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Illuminating the Scene: How Virtual Environments and Learning Modes Shape Film Lighting Mastery in Virtual Reality

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Fig. 1: Illustrations for four of the six conditions in our study, where participants engaged in virtual film lighting tasks: 1) Baseline & Individual: A single participant completing the task in a standard virtual studio environment; 2) Beach & Individual: A single participant completing the task in a beach environment; 3) Office & Individual: A single participant completing the task in an office environment; and 4) Baseline & Team: Two participants collaborating in the baseline studio environment.

Abstract—In virtual reality (VR) education, particularly in creative fields like film production, the role of different virtual environments in shaping learning outcomes remains underexplored. This study investigates how three distinct environments—baseline, a dynamic beach setting, and a familiar office space—affect students' ability to learn film lighting techniques and whether team-based learning offers advantages over individual learning. We conducted a 3×2 factorial experiment with 36 participants to examine the effects of these environments on learning performance. Our results show for individual learners, the dynamic and potentially distracting beach environment increased frustration and effort but also heightened their sense of engagement and perceived performance. In contrast, team-based learning in familiar environments like the office significantly reduced frustration and fostered collaboration, leading to improved performance. Interestingly, team-based learning excelled in the baseline environment, whereas individual learners performed better in more challenging settings like the beach. These findings provide practical insights into optimizing virtual environments to enhance both individual and collaborative learning in VR education.

Index Terms—Virtual Reality, Sense of Presence, Learning Modes, Virtual Environments, Cognitive Load, Film Lighting Mastery

1 Introduction

In recent cinematography education, virtual reality has emerged as a valuable tool to teach complex concepts such as film lighting techniques, which require a high degree of spatial awareness and creative expression [70, 77, 82]. The immersive nature of VR allows students to practice and experiment with lighting setups in a controlled environment, enhancing their understanding and skills without the constraints of physical studios. By simulating real-world scenarios and offering interactive experiences, VR provides students with hands-on opportunities that might be limited or unavailable in traditional classroom settings. This technology not only democratizes access to essential resources but also allows for repetitive practice without additional costs or logistical challenges [71].

Despite the potential of VR in this field, there is limited research on how different virtual environments affect students' learning experiences and outcomes, particularly when mastering film lighting techniques. Most existing studies focus on the general benefits of VR or simulate real-world settings [11,28,35,63,79], leaving a gap in understanding the specific impact of virtual environment design on creative performance and collaboration in cinematography education. Exploring varied virtual settings could reveal how environmental factors influence learning processes, potentially leading to more effective and engaging educational strategies tailored to the needs of film students.

The presence, considered as *the feeling of being immersed in a virtual environment*, plays a crucial role in engaging students with the learning material [6, 8, 25]. In cinematography, where creativity and spatial understanding are key, the design of the virtual environment

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can significantly influence student engagement and learning outcomes. In addition, how different learning modes, team-based versus individual learning, interact with these environments remains underexplored. Understanding this interaction is vital, as collaborative projects are a staple in film education, and the effectiveness of team-based learning in VR settings could have significant implications for curriculum design.

This study aims to address these gaps by systematically examining the impact of different virtual environments and learning modes on students learning film lighting techniques. We selected three distinct virtual scenes: a baseline studio, a beach, and an office setting, each offering unique environmental contexts. By analyzing how these environments interact with learning modes, we seek to understand their effects on students' learning experiences, cognitive load, and performance. Thus, our research questions are: **RQ1**: How do different types of virtual environments (baseline studio, beach, office) affect students' learning experience and cognitive load in film lighting tasks within cinematography education? **RQ2**: Is there a difference in the impact of learning modes (team-based learning vs. individual learning) on learning outcomes across these virtual environments? In which environments might individual learning outperform team-based learning? **RQ3**: How does the interaction between virtual environment design and learning modes affect students' learning performance and satisfaction in film lighting education?

We conducted a 3×2 factorial experiment with 36 participants enrolled in cinematography courses, examining their performance in different virtual environments and learning modes. By combining objective performance metrics with subjective experiences, we aim to provide a holistic view of how VR environments and learning modes influence educational outcomes. The findings offer practical recommendations for educators and contribute to the development of more effective VR educational tools tailored to the needs of film production students.

2 Related Work

2.1 The Sense of Presence in VR

Presence, defined as the psychological sensation of being immersed within a virtual environment, is a critical factor shaping user experience in VR [7, 60, 77]. It enables users to perceive themselves as active participants rather than external observers and is influenced by factors like environment realism, interaction responsiveness, and user engagement. Presence is typically categorized into physical presence, social presence, and self-presence [36]. Extensive research has explored these dimensions across various contexts [18, 71, 77, 78]. For instance, Do et al. found that matching a user's avatar to their ethnicity and gender enhances self-presence [15]. Povinelli et al. studied how transgender individuals use voice modulators in social VR to present their gender identity, enhancing self-recognition [52]. Xiong et al. highlighted how personalized elements, such as integrating real-world pet activities, can strengthen the sense of presence [76]. High levels of presence facilitate more natural interactions, allowing users to navigate and manipulate virtual environments more intuitively [44, 64, 70].

In education, enhanced physical presence improves students' focus and learning outcomes [19]. Philippe et al. reported that immersive virtual environments facilitate more efficient knowledge absorption [51]. Specifically in art education, Wei et al. demonstrated that a VR environment simulating a real film studio significantly improves learning outcomes compared to traditional classroom settings [71]. However, despite these benefits, there is limited understanding of how different virtual environments impact specific learning and collaboration outcomes in art education and film production [32, 37, 55, 57, 72].

To address this gap, this study selected three different virtual environments: studio (baseline), office, and beach, which were considered to be progressively increasing in terms of affective and difficulty levels. Specifically, the "baseline studio" simulates a standard filmmaking space with minimal distractions and a strong task-oriented focus, making it a low-difficulty environment. The "office" introduces richer spatial elements, such as furniture and visual cues, which, while still familiar, add greater visual complexity compared to the baseline studio. The "beach," on the other hand, features an expansive setting with more complex visual information, creating a highly contextualized environment with potentially higher levels of distraction. Within this framework, we aim to investigate how individuals and teams allocate cognitive resources and perform collaboration as the task environment becomes progressively more challenging, particularly in the context of teaching cinematic lighting.

Given that art education emphasizes spatial awareness, creativity, and collaboration, virtual environments may uniquely influence these processes. Therefore, this study address this gap by examining how different virtual environments and learning modes affect the sense of presence and learning outcomes in film lighting education.

2.2 Presence Affects Cognitive Load

Presence profoundly affects cognitive load in virtual reality environments, especially in educational and professional fields [1, 40, 43, 50]. A strong sense of presence enables users to immerse themselves more deeply in the learning process, which can influence their concentration, mental effort, and information processing efficiency [59, 61]. Specifically, when users experience a high level of presence in a virtual world, they may allocate cognitive resources more effectively, thereby improving task performance and reducing unnecessary mental strain [33, 46]. For example, in VR film production training, a heightened sense of presence can help users focus more intently on lighting setups and sound recording techniques [71, 82]. This immersive experience facilitates learning by making the virtual tasks feel more real and immediate, potentially reducing extraneous cognitive load associated with less engaging environments [71, 77, 82]. Additionally, VR provides a safe space where users can practice without concerns about real-world physical or resource limitations, which can minimize distractions and allow learners to concentrate on the core learning objectives.

Although the academic community widely acknowledges the benefits of high presence in enhancing learning experiences [20, 24, 38, 39, 75], the question of how different virtual environments, even with the same level of presence, affect cognitive load remains unclear. While it is evident that presence positively influences user engagement and attention, how the specific design and context of virtual environments shape cognitive load at similar levels of immersion has yet to be thoroughly explored.

2.3 Presence Affects Collaboration

Presence is crucial in collaboration within VR environments, particularly in tasks requiring collective problem-solving and decision-making. A strong sense of presence immerses participants in the virtual world and enhances interactions with team members, improving communication quality, trust, and group cohesion. For instance, Srivastava et al. found that social presence strengthens institutional trust in virtual settings, promoting effective organizational collaboration [66]. Similarly, Cruz et al.'s literature review revealed that increased presence helps participants better understand the virtual environment, thereby enhancing collaborative experiences, especially in three-dimensional settings [10].

Mütterlein demonstrated that immersion significantly boosts users' collaborative intentions in VR, more so than social presence or media naturalness [45]. This suggests that immersive experiences are directly related to the success of collaborative tasks. Likewise, Gomes et al. found that highly detailed virtual spaces in VR courses enhance students' sense of presence, promoting interaction and collaboration. This underscores the importance of presence in virtual environment design for improving teamwork quality [21].

Additionally, presence can alleviate challenges in remote collaboration by enabling team members to better perceive gestures and body language, making interactions smoother and more coherent [34]. Nevertheless, the complexity of the environment can also impact the level of coordination within teams: in "high-difficulty" environments with more distractions (such as the beach scene), teams require more explicit communication mechanisms and clear role allocation to address the increased stimuli and potential disruptions. Despite these benefits, research on how different task environments affect collaboration remains

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limited. In particular, the impact of various virtual environment scene types on collaborative processes has not been thoroughly explored.

2.4 Learning Modes in VR

Numerous studies have explored different learning modes in virtual reality, with a focus on individual and collaborative learning experiences [12, 27, 31, 40, 42, 49, 54]. Of particular relevance to our study is the work by Parong and Mayer [49], which investigated whether immersive VR facilitates learning more effectively than traditional computer-based methods. They found that while VR increased learners' sense of presence, it also led to higher cognitive load and poorer learning outcomes compared to a desktop slideshow presentation. This suggests that the immersive nature of VR can sometimes overwhelm learners, detracting from the educational content. Similarly, Makransky et al. [40] explored the effects of adding immersive VR to a science lab simulation. Their study revealed that although VR heightened situational interest and engagement, it did not significantly improve learning outcomes over desktop-based simulations. They emphasized the importance of aligning VR experiences with pedagogical objectives to prevent unnecessary cognitive load. In contrast, studies by Dalgarno and Lee [12] and Johnson-Glenberg et al. [31] examined collaborative and embodied learning in virtual environments. They reported that 3D virtual learning environments enhanced learners' engagement, motivation, and perceived social presence, facilitating better communication and teamwork skills essential in collaborative fields. However, they noted that these benefits are often more affective than cognitive, as there were not always significant differences in academic achievement compared to traditional learning settings. Additionally, while active manipulation of virtual objects in VR can lead to better retention and understanding of complex concepts, excessive interaction without clear instructional design can increase cognitive load, potentially hindering learning. These findings suggest that while VR can enhance engagement and collaboration, it may not automatically translate to improved academic performance without careful instructional design.

Game-based learning research has found that "difficulty calibration" is a critical factor influencing individual and collaborative performance in virtual environments [13, 16, 67]. For instance, Streicher and Smeddinck noted that personalized and adaptive adjustments to task difficulty in serious games can provide users with a dynamic learning experience that maintains a balance between challenge and frustration [67]. Similarly, the study by A. Bartl et al. revealed that different difficulty modes in the environment (e.g., from simple baseline settings to complex distraction-heavy scenarios) can significantly impact users' task completion rates in virtual environments [3].

Although VR's immersive features can boost engagement, presence, and motivation, they do not consistently enhance learning outcomes. Controlling cognitive load, designing effective activities, and aligning with pedagogical goals are crucial. Past research mostly focuses on general or scientific fields, leaving creative domains like film production underexamined. Our study addresses this gap through validated assessments comparing individual and collaborative VR learning modes in film lighting education.

3 Methods

To understand the impact of learning modes on students learning film lighting techniques in a virtual environment, our experiment considers the factors from three environments and two learning modes, leading to a 3×2 between-subjects study design.

Participants engaged in activities within three distinct situations, each representing a unique affective environment: the baseline scenario, the beach scenario, and the office scenario (Figure 2 - (1)(2)(3)). These scenarios were selected to explore how different environmental contexts influence learning experiences. The baseline scenario, serving as a neutral control, was a conventional cinematographic setting approximating the actual learning situation and offering a fundamental feeling of physical presence. The beach scenario, a virtual outdoor setting, was chosen as a challenging environment due to its dynamic and potentially distracting elements, which may increase cognitive load and frustration and enhance immersion. The office scenario replicated

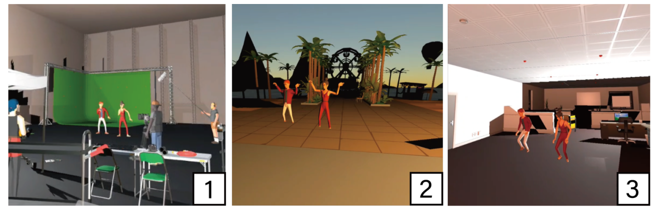

Fig. 2: (1) Baseline Scene - Standard film shooting scene; (2) Beach Scene; (3) Office Scene.

a typical everyday work environment to assess the impact of familiar settings on learning. All three scenarios were meticulously crafted with the same visual quality to ensure consistency.

On the other hand, the learning mode is another independent variable, which consists of two conditions: team-based learning and individual learning. In the team-based learning mode, a pair of participants were randomly paired to form a group to learn and collaborate on the film lighting course to complete the task together, as shown in Figure 3 - (1). In contrast, in the individual learning mode, participants worked on the task alone, with no opportunity to interact with others, as shown in Figure 3 - (2). Participants completed a film lighting/photography production task in each condition and shot a short video (30 seconds).

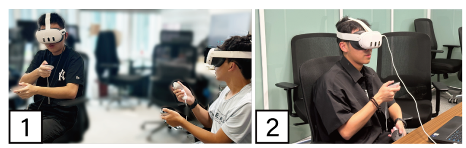

Fig. 3: (1) Team-Based learning mode; (2) Individual learning mode.

As a way to guarantee the accuracy and uniformity of the findings, we presented each participant with identical task material and learning goals, therefore mitigating any possible influence of task difficulty on the experimental outcomes. All participants were provided with identical equipment and virtual reality setups in every circumstance to guarantee that the trial outcomes were not affected by hardware or technical issues. Furthermore, the virtual scenarios employed in the tasks were consistent in terms of light intensity, sound levels, and the tools and resources utilised by the participants in all virtual settings, with the exception of variations in environment design. Furthermore, all participants leveraged avatars of uniform visual appearance, irrespective of the scenarios they experienced, to guarantee that the choices of avatars did not influence the perceptions or behaviours of the participants.

3.1 Research Hypotheses

We had the following hypotheses for our research questions:

- **H1:** Different virtual environments significantly influence students' learning experience and cognitive load. Challenging environments (e.g., the beach) may increase cognitive load and frustration for individual learners, but they can also enhance immersion within the scene.
- **H2:** The effectiveness of the learning mode depends on the type of virtual environment. In familiar or less distracting environments (e.g., the baseline or office), team-based learning outperforms individual learning, whereas in challenging environments (e.g., the beach), individual learning may show better results.
- **H3:** There is a significant interaction between virtual environment design and learning mode, which affects students' performance and satisfaction. Specifically, team-based learning improves performance and satisfaction in familiar environments, while individual learning in novel or challenging environments may increase engagement and scene perception.

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3.2 Film MetaStudio

To examine the proposed hypotheses, we designed Film MetaStudio, a VR filmmaking teaching system built upon the theoretical framework of presence. This system is implemented as a virtual studio environment and covers various aspects of filmmaking, including cinematography, lighting, production design, and directing. The system also supports collaborative learning, with multiple students participating simultaneously, as illustrated in Figure 2.

Within Film MetaStudio, we provide participants with: 1) various lighting devices (such as tungsten lamps, LED lights, and fluorescent lamps), as shown in Figure 4 - (1); 2) a variety of prop models for participants to choose from, as shown in Figure 4 - (2); and 3) a handheld VR camera that supports in-VR recording, as shown in Figure 4 - (3). In real-world filmmaking, multiple types of lighting equipment are typically combined to illuminate a scene. The content of the creation can be flexibly adjusted according to the instructor's teaching needs, including altering models and props in the scene. Moreover, the recording design of the in-VR camera adds flexibility to the participants' creative process. This diverse range of equipment and flexible content creation approach helps stimulate participants' interest and engagement in the virtual studio environment.

Fig. 4: (1) Lighting equipment (e.g., LED lights, fluorescent lights); (2) Various props available for participants to choose from; (3) Handheld camera supporting VR recording.

3.2.1 Film MetaStudio Interaction Pipeline

The Interaction Pipeline provides a user-friendly interface to help students focus on learning film production. When users enter the login screen, they can select their learning environment, as shown in Figure 5 - (1). Users can operate the camera in front of them and press the record button to begin video recording, as shown in Figure 5 - (2). Users can toggle the Sunlight on or off to observe the effects of their lighting setup, as shown in Figure 5 - (3). On the virtual panel located above the left-hand controller, there are select, move, and rotate buttons corresponding to object selection, movement, and adjustment of the light's tilt angle, as shown in Figure 5 - (4). Additionally, in the Film MetaStudio system, users can use two types of lighting, as shown in Figure 5 - (5). When a user approaches any lighting device, the dashboard automatically appears to allow better interaction with the lighting controls. The control panel offers various adjustable parameters. For all two types of lights, we have standardized controls for adjusting RGB color settings, as shown in Figure 5 - (6). This allows learners to freely generate the desired light color (Figure 5 - (7)). The system supports the simultaneous operation of multiple lights, allowing students to create complex lighting designs (Figure 5 - (8)).

In virtual film production training, as shown in Figure 5 - (9), users operate the VR controller, which has built-in sensors, using two buttons and a pointer to select, grab, and move target lights, cameras, and props. We designed two motion modes to simplify user operations. When physical space is limited, users can adjust their direction and teleport to the desired location using the remote function on the left controller. With ample space, users can set a safety zone, and movements in the virtual world synchronize with real-world movements. We also created a training environment to help users adapt to the workflow. The clean environment and adequate lighting ensure that users can easily identify the operational steps. A detailed demonstration video of the Film MetaStudio interaction pipeline can be downloaded here[1].

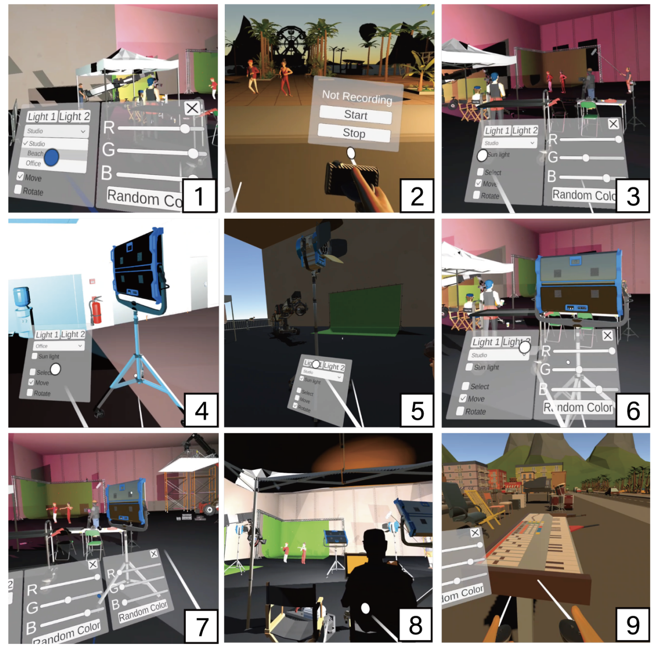

Fig. 5: (1) Selection of three training scenes; (2) Virtual camera recording/on-off control; (3) Ambient light control (on or off); (4) The select, move, and rotate buttons correspond to object selection, movement, and adjustment of the light's tilt angle; (5) Two types of lighting fixtures available; (6) A lighting control panel to control the two types of lights—users can adjust RGB color settings; (7) Randomly generate light colors; (8) Supports simultaneous operation of multiple lights for lighting design; (9) Users can select, grab, and move target lights, cameras, and props.

3.3 Dependent Variables

We primarily measure the user workload in the virtual learning environment and their corresponding learning experiences. Thus, after completing all the experimental conditions, we distributed two questionnaires after each condition, as described in the paragraphs below. Also, participants were required to participate in a 10-minute semi-structured interview to gather qualitative feedback.

NASA-TLX Questionnaire To assess participants' workload during the experiment, we employed the NASA-TLX Questionnaire developed by Hart and Staveland [22]. We chose this questionnaire due to its extensive validation and widespread use in measuring subjective workload across various domains. The NASA-TLX consists of six dimensions, each rated on a 7-point Likert scale: Mental Demand, Physical Demand, Temporal Demand, Performance, Effort, and Frustration. These dimensions are combined to generate an overall workload score, providing a detailed understanding of the cognitive and physical demands placed on participants during the task.

Learning Experience Questionnaire We used the Learning Experience Questionnaire to assess participants' virtual learning experiences, focusing on overall satisfaction, environmental impact, and the effectiveness of learning modes. The questionnaire, rated on a 7-point Likert scale, covers three areas: "Overall Experience," "Scenario Impact," and "Understanding Enhancement." The questions were adapted from previous research to ensure a comprehensive evaluation of how participants adjusted to the virtual environment, applied learned techniques, and the effectiveness of team-based versus individual learning [71,73]. This tool provides detailed insights into learning outcomes that complement other standardized assessments.

[1] https://file.io/fnb2yA4ezZLw

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Observation and Semi-structured interviews During the experiment, we continuously observed the participants' operations by streaming the VR headset's display to a computer. Upon concluding the experiment, participants engaged in semi-structured interviews to provide detailed feedback on their learning experience. These qualitative responses offered valuable insights to complement the quantitative data. Participants were asked several key questions focused on their learning outcomes and experiences, including: 1) How did the learning environment affect your ability to grasp the material? 2) What were your feelings and perceptions regarding the virtual scene you learned about? 3) How did the learning mode (individual or group) impact your overall learning experience?

Apparatus Participants used a Meta Quest 3 headset, with the program deployed via Unity 2022.3.18f1. The experiment took place in a quiet, open, and well-lit meeting room. The VR environment was streamed to a computer during the experiment to observe participants' behavior in real time, as shown in Figure 3. The source code is available at [2].

3.4 Procedure

Before the study was conducted, the research procedures were approved by the Institutional Review Board (HSEARS20240910008). The study includes a face-to-face experimental session lasting approximately 45 minutes. Prior to the laboratory session, participants were asked to complete a background survey, covering demographic information such as gender, education level, and VR usage experience. Upon arriving at the laboratory, participants are randomly assigned to one of six experimental conditions. They then received a 5-minute training session on VR operation and the teaching system to ensure that all participants were familiar with the VR interface and understood the experimental environment. Although participants completed the experiments in different environmental settings (baseline, beach, and office), the tasks and requirements remained consistent across all conditions. This ensured that any outcome differences were solely attributed to the learning modes (team or individual) and environmental context, rather than task difficulty. All participants used standardized tools and resources to complete identical lighting replication and video production tasks, ensuring consistency in the experimental design. In the VR environment, participants first engage in a 10-minute basic filmmaking techniques lesson, which covers lighting functions and principles, camera operation, and an introduction to scene composition. Afterward, participants are required to complete two tasks within 20 minutes:

3.4.1 Task 1: Lighting Setup Replication

In this task, participants are required to replicate a specific lighting setup within the virtual environment as accurately as possible. The experimenter provides a reference lighting configuration that includes the positions of the lights but not the types of lighting equipment used. Participants must infer and select the appropriate types of lights based on sample reference images from the scene they are in (see Figure 6 - (1)–(4)). They have 6 minutes to complete the lighting arrangement, considering factors such as light source selection, color temperature, and angle to match the reference setup, demonstrating an understanding of lighting principles by choosing suitable lights to recreate the desired effects in terms of shadows, highlights, and overall ambiance. After the task, three experts evaluate the participants' replicated lighting setups based on the following criteria: Accuracy of Replication (how closely the lighting setup matches the reference in terms of positions and effects), Appropriateness of Light Types (selection of suitable lighting equipment to achieve the desired outcome), Technical Proficiency (skillful adjustment of light properties like color and intensity), and Overall Visual Quality (the aesthetic appeal and coherence of the lighting within the scene). Each expert scores the setups on a scale from 0 (worst) to 6 (best), with the final score being the average of the three.

[2] https://anonymous.4open.science/r/illuminating-scene-dev-0C4A/

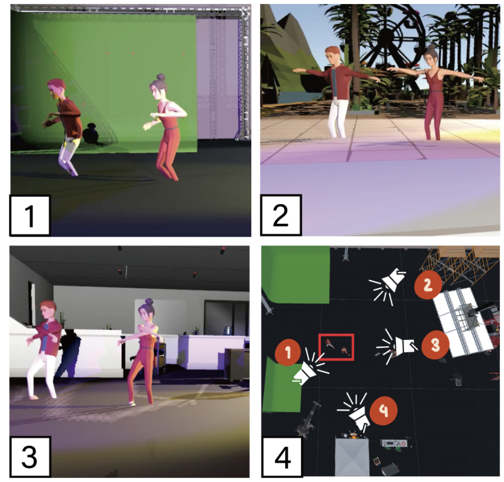

Fig. 6: Task 1 - Participants replicate the lighting based on the sample of the corresponding scene they are in: (1) Lighting sample for a baseline film shooting scene; (2) Lighting sample for a beach scene; (3) Lighting sample for an office scene; (4) Top view of the same position in the lighting arrangement of the three scenes.

3.4.2 Task 2: Camera Shot

In this task, participants are required to design the lighting, choose camera angles, and incorporate props to create a 30-second single-shot video based on the theme "Dancing in the Light and Shadow." The content of the shot is relatively flexible, encouraging participants to fully apply the filmmaking techniques they have just learned. Participants must complete the shooting within the 14 minutes and submit their 30-second video.

Participants are evaluated on the effectiveness of their visual storytelling in conveying the theme "Dancing in the Light and Shadow," with scores based on four key criteria: thematic interpretation, creativity and originality, technical execution, and artistic expression. These criteria assess the innovative use of lighting, and camera work, the proficiency in lighting design and cinematography, and the overall aesthetic quality and emotional impact of the film. Each short film is scored on a scale from 0 (worst) to 6 (best), with the final score being the average of the three experts' evaluations. If a participant's average score is greater than or equal to 4, the task is considered passed and received 1 points. Participants who scored below 4 did not pass and received 0 points. If the average score is below 4, it is considered unsatisfactory. The experts, who come from diverse backgrounds—Expert 1, a seasoned director and filmmaker with 10 years of experience; Expert 2, an educator with over 10 years of experience teaching film production; and Expert 3, a VR specialist with experience in designing VR educational systems—provide a well-rounded assessment. Participants are encouraged to explore their creativity while adhering to time constraints, demonstrating both technical skills and the ability to express complex themes through film. Notably, this same group of experts will evaluate both Task 1 and Task 2, ensuring consistency in the assessment process.

It is worth noting that in the individual mode, participants complete the above two tasks independently, while in Duo mode, two participants collaborate on the tasks. In Dou mode, a pair of participants can engage in discussion, communication, and trial and error within the environment. They can collaborate to solve problems or complete tasks, fully utilizing each other's ideas and feedback. Participants can transfer objects between each other, adjust lighting, and control the camera, among other interactions.

The experimenters observe the participants' behaviors through VR casting to an external display. Before the experiment concludes, participants are required to complete the NASA-TLX questionnaire and a Learning Experience Questionnaire, followed by a 10-minute structured interview. The entire experiment lasts approximately 45 minutes, and participants receive a $5 compensation for their participation.

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3.5 Participants

We recruited 36 participants via social media, who provided self-reported demographic details, including gender (13 female and 23 male) and age ($\bar{M}$ = 24.76 , SD = 3.56). All participants indicated that they had normal or corrected vision and no disabilities. 25 participants reported having prior experience with VR. The 36 participants were divided into six groups: Group A (individual learning) and Group B (team learning) experienced the baseline scene, Group C (individual learning) and Group D (team learning) experienced the beach scene, and Group E (individual learning) and Group F (team learning) experienced the office scene.

3.6 Data Analysis Approach

Following the guidelines outlined in the literature [15, 17], we first calculated the mean scores for each subscale question as well as the overall score. To assess the normality of the score distributions, we performed a Shapiro-Wilk test [56], which revealed that some measures did not follow a normal distribution. Consequently, we opted for the Aligned Rank Transformation (ART) approach to conduct a 3x2 factorial ANOVA [74]. This allowed us to examine both the interaction effects and the main effects of the learning environment and learning mode (team-based vs. individual).

4 Results

Table 1 presents the means and standard deviations for all measures. We first discuss the NASA-TLX results, followed by the Learning Experience Questionnaire, then report the expert ratings from both tasks, and conclude with the results from the structured interviews.

Table 1: An overview of the mean (M) and standard deviation (SD) of the questionnaire results. An asterisk (*) indicates a significant difference between environments, a plus sign (+) indicates a significant difference between learning modes, and a hash symbol (#) indicates a significant interaction effect between scene and learning mode (Scene * Learning Mode). For NASA-TLX scores (1 Best - 7 Worst) , while for Learning Experience (LE) scores (1 Worst - 7 Best).

	Baseline & Individual M(SD)	Baseline & Team M(SD)	Beach & Individual M(SD)	Beach & Team M(SD)	Office & Individual M(SD)	Office & Team M(SD)
NASA-Q						
Frustration*+#	1.33(0.52)	2.00(0.89)	4.33(2.25)	1.50(0.55)	2.50(0.84)	1.00(0)
Effort*+#	2.50(1.05)	3.17(1.33)	6.00(0.63)	3.67(1.21)	4.00(1.26)	2.50(0.84)
Performance*#	4.17(1.47)	4.50(1.52)	2.33(0.52)	3.33(1.51)	4.00(0.89)	2.33(0.52)
Temporal Demand	2.17(1.17)	2.17(1.60)	2.33(1.86)	1.83(1.17)	2.67(1.63)	2.00(1.10)
Physical Demand	2.17(0.75)	2.50(1.05)	2.50(1.64)	2.17(0.75)	2.17(0.75)	1.67(0.52)
Mental Demand	3.00(1.55)	3.00(0.63)	3.67(1.51)	3.67(1.63)	3.50(1.52)	3.00(1.10)
LE-Q						
Overall Experience*#	5.33(1.36)	6.50(0.84)	5.50(1.38)	4.17(0.75)	5.83(0.98)	5.00(0.63)
Scenario Impact#	5.50(0.84)	5.67(1.36)	6.00(0.89)	3.83(0.75)	4.83(1.47)	5.00(0.63)
Understanding Enhancement+#	5.17(0.75)	5.83(0.98)	5.50(1.05)	3.83(0.98)	5.50(1.38)	4.17(0.75)

4.1 NASA-TLX Questionnaire

Our analysis of the NASA-TLX questionnaire data revealed distinct patterns across the measured variables, as shown in Figure 7 (1) - (3). No significant main effects or interaction effects existed between environments and learning modes for Mental Demand, Physical Demand, and Temporal Demand.

Conversely, significant interaction effects between environment and learning mode were observed for Effort, Frustration, and Performance, indicating that the effect of one factor depended on the level of the other. For Effort, both environment ($F_{2,30}$ = 12.25, p <0.001) and learning mode ($F_{2,30}$ = 9.17, p = 0.005) showed significant main effects, with a significant interaction ($F_{2,30}$ = 5.51, p = 0.009). Similarly, Frustration exhibited significant main effects of environment ($F_{2,30}$ = 5.13, p = 0.012) and learning mode ($F_{2,30}$ = 16.73, p <0.001), along with a significant interaction effect ($F_{2,30}$ = 10.26, p <0.001). For Performance, a significant main effect of environment was found ($F_{2,30}$ = 4.57, p = 0.019), while the main effect of learning mode was not significant ($F_{1,30}$ = 0.92, p = 0.35); however, their interaction was significant ($F_{2,30}$ = 6.34, p = 0.005). Our analysis revealed significant interaction effects between environment and learning mode for Effort, Frustration, and Performance. While the sample size (N = 36, divided into six groups) may limit generalizability, the observed effects provide strong evidence for the influence of environmental context and learning mode.

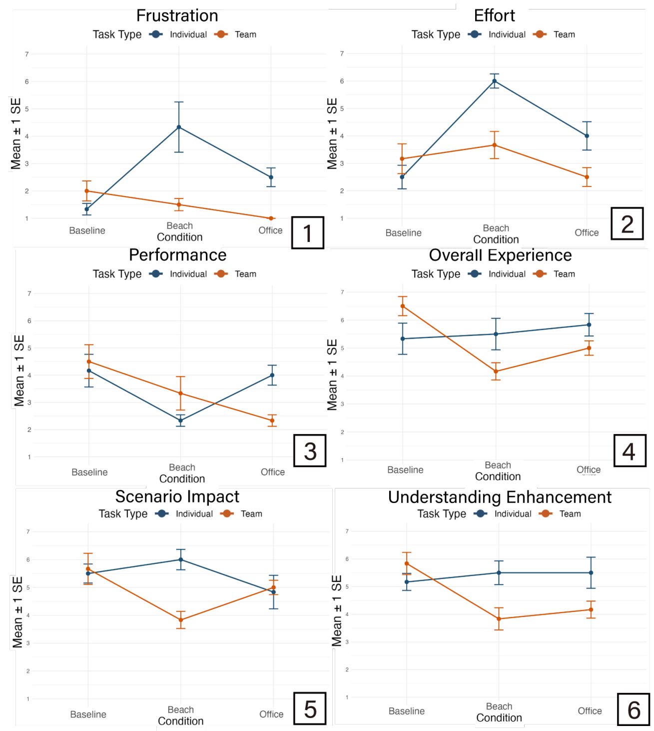

Fig. 7: We have listed all the statistically significant results, showing the mean measurements of NASA-TLX and LE along with standard error (±1 SE). The charts compare individual learning and team learning across different conditions (Baseline, Beach, Office). Sub-figures 1-3 display the NASA-TLX scales for frustration, effort, and performance (1 Best-7 Worst). Sub-figures 4-6 show the LE scales for overall experience, scenario impact, and understanding enhancement (1 Worst-7 Best).

4.2 Learning Experience Questionnaire

Statistical analysis of the Learning Experience Questionnaire data also revealed significant interaction effects between environment and learning mode on participants' overall experience, scenario impact, and understanding. Despite the limited sample size, the study results potentially reveal significant interactions between environment and learning mode, providing valuable insights for VR learning design. For overall experience, the interaction was significant ($F_{2,30}$ = 4.10, p = 0.027), with a marginal main effect of environment ($F_{2,30}$ = 3.24, p = 0.053) and a non-significant main effect of learning mode ($F_{1,30}$ = 0.76, p = 0.391). In the case of scenario impact, neither main effect was significant (environment: $F_{2,30}$ = 1.78, p = 0.186; learning mode: $F_{1,30}$ = 1.97, p = 0.170), but their interaction was significant ($F_{2,30}$ = 5.40, p = 0.010). For understanding enhancement, there was a significant main effect of learning mode ($F_{1,30}$ = 8.90, p = 0.006) and a significant interaction effect ($F_{2,30}$ = 6.23, p = 0.005), as shown in Figure 7 (4) - (6).

4.3 Task Results

4.3.1 Task 1: Lighting Setup Replication

In Task 1, we investigated the performance of six participant groups under different environmental scenes and learning modes. Figure 8 illustrates the visual effects of the "Lighting Setup Replication" task conducted in the Film MetaStudio environment (sub-figures 2, 3).

Fig. 8: Sample Results of Task 1 include: (1) a standard lighting sample for a baseline film shooting scene; (2) An individual lighting sample for the baseline scene; and (3) A team lighting sample for the baseline scene.

As shown in Table 2, Group C (individual learning in the beach scene) achieved the highest average score ($\bar{M}$= 3.67, SD= 1.11). This was followed by Group B (team learning in the baseline scene, $\bar{M}$= 3.56, SD= 0.68). The subsequent rankings were Group F (team learning in the office scene, $\bar{M}$= 3.00, SD= 0.27), Group D (team learning in the beach scene, $\bar{M}$= 2.67, SD= 0.47), Group A (individual learning in the baseline scene, $\bar{M}$= 2.22, SD= 1.36), and finally Group E (individual learning in the office scene) with the lowest average score ($\bar{M}$= 1.17, SD= 0.92). Based on these results, we conclude that both the environmental scene and the learning mode have significant impacts on performance. The beach scene enhances individual learning effectiveness, as evidenced by Group C's superior performance. Conversely, the baseline and office scenes showed better results for team learning modes compared to individual learning in the same environments.

Table 2: Three experts scored the six groups of participants (36 people) for both Task 1 and Task 2. Each participant's score was averaged across the three experts, and the group score was calculated by averaging the individual scores of all group members.

Group	Type of Study	Learning Scenarios	Task 1 M(SD)	Task 2 M(SD)
A	Individual	Baseline Scene	2.22(1.36)	3.72(1.16)
B	Team	Baseline Scene	3.56(0.68)	3.44(1.03)
C	Individual	Beach Scene	3.67(1.11)	4.39(1.52)
D	Team	Beach Scene	2.67(0.47)	3.22(0.68)
E	Individual	Office Scene	1.17(0.92)	2.72(1.56)
F	Team	Office Scene	3.00(0.27)	3.56(0.57)

ART ANOVA's results revealed significant main effects for both Scene ($p < 0.05$) and Mode ($p < 0.05$). Moreover, there was a significant interaction between Scene and Mode ($p < 0.01$). These findings emphasize that not only do environmental design and learning modes independently influence performance, but their interaction also plays a crucial role. In summary, optimizing both the learning environment and the mode of learning can lead to improved performance outcomes. This suggests that educational strategies should consider both factors to enhance learning effectiveness.

4.3.2 Task 2: Camera Shot

Figure 9 illustrates the visual effects of the "Camera Shot" task conducted in the Film MetaStudio environment (sub-figures 1 – 6).

As shown in Table 2, Group C (individual learning in the beach scene) achieved the highest average score ($\bar{M}$ = 4.39, SD = 1.52), with 4 participants passing. This was followed by Group A (individual learning in the baseline scene, $\bar{M}$ = 3.72, SD = 1.16), with 3 participants passing, and Group F (team learning in the office scene, $\bar{M}$ = 3.56, SD = 0.57), with 2 participants passing. The subsequent rankings were Group B (team learning in the baseline scene, $\bar{M}$ = 3.44, SD = 1.03), with 4 participants passing, Group D (team learning in the beach scene, $\bar{M}$ = 3.22, SD = 0.68), with 2 participants passing, and finally Group E (individual learning in the office scene, $\bar{M}$ = 2.72, SD = 1.56), with 4 participants passing despite the lower average score.

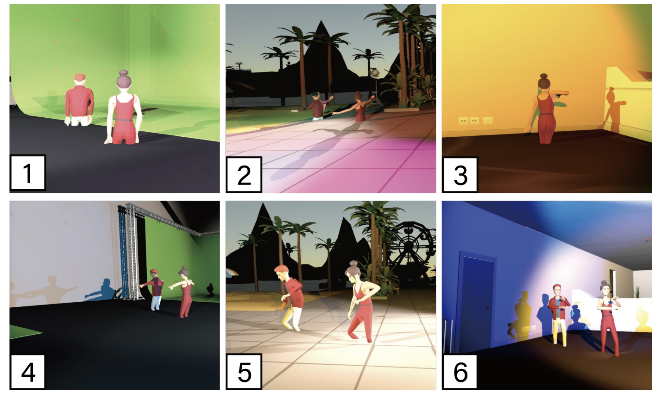

Fig. 9: Sample Results of Task 2 include: (1) An individual lighting sample for the baseline scene; (2) An individual lighting sample for the beach scene; (3) An individual lighting sample for the office scene; (4) A team lighting sample for the baseline scene; (5) A team lighting sample for the beach scene; (6) A team lighting sample for the office scene.

The results of an ART ANOVA, conducted on the dichotomous pass/fail data (where participants who passed received a score of 1 and those who did not pass received a score of 0), revealed significant main effects for both the Individual and Team factors ($p < 0.001$), as well as a significant interaction between these factors ($p < 0.001$). These findings indicate that both environmental design and learning modes significantly affect task performance outcomes, with their interaction further influencing the probability of participants achieving a passing score.

4.4 Observation and Semi-structured interviews

In our observations of individual learners, we found notable gender differences in their approach to lighting adjustments within the VR environment. Specifically, through VR streaming, we discovered that the majority of female participants paid more attention to adjusting the lighting, preferring to use vibrant and noticeable colors to enhance the visual appeal. In contrast, male participants tended to focus more on the positioning of the lights and showed greater curiosity about the overall environment in which the dancer performed.

We also observed that the team-based tasks uniquely triggered a lot of communication and interactions between the pair participants, in comparison to the individual tasks. First, most groups of participants discussed the uses of different virtual configurations of three environments by altering models and props. They also invited their partners to appreciate the immediate lighting effects, and their partners would comment on the lighting effects and express their curiosity about how to polish the scenes, e.g., the darkness or brightness, the scene's tone and color. In such multi-user collaboration, participants create interactions on the lighting effects and indicate their interest in the iterative refinement of the scenes. On the other hand, the pair participants would request task synchronization, for instance, *stop!*, *give me a second.*, or *I try to observe several lighting effects in the scenes before we start the shoot; so, please do not relocate this object, or do not rotate light props.* Notably, the participants would engage in on-scene discussions and provide their reasons why one surpasses another. In such cooperative assignments, participants had to leverage their understanding of lighting to accomplish persuasion and group consensus.

Our semi-structured interviews also revealed that participants had diverse experiences and preferences regarding different virtual environments (such as beach, office, and baseline studio) and their preferred modes of working individually or collaboratively. Many participants found the beach environment visually appealing and creatively stimulating, describing it as a *relaxing and unrestricted* creative space. In contrast, the office environment received mixed reviews due to its narrow and oppressive atmosphere, although it was appreciated for its ability to facilitate precise lighting control.

Regarding learning modes, some participants preferred working independently to fully control the creative process, while others found collaboration more beneficial for completing complex tasks, especially those requiring division of labor and creative brainstorming. Additionally, interviews emphasized that the ideal virtual learning environment should transcend mere replication of real-world settings by offering unique scenes, such as *the top of Mount Everest,* to spark creativity and engagement. Interview results revealed context-dependent preferences: simpler environments were valued for ease, creative ones for innovation; collaborative learning eased workload, while individual learning provided autonomy, emphasizing the need to align VR settings with tasks and learner goals.

5 Discussion

In this section, we first discuss the implications of our findings for VR education in cinematography, focusing on how different virtual environments affect learning experience and cognitive load. We then explore the interaction between learning modes and virtual environments, highlighting the nuances in team-based and individual learning. Next, we delve into the balance between generalizability and customization in VR education, considering how this balance impacts learning outcomes. We conclude by discussing the implications for VR research and developers, acknowledging the limitations of our study, and suggesting directions for future work.

5.1 VR's Impact on Learning and Cognitive Load

Our first hypothesis (H1) posited that different virtual environments significantly influence students' learning experience and cognitive load. Specifically, challenging environments like the beach may increase cognitive load and frustration for individual learners but can also enhance immersion within the scene. The results confirm this hypothesis, as participants in the beach environment reported heightened levels of frustration and effort, particularly when learning individually. Despite the increased cognitive load, these participants also perceived higher performance and greater scenario impact. These findings suggest that unconventional or challenging virtual environments can stimulate cognitive engagement and creativity, aligning with the concept of desirable difficulties in learning [4]. The increased cognitive load, measured by NASA-TLX, reflects the additional mental effort required to navigate these novel challenges, which can lead to deeper processing and improved learning outcomes [68]. This contrasts with previous research emphasizing that realistic or familiar environments reduce cognitive load and enhance learning [40]. Our study extends this understanding by demonstrating that less conventional environments can also be beneficial by fostering creativity and problem-solving skills essential in cinematography.

5.2 Learning Modes and Virtual Environments

Our second hypothesis (H2) proposed that the effectiveness of the learning mode depends on the type of virtual environment. In familiar or less distracting environments (e.g., the baseline or office), team-based learning may outperform individual learning, whereas in challenging environments (e.g., the beach), individual learning may show better results. The third hypothesis (H3) stated that there should be a significant interaction between virtual environment design and learning mode, affecting students' performance and satisfaction.

The findings support these hypotheses by revealing a significant interaction between the type of virtual environment and learning modes. Notably, in the beach environment, individual learners performed better than team-based learners, contrasting with observations in more familiar environments like the office or baseline studio. This suggests that when learners encounter novel or unconventional environments, individual learning may foster deeper cognitive engagement due to the heightened need for personal problem-solving and creative decision-making [3]. Conversely, team-based learners performed more effectively in structured environments where collaboration could alleviate cognitive load, as observed in the office and baseline environments [26, 53]. These results indicate that the type of virtual environment not only impacts learning outcomes but also interacts with the learning mode to influence performance. In familiar settings, team-based learning may leverage collective knowledge to reduce cognitive load, leading to improved outcomes [30,65]. However, in more challenging or creative environments, individual learning might encourage deeper engagement with the task, enhancing creativity and autonomy [58]. This interaction aligns with theories of cognitive load [68] and collaborative learning [14], emphasizing the need for adaptive educational strategies based on the learning context [62].

5.3 Generalizability vs Customization in VR Education

One of the major challenges in VR education, especially within creative disciplines like film production, is striking an optimal balance between generalizability and customization of virtual learning environments. Our study reveals that highly customizable environments, such as the beach setting, can enhance the engagement of learners and stimulate creativity. However, they also tend to increase cognitive load, particularly for individual learners, potentially hindering learning efficiency. In contrast, standardized environments such as the office or the baseline studio offer a stable foundation for learning, which seems to be more conducive to team-based tasks, but may limit opportunities for creative exploration.

The trade-off between customization and cognitive load has been a subject of interest in educational research. According to Cognitive Load Theory (CLT) [68], excessive cognitive demands can impede learning by overwhelming the learner's working memory. Overly complex or customizable environments can introduce an extraneous cognitive load, diverting attention from the main learning objectives [48]. On the other hand, customization can support intrinsic motivation and deeper engagement by allowing learners to align the learning environment with their personal interests and creative goals [58].

To navigate this trade-off, it is essential to design VR educational tools that offer customization options while managing cognitive load effectively. An approach is to implement adaptive scaffolding within the virtual environment [69]. This involves providing learners with guidance and support that can be gradually removed as they become more proficient, thereby minimizing unnecessary cognitive demands while maintaining opportunities for creativity. For instance, initial tasks could be set in more standardized environments to build foundational skills, with customization options introduced progressively as learners gain confidence.

Moreover, incorporating user-centered design principles can help tailor the level of customization to the learners' needs [5]. By allowing learners to control the degree of complexity in the environment, VR tools can accommodate different learning preferences and cognitive capacities. Prior studies have shown that adaptive systems that adjust to the learner's expertise can enhance learning outcomes [41]. Another strategy is to integrate collaborative features that leverage team-based learning to manage cognitive load in customizable environments. As our findings suggest, team collaboration in familiar settings can mitigate cognitive demands by distributing tasks and fostering peer support. In more complex environments, while collaboration can help learners collectively navigate challenges through shared problem-solving and creativity, individual learning can also be advantageous. It allows learners to engage deeply with the material at their own pace, fostering personal problem-solving skills and independent creative thought. [29].By integrating adaptive scaffolding, user-centered design, and both individual and collaborative learning features, VR educational tools can balance customization with generalizability, enhancing creativity without compromising learning efficiency. Future research should continue to explore these strategies, examining their effectiveness across different contexts and learner populations to optimize this balance.

5.4 Implications for VR Research

Our study holds important implications for the field of VR research and development, particularly in the context of educational applications within creative disciplines like film production. Traditionally, VR educational research has focused on the benefits of immersive and realistic environments for enhancing learning outcomes [11, 40].

However, our findings suggest that the relationship between virtual environment design, learning modes, and cognitive load is more complex than previously understood. First, the significant interaction between virtual environments and learning modes underscores the need for VR research to adopt a more nuanced approach when investigating learning in virtual settings. While familiar and realistic environments may facilitate team-based learning by reducing cognitive load and leveraging collective knowledge [30, 47, 65], unconventional or challenging environments like the beach setting in our study can enhance individual learners' engagement and creativity [3]. This indicates that VR research should explore a broader range of environmental designs and consider how different contexts may favor different learning modes. Second, our study highlights the importance of considering cognitive load in the design and evaluation of VR educational tools. Excessive cognitive load can hinder learning [68], but a certain level of challenge may promote deeper engagement and problem-solving skills [4]. VR researchers should investigate how to optimize cognitive load by balancing environmental complexity with learners' capacities, potentially through adaptive systems that adjust to individual needs [2, 9, 80]. While immersion and presence are valuable, introducing elements that stimulate creativity and require active problem-solving can be equally important [58]. This challenges the conventional focus on replicating real-world settings in VR and opens avenues for exploring how imaginative or abstract environments can contribute to educational objectives.

5.5 Implications for VR Development

For VR development, these insights call for a more flexible and learner-centered approach to designing educational applications. Developers should consider incorporating customizable features that allow learners to adjust the level of environmental complexity and support according to their preferences and proficiency levels. Implementing adaptive scaffolding mechanisms can help manage the cognitive load by providing guidance when needed and fostering autonomy as learners become more competent [69]. Additionally, our study emphasizes the importance of supporting both individual and collaborative learning modes within VR environments. Given that different environments may favor different learning approaches, VR systems should be designed to accommodate multiple modes of interaction. For example, in familiar environments, features that facilitate communication and coordination among team members can enhance collaborative learning [23, 81]. Providing tools that support individual exploration and creativity can be beneficial in more challenging settings. Our findings suggest that expanding research environments and learning scenarios leads to a more comprehensive understanding of how VR supports diverse learning needs.

5.6 Limitations and Future Work

While our study provides valuable insights into the impact of different virtual environments and learning modes on film lighting education, several limitations should be acknowledged.

First, it is important to acknowledge that the relatively small sample size (N = 36) in this study limits the generalizability of our findings to broader populations. While the study provides valuable insights into the interaction between virtual environments and learning modes in film lighting education, the homogeneity of the participant pool—consisting primarily of students from two academic institutions—necessitates caution in extrapolating these results to diverse learner groups. Moreover, the lack of participant diversity in terms of experience, demographic factors, and gender diversity within teams further constrains the applicability of these findings. A post-hoc power analysis indicates that achieving sufficient statistical power (80%) for detecting larger effects (f=0.35) across six conditions would require approximately 110 participants, which is still larger than our current sample. Future research should aim to include larger and more diverse samples, encompassing participants with varying levels of expertise, broader demographic representation, and balanced gender compositions to better validate the observed trends and refine our understanding of the interplay between virtual learning settings and cognitive processes.

Second, we employed predefined virtual environments that, although varied, may not fully capture the complexity and diversity of real-world film production settings. These environments were not personalized to individual users, which could influence the ecological validity of our findings. Future studies should examine how personalized virtual environments impact learning outcomes to optimize VR applications for film production education.

Third, using of standardized avatars aimed to avoid potential biases related to avatar appearance. However, this approach may have limited our understanding of how avatar personalization affects users' sense of embodiment, engagement, and learning effectiveness. While prior research has explored the role of personalized avatars in relation to appearance, gender, and ethnicity [15], future research should further investigate how these factors specifically influence learning outcomes in virtual film production tasks. Additionally, including nonbinary avatars could provide deeper insights into how users of diverse identities perceive embodiment in VR [52]. Moreover, we only examined individual and team-based learning modes in isolation. Future work could explore hybrid models or dynamic switching between modes within a single task. Investigating how flexible collaboration strategies affect cognitive load and learning effectiveness could offer valuable insights into optimizing learning experiences in complex creative environments.

Furthermore, the reliance on self-reported data, such as the NASA-TLX questionnaire for measuring cognitive load and frustration, introduces the possibility of subjective bias. Participants may overestimate or underestimate their workload or frustration due to factors such as recall inaccuracy or social desirability bias. Future studies should consider complementing self-reported measures with objective data, such as physiological indicators (e.g., heart rate variability, eye tracking) or behavioral metrics, to provide a more comprehensive assessment of cognitive load and emotional responses during VR learning tasks.

6 Conclusion

Our study examined how different virtual environments and learning modes shape students' mastery of film lighting in VR. Through the two experiments, we identified key factors that influence learning outcomes, cognitive load, and collaboration. Our results demonstrated that while team-based learning in structured environments like the baseline studio and office significantly reduced frustration and improved collaboration, individual learners excelled in more challenging and novel environments, such as the beach. This interaction between environment and learning mode suggests that VR educational tools must carefully balance environmental complexity with task difficulty to optimize learning outcomes. Importantly, our findings contribute to the broader discussion on the role of virtual environments in creative disciplines, revealing how unconventional settings can foster engagement and creativity, albeit with a higher cognitive load. This study underscores the need for further research into adaptive VR systems that support both individual and collaborative learning while managing cognitive challenges. By providing practical insights into the design of VR educational tools, we hope to guide future developments that cater to the diverse needs of film production students and other creative fields. As VR technology continues to evolve, integrating tailored environments and learning modes will be crucial in enhancing the efficacy of virtual education. Future work should explore more varied environments and learner populations to ensure the generalizability of these findings, while also refining adaptive strategies to balance immersion, cognitive load, and learning outcomes.

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