Feeling Present! From Physical to Virtual Cinematography Lighting Education with Metashadow

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ABSTRACT

The high cost and limited availability of soundstages for cinematography lighting education pose significant challenges for art institutions. Traditional teaching methods, combining basic lighting equipment operation with slide lectures, often yield unsatisfactory results, hindering students' mastery of cinematography lighting techniques. Therefore, we propose Metashadow, a virtual reality (VR) cinematography lighting education system demonstrating the feasibility of learning in a virtual soundstage. Based on the presence theory, Metashadow features high-fidelity lighting devices that enable users to adjust multiple parameters, providing a quantifiable learning approach. We evaluated Metashadow with 24 participants and found that it provides better learning outcomes than traditional teaching methods regarding presence, collaboration, usability, realism, creativity, and flexibility. Six experts also praised the Metashadow's expressiveness and its learning outcomes. Our study demonstrates the potential of VR technology to enhance cinematography lighting education while imposing a smaller cost burden and space requirement.

CCS CONCEPTS

• **Human-centered computing** → **Virtual reality**; **User studies**.

KEYWORDS

Presence, Virtual Reality, Cinematography lighting, Learning Effect, VR Education, VR Creativity

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1 INTRODUCTION

On-site training is essential to teaching students in the lectures on cinematographic lighting [48] since students acquire not only hands-on experiences and instructions of technical and artistic aspects. Nonetheless, teaching cinematographic lighting can be limited by expensive industrial-grade equipment or the unavailability of professional-grade studio space. It is important to note that the traditional approach to teaching cinematographic lighting is the standard PowerPoint courseware, with limited accessibility to the physical studio for practising fundamental lighting fixture operation [14, 51]. The learning effectiveness of cinematographic lighting diminishes due to the lack of equipment and studio. For instance, students and teachers are limited to oral discussions and lectures with visual illustrations supported by Microsoft PowerPoint in the classroom, which also impedes the desired training results. Although the instructional model includes a genuine training component, significant differences exist between fundamental lighting fixtures and lighting equipment used in the film industry. The teaching paradigm utilized by most art institutions has impeded students' ability to master cinematography lighting techniques, resulting in unsatisfactory teaching outcomes and practicality [14]. It is necessary to reconsider alternative mediums to reach industry-grade resources for student learning.

Therefore, we introduce Metashadow, a highly realistic simulation driven by Virtual Reality (VR) which is a virtual film studio for supporting teaching cinematography illumination. Its immersive environments and tasks are based on a framework of presence theory for cinematic lighting. The learning modules of Metashadow aim to improve spatial presence, involvement, and realism to enhance students' learning. Figure 1 illustrates our system, which targets to build an immersive and present environment to assist cinematography teaching and learning without physical equipment and studios.

Two layers comprise the system of Metashadow. The first layer of the virtual studio contains a user login window and a pre-training model of lighting fixtures. When the user enters the second layer of

Figure 1: Metashadow's cinematography lighting education.

the virtual studio via the login window, the film lighting teaching training officially commences. In the virtual studio, students have access to a variety of high-simulation lighting equipment and film cameras, and they can learn more quantitatively about film lighting techniques with the help of visualization tools that precisely control multiple parameters such as light intensity, colour temperature, angle, range, and other indicators. We recruited 24 participants to evaluate the difference in learning outcomes between Metashadow and PowerPoint lectures on film illumination. Metashadow outperformed traditional PowerPoint lectures regarding immediacy, creativity, and many other metrics. Our contributions are as follows:

- We develop a virtual reality (VR) simulation for teaching cinematography lighting that considers the impact of immersion on learning outcomes, creativity, and the distinctions between traditional teaching models.
- We use the presence theory to improve learning outcomes and the system facilitates teaching by alleviating the constraint of costly and limited venues. Metashadow serves as an alternative to PowerPoint in teaching cinematography lighting.
- After our evaluation with 24 participants and six experts, the participants praised the usability of Metashadow, and experts validated the expressiveness of the learning outcome via our system.

2 RELATED WORKS

Our related work consists of three parts: education in VR scenarios, PowerPoint lectures versus virtual reality simulated lectures, and the creative nature of VR.

2.1 Education in VR Scenarios

Virtual reality (VR) simulation is a technology that replaces or enhances the senses of the physical world with a near-real experience that reproduces the actual sensations of the physical world in various types of interactions [37, 39]. Learning modules with VR simulation have now been shown to benefit learning [22, 33], stimulating students' motivation and other cognitive abilities. Integrating various forms of film and stage lighting design into the narrative of virtual environments creates a positive experience for the audience. Driven by VR environments, art creators of film lighting summarised the film lighting guide for the characteristics and specifications of lighting [2]. VR simulations are advantageous compared to the high costs and hazards associated with traditional and cinematic lighting training. Virtual studios can save training costs or reduce the risk of accidents associated with the training session in physical venues [33, 41]. In addition to practical exercises, traditional teaching in the field of cinematographic lighting is primarily based on monographs [23, 34], periodicals [15], interviews, and numerous case studies combined with multimedia tools such as PowerPoint. Although the literature is abundant on cinematography and lighting [10, 11, 13], to the best of our knowledge, only a few studies teach training on theories of soundstages in digital environments. In contrast, we are the first work that examines the effects of multimedia teaching of film lighting using virtual reality (VR) simulations.

2.2 PowerPoint Lectures versus VR

The significance of PowerPoint (PPT) in higher education is a result of its widespread use by students and instructors since 2000 [35]. However, as the use of PowerPoint in education has increased, more and more issues have emerged. Ding et al. found that PPT instruction neglects student interaction and participation. It also decreases instructor improvisation in the classroom. Additionally, too many images unrelated to the task's objective hinder student comprehension [50]. Also, in 2000, a study by Antonietti et al. introduced VR simulations into art education scenarios for the first time. They found that students who received VR instruction could better describe and comprehend paintings [6]. It is also important to note that realism and learner interaction is essential to VR simulation instruction [16]. Jones et al. noted that, unlike traditional learning methods, VR simulation instruction could engage students by enhancing instructional content that interests them [29]. Lee et al. investigated VR simulation in two college disciplines, botanical medicine and ecotourism [21]. More evidence has shown that VR simulations outperform PowerPoint lectures regarding student engagement, interaction, and comprehension. Our work concentrates on utilizing VR simulations to improve the interactivity and engagement of students in the context of lighting learning for cinematography.

2.3 Creative Nature of VR

Creativity, which is defined as a "useful novelty" [18], is an important research topic in the design education community, and recent research has increasingly concentrated on the effects of VR on creativity [3, 19]. Due to VR's capacity to emulate the actual world, the valuable novelty of VR results in a greater increase in knowledge [47]. Zhou et al. discovered that VR-enabled learning technology could facilitate effective teacher-student interaction, allowing students to improve their design knowledge and be more inclined to devote more time to practice [54]. VR instruction in professional fields provides knowledge that enables users to acquire more skills on-site, resulting in new creativity and problem-solving abilities. This creativity continues to grow due to VR training related to abstract concepts and professional fields [18]. In contrast, we also investigate the effect of VR film lighting instruction on students' creativity in this dimension.

3 PRESENCE

The presence or Liveness theory refers to the extent of actual life represented by physical mediums and social environments. Users experience a sense of presence or liveness in virtual reality due to the vividness and interactivity of the simulated environment, which significantly enhances the sense of realism [44]. According to Schubert et al.'s study, the sense of presence consists of three components: spatial presence, involvement, and authenticity, corresponding to the user's perception of virtual reality [42]. Numerous studies on VR learning have demonstrated that presence [1, 5, 31, 45] is crucial for evaluating learning effectiveness or its process factors. To conclude the instruction of cinematic lighting using a virtual studio, we developed Metashadow, a VR teaching system model with a strong sense of presence based on the theoretical framework of presence. Spatial immersion refers to a student's capability to experience "immersion" [43]. In Metashadow, we designed the scenes based on the principle that the visual and auditory senses of the scene completely simulate the natural environment, such as the choice of the studio environment with a sense of aged material mapping and the colour temperature and brightness of the lighting fixtures on the studio's roof. Our work intends to signify that we have a variety of illumination configurations and adaptable, creative content to increase students' interest and focus in the virtual studio. Metashadow demonstrates the viability of collaborative multi-user learning of film lighting in a virtual studio that suits complex lighting design.

4 METASHADOW

Figure 2: Metashadow Features

The realm of cinematography and lighting presents a fascinating domain where scholars are still in the process of unravelling the most effective methods to harness the potential of virtual reality as an educational tool for lighting courses. Based on the presence theory, this section describes the system design of Metashadow (Figure 2).

4.1 System Design under a Sense of Presence

Numerous studies have demonstrated the crucial role of presence in virtual reality (VR) and VR learning to assess learning outcomes. Based on the theoretical framework of presence, we designed a highly immersive VR teaching system named Metashadow. It employs a virtual studio for cinematographic lighting instruction. Notably, the spatial presence of Metashadow allows students to feel immersive in the environment [24]. At the same time, its accurate simulation of realistic environments and "naturalism" are essential in VR learning [40].

In Metashadow, we have fully implemented the design principles of "naturalism" at the visual level of the scene. We selected material textures that conform to a unified visual reference for a specific era, and applied them to objects, such as the studio, lighting, cameras, and scene models. Regarding involvement, we provide various lighting fixtures (e.g., Tungsten luminaires, LED luminaires, Daylight luminaires) and multiple prop models for learners. Real-world cinematographic lighting typically involves a combination of various lighting fixtures to illuminate a scene. The creative content can be adjusted according to the instructor's teaching requirements, changing the models and props within the scene. This diverse selection of lighting fixtures, combined with flexible creative content, enhances students' interest and attention in the virtual studio. Realness is derived from the learning activities within the virtual studio, which adhere to the methods used in the physical world as much as possible. This includes learners' movements and the actual operation of equipment.

4.2 Metashadow Interaction Pipeline

Accordingly, we summarize the interaction pipeline of Metashadow into three modules, with a demonstration video[1].

Spatial Presence The lighting design creates an environment where learners cannot distinguish between the virtual and real aspects of the studio and equivalent responses [30]. The overhead lighting fixtures in the studio have been designed to visually resemble those found in the physical world in terms of style and layout. Furthermore, learners can control the lighting switches (Figure 3 – (4)). The Unity engine offers robust capabilities for rendering lighting, enabling us to match the colour temperature, brightness, and operational modes of the real environment. Additionally, the proportion, material, and reflectance of various objects within the studio are designed to emulate the physical world.

Involvement Involvement Pipeline Module aids students in focusing on illumination learning by providing a user-friendly interface. Users can choose their teacher or student role upon entering the login screen, as illustrated in Appendix A: Figure 10 – (1). If the user selects the student role, they must enter the invitation code provided by the teacher to access the shared virtual environment, as shown in Figure 10 – (3). Within the Metashadow system, two types of virtual equipment and four lighting categories are available for users, as depicted in Figure 10 – (5a). A Dashboard appears automatically when the user approaches any lighting device to facilitate better interaction with the lighting controls. The Dashboard offers a variety of adjustable parameters. For the lamp type Light-1(Tungsten lamp), we have designed controls for adjusting the light intensity and illumination range, as illustrated in Figure 10 – (5b). In the case of the lamp type Light-2, we have developed controls for adjusting light intensity, illumination range, and RGB colour settings. This enables learners to freely generate desired lighting colours, as shown in Figure 10 – (5c), (8a), and (8b). If a student does not require a lighting device can be easily removed, as demonstrated in Figure 10 – (5d).

Realness Realness Pipeline Module is derived from the ability to generate and present scenes, experiences, and processes that closely resemble those in the physical world. The realness can be further categorized into action realness and scene realness [17]. Action realness involves simulating a range of actions that individuals can perform in their real lives. In the context of virtual film lighting education, as shown in Figures 10 – (6) and (7), users manipulate the VR controllers, equipped with built-in sensors, by combining

[1]https://github.com/metartmirror/metashadow

the two buttons on the controller and the controller's pointer to select, grab, and move the target lighting equipment. Simultaneously, adjusting the angle of the lampshade panel follows the same procedure as moving the lighting fixtures, closely resembling the actions performed in real-world scenarios. Two sets of motion patterns have been designed for the user's movements. When physical space is limited, users can remain stationary in the virtual environment and control the direction using the left controller's remote sensor. The 'G' buttons on both left and right controllers enable instantaneous movement to the point indicated by the controller's pointer. If the physical space is sufficiently large, users can define a safe operating zone, and their movement in the virtual environment will be synchronized with their real-world movement. We have established a user training environment to help users adapt to our operating mode. Ample lighting and a clean environment enable users to discern the operating steps.

4.3 Metashadow Teaching Design

Teachers and students enter the Metashadow system and interact with each other. Although the system supports individual or collaborative learning in a virtual photography studio for practising film lighting, the course outline is designed for a multi-person collaborative teaching mode to maintain consistency in the course content. That is, the mode contains one teacher who guides multiple students. The first author has received formal training in film photography lighting and has been engaged in film photography lighting creation for five years. While selecting the film lighting course outlines, the author searched for publicly available film lighting course outlines on the Internet. After thoroughly examining, the author confirmed one film lighting teaching outline designed for traditional PPT teaching. To ensure that the chosen film lighting teaching outline can be used in both traditional teaching scenarios (i.e., traditional classroom with illustrations by PowerPoint) and Metashadow teaching scenarios supported by virtual reality, the author modified the outline while maintaining the same course content and duration, adapting it to the characteristics of Metashadow.

Before the formal lecture, the teacher will provide a detailed introduction to the operation of the VR controllers and the usage of various function menus, and allow students to complete self-directed navigation under the teacher's supervision. This warm-up session takes around 5–10 minutes and is not counted in the total course teaching time.

Once the formal lecture begins, a 55-minute session will proceed according to the designated film lighting course outline. The session is divided into the following five parts, as follows. Part I (8 minutes) introduces the lighting equipment, introducing the two built-in lights in Metashadow, Light 1 and Light 2, which correspond to tungsten and LED lights in the real world. The teacher will explain the functions and features of the various parts of the lighting equipment and the differences between real and virtual operation, as well as provide students with specific usage scenarios and the advantages and disadvantages of these lights.

Part II (approximately 15 minutes) introduces four characteristics of lighting, which are the direction of illumination (source of light, such as top lighting), quality of illumination (e.g., soft light vs hard light), light source (e.g., key light or fill light), and colour (e.g., cool light). The instructor demonstrates these four lighting characteristics to the students using the virtual lighting equipment in Metashadow. At the same time, students observe the instructor's lighting operations. Subsequently, the instructor introduces a core concept called 'lighting ratio' — precisely controlling the relationship between the key light and fill light on a subject's face. The concept is crucial for cinematography lighting. Cinematographers can create a rich and nuanced range of contrast in their frames by adjusting the lighting ratio in different frame sections. The audience receives visual perception resulting from differences in brightness and contrast. This is essential as controlling the lighting ratio can produce immediate impressions and expressive effects [25]. The instructor will demonstrate the visual differences of 8:1, 4:1, and 1:1 lighting ratios to the students using two Light-1 fixtures on a cylindrical plaster model, see Figure 3 – (1).

Part III (12 minutes) introduces five types of light direction and the related application scenarios mentioned in Part II, including Frontal light, Sidelight, Backlighting, Underlighting, and Top lighting. After receiving the teacher's guidance and demonstration, the students are asked to work in pairs to practice Light 2 in Metashadow and further create Frontal light on a plaster portrait model, see Figure 3 – (2). Part IV (5 minutes) introduces the light sources mentioned in Part II, specifically covering High-key light, Low-key light, Key lighting, and Fill light [49]. This part explains how these light sources are generated and their specific application scenarios. The teacher explains and demonstrates the key-lighting effect during this part, as depicted in Figure 3 (3). Part V (15 minutes) introduces the lighting colours, including warm, cool, white, and coloured lighting. The teacher demonstrates all colour lighting examples and introduces the definitions and effects of each colour light. Then, the teacher arranges a pair of students as a team. Each team operates a Light-2 lighting device to create a coloured lighting scheme on a plaster bust collaboratively. The teacher will select a group of students' lighting schemes to review and critique, see Figure 3 (4).

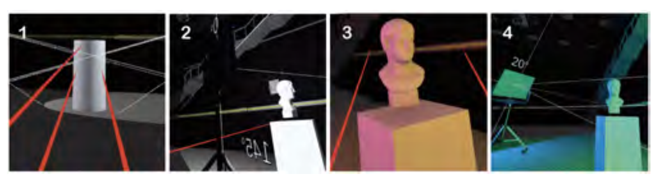

Figure 3: Metashadow's Demonstrations: (1) The instructor showcases (1) a 1:1 lighting ratio and (3) key lighting techniques. Student pairs work collaboratively on (2) frontal lighting effects and (4) creative coloured lighting.

4.4 Implementation

To experimentally assess the usability, pedagogical effectiveness, and creativity of Metashadow, we implemented the system in Unity and integrated it with Unity's multiplayer networking for communication among multiple users. The Unity multiplayer networking enables the application to transmit spatial information of various virtual objects and world data to all users for synchronization. One user creates a room as a host. A join code is generated and provided to other users to enter the same room for the task. The lights' position and status are shared and synchronized with all users. Additionally, Blender creates scene models. The source code is available at https://github.com/metartmirror/metashadow.

5 EXPERIMENTAL DESIGN

This section details our experimental protocol based on the developed system.

5.1 Participants

We recruited 24 participants (13 M, 11 F) from the university campus, aged between 18 and 40 years ($\bar{M}$ = 19.83, SD = 22.37). Half were randomly selected to participate in the traditional teaching method (with PowerPoint (PPT), i.e., the baseline). The rest were trained in the virtual environment, i.e., Metashadow's film lighting learning. Additionally, all participants own good eyesight or corrected vision. Among the 12 participants in the PPT mode learning, 6 had prior experience with virtual reality (VR) devices, and the remaining six did not have any experience with VR experiences. In contrast, among the 12 participants with Metashadow, 9 out of them had prior experience with VR devices. Participation was voluntary, and the university's institutional review board approved the experimental protocol. Upon completing the experiment, a monetary incentive of $10 USD was provided to each participant.

5.2 Experimental Procedures

To assess the functional and educational performance of Metashadow against the traditional classroom (PowerPoint, PPT) for the teaching of cinematographic lighting, we performed user evaluations in both the Metashadow (as stated in Section 4) and PPT conditions, as illustrated in Figure 4 –(1) & (2). Both conditions utilize the cinematographic lighting course curriculum validated by related experts. Twelve participants used Metashadow for virtual cinematographic lighting, whereas 12 used PPT. Except for the difference in teaching medium, the course content, exercises, and other material were identical under the cinematography lighting course syllabus. The Metashadow students will have a 5-10 minute VR instruction before the course to guarantee their familiarity with VR equipment.

The teaching condition is divided into two: The first is PowerPoint (PPT) based teaching that is a comprehensive presentation developed in alignment with a course outline[2], which encompasses detailed textual explanations and illustrative image examples for each knowledge point. The duration of each section of the course adheres strictly to a designated teaching schedule. The teacher employs vivid and concrete language and corresponding visuals in the PPT to elucidate the various lighting effects, and impacts delineated in the outline. The fifth section of the course entails collaborative learning. The teacher divides students into groups of 2, as per the course outline's predetermined schedule. The students are asked to make creative solutions for lighting design. Every student group is selected to present their corresponding lighting design orally, and the teacher will provide feedback accordingly. In contrast, the condition of Metashadow refers to Section 4.3.

[2]https://www.matrix.edu.au/film-techniques-lighting/

Figure 4: Cinematography Lighting Course: (1) PowerPoint lessons, and (2) Metashadow.

Afterwards, all participants were required to complete two tests (Tests 1 & 2) to assess their learning efficacy. To ensure comparable results, participants with both conditions (PPT and Metashadow) are evaluated in physical tasks (Tests 1 & 2). The only difference is that the participants, under two conditions, received different teaching mediums, either VR or physical lecture with PowerPoint, before the physical tasks.

Test 1 is a light ratio task, which could evaluate students' understanding and control of the lighting for cinematography. It is computed quantitatively to assess the effectiveness of students' learning after the teaching session, either Metashadow or PPT. In a physical environment, every participant had five minutes to create a lighting design with a plaster bust using two 650W tungsten lamps. The required lighting ratio for the bust was 4:1, where the lighting ratio is measured by a professional light meter to obtain exposure value (EV), see Figure 5 – (1) & (2a). EV is a numerical representation of camera exposure, determined by the combination of aperture, shutter speed, and ISO settings. The unit of EV is "stops" which represents a doubling or halving of light value, e.g., +1 EV represents a doubling of light [38], or vice versa. We obtained the lighting ratio by reading the EV difference between the left and right sides of the plaster bust. A 4:1 ratio corresponds to an EV difference as a value of 2 (Figure 5 –(3a) & (3b)). We define a 3-level marking scheme – if the participants receive 2 points for achieving the 4:1 light ratio requirement. Completed work of either 2:1 or 8:1 light ratio within the time limits earns 1 point; otherwise, 0 points.

Test 2 refers to the expressiveness test to assess learners' performances [12, 26, 28]. It compares the ability of both Metashadow and PPT modes of instruction to improve student lighting expression. Each participant had 5 minutes to create a lighting design for the plaster bust that conveyed the concept of "Passionate." The participant can utilize the apparatus of two 650W tungsten lamps and green-, orange-, and blue-colour paper to accomplish the task. Using lamps was mandatory, while using colored paper was at the participant's discretion. Figure 5 (2b) illustrates a sample result. We invited six industry experts to score the works created by the participants. Experts 1, 2, and 4 were from the cinematography industry and had over five years of industry experience. Experts 3 and 5 were from universities, teaching cinematography and holding the title of associate professor. Expert 6 was a lighting designer from a film production company who participated in the lighting creation of several outstanding films and had more than eight years of industry experience. We customize our testing criteria: Six experts evaluated all students' work in a blind review process. They scored the lighting designs based on effectively conveying an abstract concept of "passion". The expert rating follows a 7-point Likert scale, ranging from (1) – "strongly disagree" to (7) – "strongly agree". Multiple scores given by the six experts are averaged to reduce biases. A student's work is considered to have passed the test if the average score exceeded 4, and to have failed the test if it was less than or equal to 4.

Finally, after the tasks, the participants were asked to complete a questionnaire regarding their learning experiences and hands-on exercise under two conditions. The questionnaire follows Likert 7-point scale (1: the worst, and 7: the best) and consists of 12 questions reflecting six dimensions: Presence, Collaboration, Usability, Realism, Creativity, and Flexibility, i.e., two questions per dimension.

Figure 5: Lighting tests, performed by a student (1), giving (2a) A sample answer of Task 1 results of Test 1 (light ratio of 4:1); and (2b) sample answer of Task 2. Light meter measuring EV on the right-hand (3a) or the left-hand (3b) sides of the plaster portrait during Task 1.

6 EVALUATION RESULTS

Based on the data of user performances and user feedback under two conditions, we quantitatively analyze students' learning outcomes to evaluate the effectiveness of Metashadow and PowerPoint (PPT) in cinematographic lighting education.

6.1 Test 1: Control of Light Ratio

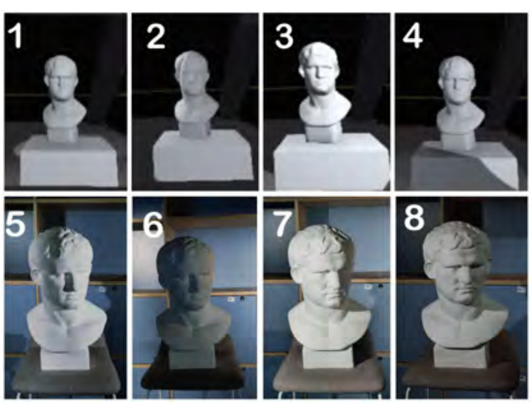

Figure 6: Sample Results of Task 1 – Light Ratio: (1-4) Training in Metashadow; (5-8) Testing in real environments.

Nine of the twelve participants with Metashadow passed the test ($\bar{M}$=1.75, SD=0.43). The tests were passed once a participant made the 1:4 lighting ratio and earned 1 point; otherwise, 0 points. In contrast, only five participants with PPT passed the test, revealed by the One-way ANOVA ($\bar{M}$=1.17, SD=0.80). We conclude that Metashadow delivers more effective learning content of cinematographic lighting than PPT ($F_{1,22}$ = 4.529, p <0.05). Metashadow can be employed in daily training in cinematographic lighting due to its teaching effectiveness. Figure 6 depicts the visual effects of lighting training in the Metashadow environment (sub-figures 1 – 4), in comparison to the light effect in real scenes correspondingly (sub-figures 5 – 8). These scenes demonstrate visual similarity, potentially paving a path of leveraging virtual environments and eventually replacing some realistic scenes for teaching cinematographic lighting at scale.

6.2 Test 2: Expressiveness

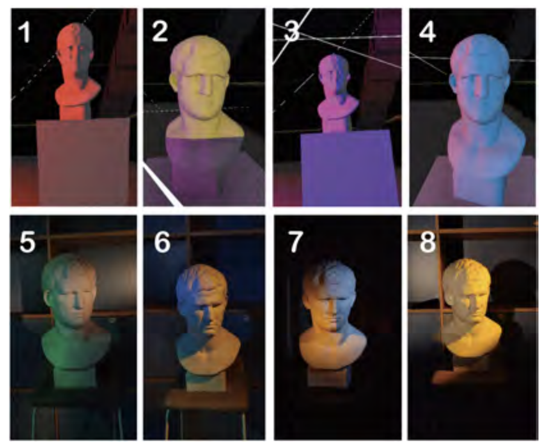

Figure 7: Sample Results of Task 2 – Expressiveness: (1-4) Training in Metashadow. (5-8) Testing in real environments.

Figure 7 illustrates the visual effects of Metashadow to demonstrate object expressiveness, compared to the physical scenes: (Sub-figures 1 – 4) visualize Metashadow, while (Sub-figures 5 – 8) are the corresponding real scenes in the physical environment. All 24 participants completed Test 2, and we evaluated their expressiveness after the learning sessions. The results, scored by the six experts, showed that seven participants with Metashadow ($\bar{M}$=4.24, SD=1.22) achieved 4 points or above (7-point scale). In contrast, only five participants with PPT ($\bar{M}$=3.61, SD=1.34) achieved 4 points above. As shown in Figure 8, Metashadow has a slightly significant advantage over PPT in terms of expressiveness, supported by the One-way ANOVA ($F_{23,120}$ = 6.649, p <0.001). We found that participants who learned in Metashadow had better learning outcomes than those who learned in the traditional classroom (i.e., PPT). As such, participants who used Metashadow better understood cinematographic lighting and thus used the skills in their creativity tasks with stronger expressiveness.

6.3 Questionnaire Results

Figure 9 depicts the results of six dimensions (equivalently twelve questions) under two conditions. We performed Mann-Whitney U Test to compare the mean differences between the MetaShadow

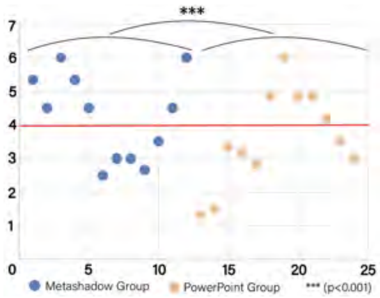

Figure 8: Test scores for Expressiveness, rated by the six experts: X-axis: Participant IDs, and Y-axis: score.

and PPT groups on all results. We report the detailed results of the questionnaire as follows.

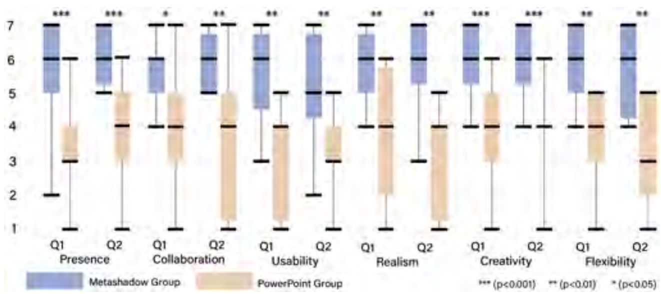

Figure 9: Participants' ratings on Presence, Collaboration, Usability, Realism, Creativity, and Flexibility, ranging from 1 (Strongly Disagree) to 7 (Strongly Agree).

Presence As for the sub-question (Q1) '*I could feel like I was there to operate the lights*', we observe a significant difference in the two conditions (U = 15.5, p <0.001). The participants with Metashadow showed a greater sense of immersion in the scene ($\bar{M}$=5.67, SD=1.37) than the traditional PPT mode ($\bar{M}$=3.25, SD=1.30). This means Metashadow's course module offers an immersive experience emulating lighting operations. The sub-question (Q2) '*I could feel the environment as if I were in the studio*' also aligns with the above, with statistical significance being observed (U = 11.5, p <0.001). The higher level of environment immersion provided by Metashadow's cinematography studio ($\bar{M}$=6.08, SD=0.76) can better facilitate students' learning than the PPT counterpart ($\bar{M}$=3.83, SD=1.40). We summarize that the objects and environments of Metashadow and the corresponding instructions provide significant advantages over the traditional PPT teaching mode.

Collaboration The sub-question (Q1) '*I could communicate with teachers and students about the course content*' reflects an obvious difference (U = 36, p <0.05) among two conditions: Metashadow ($\bar{M}$=5.67, SD=0.94) and PPT ($\bar{M}$=4.17, SD=1.86). The sub-question (Q2) '*I could work with teachers and students to complete the task collaboratively*' reinforce the above by showing the statistical difference (U = 27.5, p <0.01) . Participants believed that Metashadow enables better collaboration between teachers and students ($\bar{M}$=5.83, SD=0.80) than PPT ($\bar{M}$=3.75, SD=2.00).

Usability The sub-question (Q1) '*I found the lighting instruction to be very functional*' demonstrates differences among two conditions (U = 21, p <0.01). Metashadow rated the lighting tutorial as more comprehensive ($\bar{M}$=5.58, SD=1.38) compared to those who used PPT ($\bar{M}$=3.25, SD=1.48). Metashadow ($\bar{M}$=5.58, SD=1.38) and PPT ($\bar{M}$=3.25, SD=1.48). indicating that Metashadow's film photography lighting instruction provides more detailed explanations of various lighting tools compared to PPT-based instruction. Regarding the sub-question (Q2) '*I would choose the same mode of course delivery*', the two conditions are differently performed (U = 27, p <0.01). Most participants with PPT expressed a negative attitude towards the traditional teaching mode for lighting instruction ($\bar{M}$=3.33, SD=1.25). In contrast, participants with Metashadow demonstrated a more positive attitude towards continuing to use it for cinematography lighting instruction ($\bar{M}$=5.17, SD=1.67). These findings imply that the usability of Metashadow made itself a promising instructional tool with a potential for large-scale implementation.

Realism The sub-question (Q1) '*I think this course is sufficiently realistic to help my operation of lighting equipment*' shows a difference significantly (U = 25.5, p <0.01). Participants with PPT ($\bar{M}$=3.75, SD=1.83) and Metashadow ($\bar{M}$=5.83, SD=0.90) achieved varied understandings of operating lighting equipment. The difference is primarily due to different learning mediums. The sub-question (Q2) '*I think this course content is true to help understand lighting*' also indicates a significant gap between two conditions (U = 25.5, p <0.01). The participants with Metashadow feel an authentic understanding of lighting ($\bar{M}$=5.92, SD=1.26), whereas those who learned through PPT did not think that the course could offer an authentic understanding of lighting ($\bar{M}$=4.25, SD=1.48). These findings suggest that, compared to PPT, Metashadow has a significant advantage in helping learners to understand the real-world aspects of cinematography lighting.

Creativity The sub-question (Q1) '*I can focus on teaching scenarios to stimulate my creativity*' reflects that the participants believed that Metashadow could help them focus more on the teaching scenario and thus enhance their creativity ($\bar{M}$=6, SD=0.91). On the other hand, participants with PowerPoint had mixed opinions regarding the issue of whether it could enhance their creativity by focusing more on the teaching scenario ($\bar{M}$=3.92, SD=1.44). The findings indicate that Metashadow triggers more consistent outcomes than PPT (U = 17, p <0.01). Another sub-question (Q2) refers to '*I can leverage changes in lighting to design creative lighting effects*'. Participants with Metashadow ($\bar{M}$=6, SD=1.08) show better adaptability when dealing with creative tasks than PPT ($\bar{M}$=3.92, SD=1.11), with significant differences (U = 15.5, p <0.001). Participants with PPT found it difficult to design creative lighting effects using light variations after the lesson.

Flexibility The sub-question (Q1) '*I feel confident of changing the lighting configuration and estimate the effects*' indicates that the participants with Metashadow manage to change the light after the teaching session ($\bar{M}$=5.93, SD=1.11). At the same time, the counterpart of the traditional classroom poses a relatively negative view ($\bar{M}$=3.83, SD=1.28). The result implies that Metashadow is more flexible than traditional teaching (U = 18, p <0.01). Another sub-question (Q2) refers to '*I can change the lighting at will*'. Participants with Metashadow ($\bar{M}$=5.75, SD=1.16) made a higher sense of agency than the counterparts of PPT ($\bar{M}$=3.33, SD=1.37), demonstrating statistical significance (U = 15.5, p <0.01).

7 CONCLUSION AND DISCUSSION

This paper presents a virtual cinematography lighting teaching system named Metashadow, which provides an inexpensive, convenient, and highly realistic way to teach cinematography lighting. The experimental system of Metashadow serves as evidence demonstrating that virtual environments are an appropriate medium for cinematography teaching. Users can achieve better learning results and better performance in creativity and expression. The following paragraphs discuss the lessons learned and limitations.

7.1 Towards Virtual Education to Film Making

Previous research has explored the potential of virtual reality (VR) in various fields, such as primary school 3D art courses [9], medical education and treatment [8], and digital art creation experiences [4]. Building upon this prior work, our study investigates the integration of vocational and art education, expanding the application of VR in film art education. Specifically, Metashadow is designed to assist students in learning and mastering professional techniques in cinematography lighting, achieving outcomes that align with those of real-world cinematography studios. The immersive learning environment of Metashadow enables students to immerse themselves in the learning scenario and focus on the professional knowledge of cinematography lighting. Additionally, the collaborative working environment of real cinematography lighting scenarios can be accurately reproduced in Metashadow. Our experimental results demonstrate that Metashadow has clear advantages in terms of usability and flexibility. Moreover, it exhibits high universality and synergy in terms of collaboration, which can help learners build confidence in their learning. These advantages can result in better learning outcomes for learners in virtual courses [7, 36, 46].

7.2 VR for Understanding Abstract Content

Cinematography lighting is a highly abstract subject matter that requires significant effort to comprehend [10, 52]. In traditional cinematography lighting education, teachers typically use pictures and descriptions to introduce lighting characteristics, such as adjusting light angles. However, they often avoid providing specific numerical values and instead rely on vague instructions like "higher" or "lower," making it difficult for students to grasp how to manipulate lighting effectively. Additionally, students may struggle to understand lighting intensity despite the detailed picture explanations offered by their instructors, as the information provided may be limited and not accurately reflect reality, as evidenced by the findings from Test 1. We discovered that Metashadow could assist students in comprehending cinematography lighting from six aspects. For instance, Metashadow employs various annotations to visualize abstract lighting dimensions, such as light color temperature, range, and intensity, which are challenging to perceive intuitively. Metashadow's unique designs enhance lighting visualization by incorporating auxiliary light lines, light intensity adjustment panels, and light RGB color adjustment panels, making it easier for students to understand complex and abstract concepts. The experimental results of Test 1 on light ratios demonstrated that Metashadow's effective auxiliary teaching visualization designs in virtual reality improved learning outcomes. By leveraging technology, virtual reality can simplify abstract and obscure content, making it more accessible to learners. Moreover, expert evaluations of Test 2, which involved abstract expressive testing, recognized the efficacy of VR teaching. These findings underscore the need for further research on the potential benefits of Metashadow and explore its potential as a widespread teaching tool in the film industry.

7.3 User Feedback and Potential Improvements

All participants in our study praised the usability of the Metashadow system. However, we also identified some issues during the study. The most common issue was insufficient accuracy in grasping virtual lighting fixtures, which led to failed grasping attempts. Nevertheless, as participants became more familiar with the system's operation, the frequency of failed grasping attempts decreased. In future iterations of the system, we plan to redesign the grasping logic and increase the recognition range to improve the accuracy of object grasping. Some participants suggested introducing a set of virtual avatars to the system, which would enable participants to interact more effectively within the virtual environment [20, 32]. Currently, participants have only a subjective point of view and cannot see themselves, but they can see the teacher and other participants. Introducing virtual avatars could enhance the teaching experience [27]. Furthermore, some participants expressed dissatisfaction with the lighting accuracy in the system. They believe that real-time rendering of lighting effects, similar to those in the physical environment, could significantly improve the overall teaching experience. However, the limited computational power of the system currently restricts the real-time rendering of lighting effects.

7.4 Generalizability of the VR Education System

This work focuses on exploring the effectiveness of the VR education system compared with traditional PPT education for teaching cinematography. The study results suggest that the VR education system can effectively teach various concepts in various disciplines. However, it is crucial to consider the generalizability of the findings and the potential limitations of the virtual education system [53]. To increase the generalizability of the findings, further research is needed to fully explore the advantages and limitations of VR technology for teaching various aspects of cinematography beyond lighting, such as camera work and composition. Furthermore, the potential of VR technology for creating immersive and interactive learning environments could be further investigated to provide students with a more personalized and engaging learning experience. Incorporating real-time feedback and assessment into VR instruction could enhance the system's effectiveness. Additionally, exploring the use of VR technology in collaborative learning environments, where students can work together in virtual spaces to develop their skills and solve problems, could provide valuable insights into the potential of the VR education system.

A ADDITIONAL INFORMATION

An introduction to Metashadow's operating procedures.

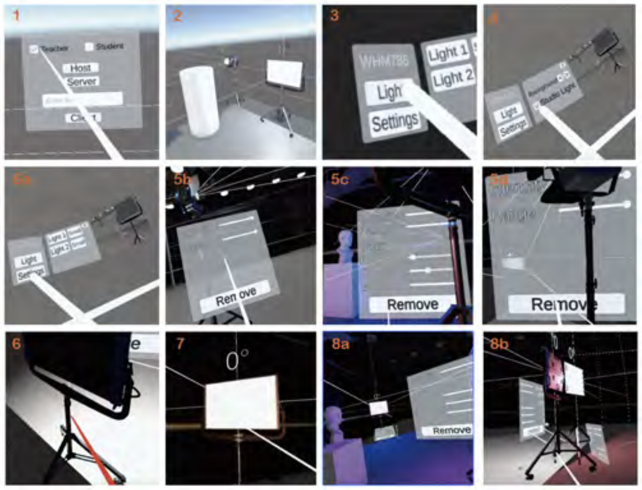

Figure 10: The Metashadow's environments and experience for educators and learners: (1) login page & role selection; (2) user training; (3) invitation codes to initiate sessions; (4) control over sound and lighting (on or off); (5) a lighting control panel for types of lighting fixtures, such as 2nd-gen and 4th-class lights – users can (de-)activate or remove the lighting fixture from the panel. (6) The placement of lighting fixtures by drag-and-drop, & a guideline indicates the bottom of the lighting fixture. (7) Adjust the angle of lighting fixtures by rotation, & a guideline indicates the lighting panel. (8) Modifying colour (RGB), brightness, and lighting range.

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