. Previous studies have shown that the use of ambient sounds in VR environments can contribute to the realism and authenticity of the experience (Li et al., 2021).

Participants used an HMD to view the virtual environment. As depicted in Figure 1, each scene was viewed from the same viewpoint, with the participant sitting in the middle of the third row of tables, allowing for a clear impression of the entire area. The VR HMD used in this study was the Oculus Rift, which featured a resolution of 1832 x 1920 pixels per eye, a vertical and horizontal field of view of 110 degrees and a refresh rate of 72 Hz. In order to create the virtual classroom, Unity 3D was used to import the 3D models of the objects created using the SketchUp software.

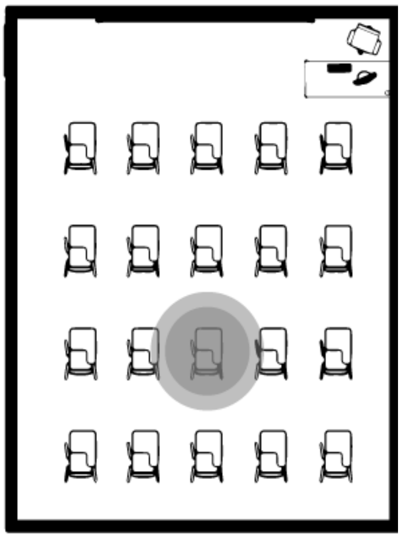


Figure 1. A floor plan of the virtual environment, with the position of the participant indicated by a circle.

2.3 Participants

We collected data from a total of 30 undergraduate and graduate students (10 male and 20 female) with a mean ± standard deviation age of 24.62 ± 3.13 years. All of them had normal vision, and none of them suffered from motion sickness. In addition, before their participation in the experiment, the experimenter confirmed that none of the participants exhibited abnormal colour recognition abilities. All the participants provided informed consent prior to their participation.

2.4 Measures and instrumentation

2.4.1 Cognitive attention task

To assess participants' attention, a cognitive task was administered in a VR scene. The study employed the Stroop task, which has been widely used to investigate attentional processes, cognitive control and executive functioning (Brown et al., 1999). The results yielded an indirect means of understanding the impact of colour on cognitive capabilities. In the Stroop task, participants were presented with a list of colour words (such as "red," "blue" and "green") with a mismatch between the name of a colour and the colour in which it is printed (i.e., the word ‘red’ printed in blue ink instead of red ink). Participants were instructed to name the colour of the ink as quickly and accurately as possible. The speed and accuracy of participants' responses were analysed as an indicator of their attention. Prior to the experiment, participants completed one practise trial to ensure that they understood the task.

2.4.2 Subjective survey

The participants were asked a questionnaire verbally to evaluate their subjective experiences in the VR environment. Using a 5-point Likert scale, the questionnaire measured three preferences: willingness-to-stay, immersion and cybersickness. Higher scores on the willingness-to-stay and immersion scales indicated a greater preference, whereas a lower score on the cybersickness scale indicated a stronger preference.

2.5 Procedure: VR experiment

The experiment was performed in a quiet area of the laboratory. It lasted approximately 40 minutes per participant. The experimenter verbally explained the process and provided the participants with instructions on how to perform the attention task. Participants then signed an informed consent form. After wearing the VR equipment, the participants were given the opportunity to practise the task once. In each scene, they were asked to acclimatise to the virtual environment for 30 seconds. After adaptation was complete, they performed the attention task without any time constraints. Afterwards, they completed a verbal survey displayed on the whiteboard. Each participant completed 18 experimental scenes (3 colour schemes x 6 colour configurations) in a randomised order. To minimise potential cybersickness, participants were instructed to take a two-minute break by removing their HMDs in the middle of the experiment.

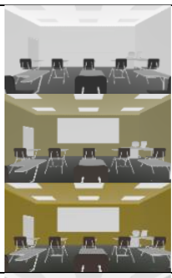
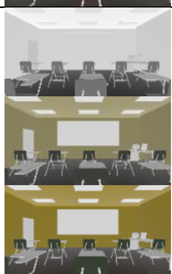
3. Result

3.1 Effects of colour schemes and configurations

A two-way ANOVA was conducted to analyse the effects of colour schemes and configurations on participant responses. In terms of subjective responses, our analysis revealed similar results for all questions. There was no significant main effect of colour schemes on participants' responses except for cybersickness (willingness-to-stay: $F = 0.81$, $p = 0.45$; immersion: $F = 6.52$, $p = 0.12$; cybersickness: $F = 5.80$, $p < 0.05$). However, there was a significant main effect of colour configurations (willingness-to-stay: $F = 8.27$, $p < 0.05$; immersion: $F = 6.52$, $p < 0.05$; cybersickness: $F = 9.91$, $p < 0.05$), suggesting that the participants' responses differed depending on the configurations (see Table 3). Out of all the configurations, configuration 3, which consisted of a neutral wall/ceiling, dark furniture and a light floor, was found to have the highest preference in all subjective evaluations. Conversely, configuration 1, which consisted of a light wall/ceiling, dark furniture and a neutral floor, was largely unfavourable. Regarding the speed and accuracy of the attention task, neither colour schemes nor configurations demonstrated statistically significant differences ($p > 0.05$).

To analyse the degree of impact different configurations had on each colour scheme, a one-way ANOVA was performed, and the effect size ($\eta2$) was calculated. Typically, $\eta2$ around 0.01 is considered small, around 0.06 is considered moderate and around 0.14 or higher is considered large. Table 4 reveals the resulting effect sizes. The results indicated that the differences between each configuration were largest in the saturated colour scheme, with effect sizes of $\eta2 = 0.24$, $\eta2 = 0.18$ and $\eta2 = 0.69$ for willingness-to-stay, immersion and cybersickness measures, respectively. Conversely, the achromatic scheme and desaturated scheme showed relatively small effect sizes, indicating that the participants perceived a noticeable difference in response to the saturated colour scheme when compared to the achromatic and desaturated schemes. Additionally, there were no significant differences concerning the speed and accuracy of the attention task ($p > 0.05$).

Table 3. Results of the subjective survey and attention task for each configuration (shown as the mean [standard deviation]).

Config-uration	Image	Willingness-to-stay*	Immersion*	Cyber-sickness*	Task Time (s)	Task Error
1		2.33 (0.14)	2.60 (0.15)	2.61 (0.17)	24.72 (0.72)	0.44 (0.21)
2		2.40 (0.13)	2.68 (0.13)	2.42 (0.19)	23.59 (0.79)	0.44 (0.21)
3		3.22 (0.13)	3.29 (0.12)	1.71 (0.12)	23.37 (0.71)	0.22 (0.02)

4		3.01 (0.13)	3.20 (0.14)	1.79 (0.15)	23.73 (0.78)	0.22 (0.02)
5		2.87 (0.16)	3.12 (0.17)	2.10 (0.15)	23.54 (0.70)	0.03 (0.02)
6		2.99 (0.14)	3.17 (0.15)	1.97 (0.15)	23.39 (0.14)	0.11 (0.04)

** indicates significance at p < 0.05.*

Table 4. Effect size (η^2) of colour configurations measured for each colour scheme.

Colour Scheme	Willingness-to-Stay*	Immersion*	Cybersickness*	Task Time (s)	Task Error
Achromatic	0.08	0.12	0.44	0.07	0.01
Desaturated	0.12	0.09	0.30	0.06	0.03
Saturated	0.24	0.18	0.69	0.01	0.03

** indicates significance at p < 0.05.*

3.2 Influence of individual interior elements

To determine the degree of influence of each interior element, we regrouped six colour configurations by fixing one of the three elements—wall/ceiling, furniture and floor. Table 5 shows the results of the paired sample t-test. When the wall/ceiling colour was kept constant across the different configurations, there were no significant differences observed in the subjective responses, except for cybersickness. This indicates that the colour of the furniture and floor had a relatively minor impact on the participants' perception.

However, when the furniture or floor colour was the same, significant differences were observed, indicating that the wall/ceiling had a stronger impact on subjective responses. In summary, the results suggest that the colour of the wall/ceiling has the strongest effect on the participants' responses, followed by the furniture, while the floor did not have a significant impact. However, there were no significant differences observed in terms of task performance.

Table 5. T-test results for each interior element's degree of influence. Shown are t-values.

Factor	Colour Scheme	Fixed Colour	Config-uration	Willingness-to-Stay	Immer-sion	Cybersick-ness	Task Time (s)	Task Error
Wall/ ceiling Fixed	Achro-matic	White	(1 vs. 2)	0.36	0.23	0.00	1.06	0.57
		Grey	(3 vs. 4)	0.14	-0.13	1.43	-2.21*	-1.00
		Black	(5 vs. 6)	-0.58	-1.56	1.47	-1.18	-1.68
	Desat-urated	Yellow	(1 vs. 2)	-0.29	-0.53	1.96	0.92	-1.44
		Green	(3 vs. 4)	1.43	0.00	0.00	-0.05	1.00
		Brown	(5 vs. 6)	-1.72	-0.36	0.32	2.66*	0.00
	Saturat-ed	Yellow	(1 vs. 2)	-1.00	-1.10	0.44	1.13	0.57
		Green	(3 vs. 4)	1.09	1.12	-3.00*	0.63	0.00
		Brown	(5 vs. 6)	0.93	1.19	0.00	-0.39	-1.36
Furniture Fixed	Achro-matic	White	(4 vs. 6)	-1.14	-1.78	-0.87	0.55	-1.80
		Grey	(2 vs. 5)	-1.79	-2.10*	1.43	1.11	1.00
		Black	(1 vs. 3)	-1.59	-1.88	2.54*	3.82*	1.44
	Desat-urated	Yellow	(4 vs. 6)	0.00	1.04	-1.68	1.90	-1.44
		Green	(2 vs. 5)	-0.50	-1.26	-0.57	-0.71	0.00
		Brown	(1 vs. 3)	-2.73*	-2.28*	2.66*	0.50	-1.00
	Saturat-ed	Yellow	(4 vs. 6)	1.44	2.08*	-0.49	-0.56	-1.36
		Green	(2 vs. 5)	-2.62*	-2.15*	2.63*	-0.07	0.00
		Brown	(1 vs. 3)	-5.76*	-4.11*	6.89*	0.95	0.57
Floor Fixed	Achro-matic	White	(3 vs. 5)	-0.50	-0.90	-1.10	-0.69	0.57
		Grey	(1 vs. 6)	-2.10*	-3.22*	2.80*	0.80	-0.70
		Black	(2 vs. 4)	-1.72	-1.90	3.79*	-0.86	0.00
	Desat-urated	Yellow	(3 vs. 5)	3.25*	1.32	-1.90	-0.44	-0.57
		Green	(1 vs. 6)	-2.58*	-1.82*	1.46	2.22	-1.44
		Brown	(2 vs. 4)	-2.19*	-2.43*	1.00	-0.28	1.44
	Saturat-ed	Yellow	(3 vs. 5)	2.09*	2.54*	-3.36*	0.21	0.00
		Green	(1 vs. 6)	-3.13*	-1.78*	3.98*	0.39	-1.00
		Brown	(2 vs. 4)	-3.16*	-2.17*	3.02*	0.24	0.00

** indicates significance at $p < 0.05$.*

3.3 Colour preferences on wall/ceiling

A one-way ANOVA was conducted to determine the colour preferences for the wall/ceiling element across different colour schemes (Table 6). The analysis revealed significant variances in preferences across all subjective responses. In the achromatic scheme, participants preferred black as the wall/ceiling colour, followed by grey, then white under the willingness-to-stay and immersion criteria (willingness-to-stay: $F = 3.95$, $p < 0.05$, $\eta^2 = 0.12$; immersion: $F = 6.94$, $p < 0.05$, $\eta^2 = 0.19$). For the cybersickness criteria, the sequence was grey, black, then white ($F = 8.93$, $p < 0.05$, $\eta^2 = 0.24$). In both the desaturated and saturated chromatic colour schemes, the preferred colour sequence was green, brown, then yellow across all criteria. These preferences were statistically significant in both the desaturated (willingness-to-stay: $F = 6.48$, $p < 0.05$, $\eta^2 = 0.18$; immersion: $F = 4.80$, $p < 0.05$, $\eta^2 = 0.14$; cybersickness: $F = 4.01$, $p < 0.05$, $\eta^2 = 0.28$) and saturated schemes (willingness-to-stay: $F = 17.43$, $p < 0.05$, $\eta^2 = 0.38$; immersion: $F = 12.71$, $p < 0.05$, $\eta^2 = 0.31$; cybersickness: $F = 20.38$, $p < 0.05$, $\eta^2 = 0.41$). The effect size was notably large in the saturated scheme, suggesting that wall/ceiling colour considerably impacts participant preference, indicating the criticality of careful colour choice in saturated schemes due to its significant influence on preferences.

Table 6. Results of the subjective survey and attention task measured for each wall/ceiling colour (shown as the mean [standard deviation]).

Colour Scheme	Wall/Ceiling Colour	Willingness-to-stay *	Immersion*	Cybersick-ness*	Task Time (s)	Task Error
Achromatic	**White**	2.47 (1.14)	2.68 (1.01)	2.43 (0.18)	23.84 (4.14)	0.05 (0.15)
	Grey	2.88 (0.63)	3.08 (0.76)	1.72 (0.12)	23.29 (4.55)	0.02 (0.09)
	Black	3.07 (0.82)	3.38 (0.92)	1.90 (0.13)	23.33 (4.49)	0.07 (0.22)
Desaturated	**Yellow**	2.53 (0.79)	2.78 (0.82)	2.13 (0.18)	23.81 (4.64)	0.03 (0.13)
	Green	3.25 (0.94)	3.40 (0.92)	1.70 (0.14)	23.73 (4.29)	0.02 (0.09)
	Brown	2.90 (0.88)	3.20 (1.02)	2.00 (0.18)	23.26 (4.34)	0.07 (0.17)
Saturated	**Yellow**	2.10 (0.94)	2.45 (0.99)	2.98 (0.21)	23.93 (3.90)	0.05 (0.15)
	Green	3.22 (0.81)	3.25 (0.70)	1.83 (0.15)	23.61 (4.13)	0.03 (0.13)
	Brown	2.82 (1.05)	2.85 (0.91)	2.20 (0.20)	23.78 (4.36)	0.08 (0.19)

** indicates significance at p < 0.05.*

4. Discussion and conclusion

This study investigated the subjective and cognitive effects of various colour schemes (achromatic, desaturated and saturated) applied to distinct interior elements (wall/ceiling, furniture and floor) in a virtual classroom setting. The novelty of this study lies in its exploration of the effects of both colour schemes and configurations, given that most existing research has predominantly focused on the impact of a single colour on one interior element. Participant evaluations in terms of willingness-to-stay, immersion and cybersickness showed similar trends; nevertheless, no significant impacts were discerned with respect to the attention task.

The results indicated that the colour configuration had a significant influence on participants' responses across all three subjective measurements. On the other hand, colour schemes didn't demonstrate a noticeable difference, with the exception of cybersickness. This implies that the colour configuration played a more substantial role in shaping participants' perceptions than the colour scheme. Notably, the participants preferred configurations that used a neutral tone for the wall/ceiling, a dark tone for furniture, and a light tone for the floor. In contrast, the least preferred configurations involved a light tone for the wall/ceiling, dark-tone furniture and a neutral-tone floor. These findings, along with prior research, imply that even a single colour scheme can elicit varied subjective responses based on its application in a virtual setting (Cho & Suh, 2020). It underscores that designers must move beyond the traditional colour palette method—typically an array of coloured chips representing colour combinations—and adopt a more intricate approach to colour design. Often, when studying colour theory, students might focus solely on small colour swatches, overlooking the application of these colour schemes to three-dimensional spaces. It's crucial for designers to demonstrate how colour schemes will be practically applied to actual interior elements. Adopting such practises could enable designers to create colour experiences with the potential to positively affect the intended space's occupants.

Another major finding of our study pertains to the relative impact of different interior elements on participants' responses. According to our results, the wall/ceiling colour has the greatest influence on participants' virtual experiences, while the furniture colour has a relatively smaller effect. In contrast, the colour of the floor did not significantly affect participants' responses. This outcome may be partially attributable to the restricted viewing angle of the HMD employed in this study. The experiment utilised a 110-degree fixed viewing angle, which required participants to maintain a forward-facing position while wearing the HMD. Previous studies have shown that the confined viewing angle of an HMD does not encompass a substantial portion of the visual field, thereby limiting the scope of perception (Vasylevska et al., 2019).

In addition to the influence of interior elements, we examined specific colour preferences. Our analysis indicated that light tones for wall/ceiling colours were not preferred over neutral and dark tones. This aligns with research suggesting the brightness of an HMD may contribute to cybersickness (Vasylevska et al., 2019). Interestingly, the human eye is particularly sensitive to the wavelength of yellow light (Gegenfurtner & Kiper, 2003), which could explain the participants' aversion to light-tone yellow-coloured walls/ceilings in the desaturated and saturated colour schemes. It's worth noting, however, that yellow is a popular colour among young children, suggesting that participant demographics may influence colour preferences (Ellis, 2020).

We acknowledge certain limitations of this study that provide scope for further exploration. Initially, the analysis of task performance using time and error revealed no significant differences, possibly as a result of the Stroop task's short evaluation period. Therefore, implementing longer-exposure tasks could yield different outcomes. Additionally, the study's focus on attention didn't extend to other cognitive domains like memory, creativity and problem-solving. Future research should consider how VR technology impacts these other cognitive areas, as different results might emerge in a virtual learning environment designed for creative or play-based learning as opposed to tasks requiring focus. Furthermore, the study only probed a specific range of colour schemes and interior elements. Future work could explore a more diverse range of topics to gain deeper insights into the user experience in virtual environments. The study also involved interior elements devoid of finishing materials, potentially reducing the realism of the virtual environment and negatively impacting the user experience. To enhance realism, future studies could incorporate finishes akin to those found in actual settings. Lastly, it is important to note that the study was conducted in a virtual classroom setting without the presence of classmates and instructors. Their presence could substantially affect user experiences, and VR technology could provide varied social environments via the controlled appearance and interactions of virtual characters (Hasenbein et al., 2022). The absence of such interactions might influence our study's responses.

In conclusion, our study offers valuable insights into the impact of colour schemes and configurations on the preferences of virtual learners. It also underscores the pivotal role colour selection plays in designing effective virtual classrooms and outlines the foundational principles of colour design in VR environments. These findings can aid both researchers and practitioners in predicting the potential outcomes of colour perception, tailored to their specific objectives for using virtual classrooms.

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