Transforming Cinematography Lighting Education in the Metaverse

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Abstract

Lighting education is a foundational component of cinematography education. However, many art schools do not have expensive soundstages for traditional cinematography lessons. Migrating physical setups to virtual experiences is a potential solution driven by metaverse initiatives. Yet there is still a lack of knowledge on the design of a VR system for teaching cinematography. We first analyzed the educational needs for cinematography lighting education by conducting interviews with six cinematography professionals from academia and industry. Accordingly, we presented *Art Mirror*, a VR soundstage for teachers and students to emulate cinematography lighting in virtual scenarios. We evaluated *Art Mirror* from the aspects of usability, realism, presence, sense of agency, and collaboration. Sixteen participants were invited to take a cinematography lighting course and assess the design elements of *Art Mirror*. Our results demonstrate that *Art Mirror* is usable and useful for cinematography lighting education, which sheds light on the design of VR cinematography education.

Keywords:
Education; Learning; Virtual Reality; System; Cinematography Lighting

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1. Introduction

Since 2021, the metaverse has become a popular term describing many types of virtual worlds (Augmented Reality and Virtual Reality) connecting together that potentially construct the next Internet of immersive environments featured with realism, a sense of presence, and multi-user collaboration Lee et al. (2021); Zhao et al. (2022). The metaverse can provide diversified functions and venues similar to our physical worlds, and users could gain immersive experiences through mobile headsets. Among many functions, education can potentially become a significant application domain in the metaverse for improved learning contents Rajaram and Nebeling (2022), authoring Zhang and Oney (2020); Nebeling et al. (2020), sketching interactive material Suzuki et al. (2020), storytelling Liu et al. (2022); Bahng et al. (2020), and pedagogy with virtual agents Petersen et al. (2021). In particular, the development of the metaverse through the use of augmented and virtual reality technologies brings new possibilities for the teaching and learning of science-related disciplines on smartphones like mathematics[1], physics[2], and chemistry[3]. In addition, some headset applications focus on arts and creative content, such as painting[4] and instrument playing[5], where students can expose to the artistic contents easier than ever before.

Soundstage lighting is one of the fundamental courses in cinematography[6]. It refers to the methodical instruction of physical modifications to lighting effects in order to generate the desired effects during filmmaking Brown (2016). Lighting is important because it helps convey information, show emotions, and affect the tone and style of the work Millerson (2013). However, the high expense of soundstage spaces and equipment (e.g., lightning devices) has hindered cinematography education for people with interests. In particular, we highlight the pain points of operating physical soundstages as follows. In addition, even if a soundstage is accessible inside the school, students must undergo a lengthy booking and waiting period before they may utilize it. Physical soundstages require manpower for a great deal of heavy lifting, which adds extra time and effort to the learning process. Moreover, since every student is different and learning about lighting requires repeated observation and practice, physical soundstages cannot meet their personalized learning needs.

Virtual scenarios in the metaverse can potentially serve as a solution for

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[1] https://apps.apple.com/us/app/ar-math-arithmetic/id1276691203

[2] https://play.google.com/store/apps/details?id=com.cg_physics.cg_physicsAR

[3] https://play.google.com/store/apps/details?id=com.petra.topher.chemistry&hl=en&gl=US

[4] https://www.oculus.com/experiences/quest/3106117596158066/

[5] https://www.oculus.com/experiences/quest/3907485762605933/

[6] https://academy.wedio.com/film-lighting/

alleviating the space and cost issues in cinematography education. Nevertheless, cinematography education in the metaverse is still an underexplored area, although we have witnessed that rapid progress is being made in the field of metaverse education. Cinematography education in VR environments has various design concerns, including interaction design requirements for teaching and learning. Rather than taking an opportunistic approach to establish a series of cinematography education modules, extra research effort becomes necessary.

Figure 2: *Art Mirror*, a virtual soundstage for lighting education (right), in contrast to a scene of physical soundstage (left). Two snapshots in the middle refer to the frame of a classic movie with lighting effects generated by physical (bottom) and virtual (upper, our solution) soundstages, respectively. The comparable effects between virtual and physical scenes demonstrate the *Art Mirror*'s ability to restore lighting effects in scenes for cinematography education.

To address these limitations, we especially focus on exploring the design of a VR system for teaching cinematography. This paper serves as a groundwork for collecting feedback from specialists and accordingly designs lighting training for cinematography education in the metaverse. To meet the need for a soundstage-based education dedicated to cinematography, especially for the foundational component–lighting education, we propose designing and developing a virtual soundstage for teaching and studying cinematography lighting. Our target users are students studying cinematography at universities who need to use the soundstage and university teachers who need to use the soundstage for teaching. We first interviewed six cinematography educators and professionals to elicit the requirements and challenges of soundstages for lighting education. On this basis, we present *Art Mirror*, a virtual reality solution for lighting education on a computer-mediated soundstage (see Figure 2) including a set of system design considerations. It is suited for soundstage teaching as pre-training courses in art schools and universities. Students can get a more intuitive understanding of lighting configuration and how lighting devices operate. *Art Mirror* can serve as a complementary learning material with education in physical soundstages. In particular, we designed the visual cues of lighting (i.e., ranges and directions) and shared them among instructors and learners, enabling swift discussion and effective learning by observing the illumination.

Finally, we recruited eight instructors and eight learners to evaluate *Art Mirror* by collecting their quantitative and qualitative feedback. Remarkably, the instructors agreed that the virtual soundstage might considerably reduce the difficulty of communicating abstract ideas about lighting settings and the resulting effects. Meanwhile, *Art Mirror* results in enhanced learning experiences and outcomes for learners on the effects of lighting and scene settings in the virtual soundstage.

The contribution of the paper is twofold. First, we design and implement a virtual soundstage for cinematography that enables instructors and learners to teach and learn lighting effects interactively and effectively. Second, we conduct a user study with 16 participants using *Art Mirror* to evaluate its usability, sense of agency, realism, presence, and collaboration. We further derive design implications from realism and quantitative measurements for lighting education. In particular, our evaluation demonstrates that the proposed virtual soundstage is usable and useful for lighting education.

2. Related Work

Virtual Reality (VR) based learning environments have been shown to be beneficial for education Kavanagh et al. (2017). It not only visualizes abstract concepts for students Youngblut (1998) but also allows students to access inaccessible or even "hard-to-reach" learning environments, such as history and solar system Freina and Ott (2015). Different VR applications have been investigated in higher education Radianti et al. (2020), construction Ogunseiju et al. (2021), medical Pottle (2019), and safety training Getuli et al. (2021). Our work is inspired and informed by prior work on *Lighting Education in Cinematography*, *Digital Learning and Education in VR*, and *Annotation and Communication in Immersive Environments*.

2.1. Lighting Education in Cinematography

First, we give a background of cinematography education and its relationship with lighting. Since the 1940s, academics have studied and documented the soundstage-based teaching of cinematic lighting Garrison et al. (1999); Mascelli (1965). In 1948, cinematographer John Alton's *Painting With Light* Alton (2013), an early tool for teaching lighting of lamps in the classical Hollywood period, served as a comprehensive instructional guide for American cinematographers in the 1950s. Even though it is no longer applicable, it nonetheless contains a lot of information for historians of classic Hollywood lighting methods.

On a technical level, *Film Style and Technology in the forties* Salt (1977) by Barry Salt gives a thorough chronological overview of the developments in lighting technology and the evolving notion of lighting in film, reserving records on the historical use of technology as a reference. In addition, the academic monograph by Sven Nykvist et al., namely *Making Pictures: A Century of European Cinematography* Nykvist et al. (2003), analyses an in-depth exploration of 100 films, including *Battleship Potemkin* (1925) IMDb (2022a), *The Blue Angel* (1930) IMDb (2022b) and others, in which the monograph highlights the analysis on lighting night settings, the role of the cinematographer, and commentary on the intricate details of the direction of photography. Other aspects include noteworthy technical aspects and commentary on the use of light, backgrounds, and mood, contributed by the well-known cinematographer Nick Vest.

On the other hand, considering a cultural level, the American scholar Patrick Keating's book – *Hollywood Lighting from the Silent Era to Film Noir* Keating (2009) documents abundant interviews and case studies about the characteristics of American cinematographers' lighting work in different periods and how those changes affected culture, as well as how people's ideas about lighting changed as culture changed. *American Cinematographer* of Cinematographers (2022), one of the most influential professional journals on cinematography today, contains a wealth of interviews with cinematographers and behind-the-scenes information on their films from 1920 to the present day, with numerous references to technical changes and trends relating to lighting.

Although a significant amount of literature on cinematography and lighting exists Brown (2014, 2016); Burum (2007); Landau (2014); Brown (2012); Millerson (2013), the teaching of cinematography lighting still primarily relies on monographs, journals, and other literature, in addition to the hands-on training on physical soundstages. This work opens opportunities for leveraging virtual reality for cinematography education. In particular, very little has been investigated in human-computer interaction and education.

2.2. Digital Learning and Education in VR

Traditional learning has been threatened by the shortage of high-quality learning materials and effective teaching instruments since the emergence of COVID-19. However, by the human-computer interaction (HCI) community Chen et al. (2021), for example, students may often suffer lower learning effectiveness as live streaming learning takes more time and lessened engagement and collaboration Higgins et al. (2012) as the learning environment shifts from a public location supported by multiple university facilities to a private place with fewer resources. Several strategies have been proposed by researchers to help instructors and students cope with the challenges of live streaming classes through computer agents and natural user interaction Winkler et al. (2020). As such, students could complete some learning modules and hands-on exercises, leading to benefits such as intrinsic motivation Zhang and Liu (2019), a better understanding of knowledge, engagement level Ma et al. (2022), and presentation skills Shoufan (2019).

Apart from traditional 2D interfaces, VR can serve as an excellent medium for delivering learning content, as VR owns unique features including Ego-referenced perspective, increased sensory, closed-loop interaction, dynamic rendering, and 3D immersion Wickens (1992); Speicher et al. (2019). Remarkably, most learners are not skillful at acquiring counter-intuitive and abstract concepts unless sufficient demonstration and hands-on exercise have been done. For example, Brelsford Brelsford (1993) created a physics simulator to help students get a deeper understanding of the physical process by putting them in a similar situation. In this simulator, one class was given a pendulum whose length they could adjust, as well as three balls of varying masses. During this hour-long experiment, students can change the variables for the pendulum. In contrast, another group of students, the control group for comparison, received a traditional classroom lecture on the same topic. An examination after four weeks demonstrated that students who had participated in the virtual laboratory had greater long-term retention than those who had participated in traditional lecture-based instruction. To a similar extent, Yalow and Snow Yalow and Snow (1980) found that providing students with visuals and maps of concepts, rather than solely words, enhanced their instant understanding. As a result, researchers have looked at the advantages of online education extensively.

Virtual environments can serve as a promising tool for teaching and learning Lieux et al. (2021). In addition, virtual reality has made substantial contributions to various pedagogical use-cases, such as managing a physical-chemical lab by interaction with a virtual lab Lu et al. (2021) and instructing students in physical geography via immersion in 360-degree videos Jong et al. (2020). Nowadays, virtual reality (VR) has numerous applications in the field of education and training. That is, surgical procedures, psychotherapy, and STEM education are just a few of the areas where virtual reality (VR) has proven useful because of the advancement in computing devices and the widespread availability of low-cost head-mounted displays (HMDs) Fabris et al. (2019). Nonetheless, it also has certain drawbacks that must be overcome Velev and Zlateva (2017). A prominent unfavorable factor is that people treat virtual reality as a leisure activity. The learning purpose of increasing students' knowledge and critical thinking abilities is sidelined as the students unavoidably focus on doing well in the interactive elements and game contents. In contrast, we extend the VR education to the area of cinematography, and explore how to design enriched and interactive tool for effective learning and teaching.

2.3. Annotation and Communication in Immersive Environments

Adding annotation and visual elements is a common practice to enhance communication effectiveness Kasapakis et al. (2021). Similarly, applications and services in virtual worlds require designated design considerations of annotations and communication cues to facilitate communication Piumsomboon et al. (2017). For example, virtual objects act as an indicator of user conversation and further visualize the balance (e.g., the conversation time taken by whom) of turn-taking conversation in virtual reality Li et al. (2022). Suzuki *et. al.* Suzuki et al. (2020) implemented RealitySketch to formulate a taxonomy for visualizing various properties of physics learning, *e.g.*, angle and distances between objects, facilitating people to reveal, explore, and analyze diversified physical phenomenons. Moreover, expressiveness, coherency, easier interaction with common devices, and adaptability drive the communication in remote demonstrations in which communication occurs between instructors and content viewers Chung et al. (2021). Accordingly, other variants, such as a pointer, signs supported by hand gestures, and simple sketches in mid-air, and their combined uses of communication cues can facilitate the instruction given by an instructor and hence the receiver's understanding (e.g., guidance from a remote expert to a local worker) Kim et al. (2019). Other non-verbal communication cues in virtual reality include the visualization of gaze (i.e., indicating the attention point in VR) Rahman et al. (2019), heart rate Jing et al. (2022), embodied avatars Jing et al. (2021), and haptic-driven touches Zhou et al. (2020) that effectively improve user communication and task collaboration in real-time.

Furthermore, 3D modeling and game engine tools, such as Blender[7], Unity[8], and Unreal Engine[9], employ visual cues and annotation as gizmos for visual debugging, aiding developers to setup the virtual scene like camera and lighting. It is important to note that these annotations are mainly used by individuals like developers and designers but rarely applied for communication between teachers and students.

It is still unknown whether the aforementioned visual cues and annotation could be beneficial for teachers to teach or students to understand the abstract concepts of cinematography in terms of camera configurations and lighting effects. Therefore, the research community should explore the use of annotation and communication for cinematography education in VR, given the success in prior work. Cinematography education leverages both advantages of using VR. First, soundstage, for students to learn scene preparation, is very expensive and space-consuming, which not many schools can afford. Second, cinematography involves abstract concepts, such as lighting angles, hard and soft lighting, and color. Following this line of research, our work aims to explore how VR can become more expressive for communication between learners and instructors in the context of cinematography education.

3. Expert Interview

In the formative stages of *Art Mirror*, we conduct in-depth interviews with six seasoned cinematography specialists, including academics, directors, and cinematographers. The primary purpose of the interview is to gather needs for building education modules on lighting configuration on a virtual soundstage, as such education modules are rarely studied in the literature.

[7]https://www.blender.org/
[8]https://unity.com/
[9]https://www.unrealengine.com/

3.1. Participants and Recruitment

According to the expertise and connection among the authors, the invitation was sent to the potential participants based on their relevance to both industry experiences and education programs in cinematography. The first author has about five years of film teaching experience, while the third author, a cinematographer, has about nine years of cinematography teaching experience. One-to-one contacts and invitations were made through email and phone connections with teachers and specialists in universities and industry sectors.

We used a saturation method Bernard and Bernard (2013) to determine the number of interviews with six specialists. The two authors analyzed the conversation after each interview, and they identified that many similar opinions repeatedly appeared after the sixth interview, which suggested that the views of specialists reached saturation. So we stopped inviting the next specialists and ended up interviewing six specialists who were representatives. Inspired by Krueger (2014); Lin and Van Brummelen (2021), we did our utmost to diversify the backgrounds of the specialists, as their backgrounds will impact how they see the requirements of virtual soundstages. As such, the six interviewees were from the U.S. (2), Mainland China (2), and Hong Kong SAR, China (2). Four males and two females between the ages of 30 and 50, with a minimum of eight years of professional experience using and instructing soundstages, were recruited from the cinematography, film, and education industries. Table 1 lists the background of the participants. The interviews were conducted through either face-to-face or online meetings in a two-to-one manner (two authors and one specialist).

3.2. Interview Protocol

Inspired by Kim et al. (2022); Xu et al. (2022); Lan et al. (2022), we conducted this interview as the following phases. To ensure that all participants had a shared knowledge of virtual environments, we first began the expert interview by introducing the notion of virtual reality and its applications in the real world. Then, we explained the objective of our study to the participants. The objective of the study was to establish the design of a metaverse that facilitates interactive instruction and learning on a virtual reality soundstage. Accordingly, the participants were told to express their views on teaching requirements, arrangements, and challenges for cinematography education by leveraging many virtual environments inside the metaverse. Our study with the six specialists were semi-structure interviews, consisting of four primary

ID	Gender	Occupation(s)	Experience
E1	M	Top-tier Cinematographer & Uni. Prof.	20 years in both academia and industry
E2	M	Full-time University Professor	25 years teaching experience in cinematography
E3	M	Senior Cinematographer	9 years industry experience in cinematography
E4	M	Cinematographer & College Lecturer	8 years in both academia and industry
E5	F	Television Programmer Director	19 years industry experience in cinematography
E6	F	Full-time University Professor	12 years teaching experience in cinematography

Table 1: The background information of the six specialists that participated in our in-depth interviews.

aspects, as follows: (1) What are the primary skills taught to students on a soundstage? Which of these are also suited for virtual soundstage education? (2) What professional functions and environments are required to train these talents on a soundstage? (3) What are the hurdles and obstacles associated with soundstage instruction? (e.g., Limited number of students, restricted space, and difficulty transporting equipment in physical environments.) (4) While keeping an eye on the future of virtual reality on the metaverse-driven soundstage, we did introduce the auxiliary lines of illumination that engines such as Unity, Unreal, and others have proposed to help teachers and learners with lighting design in practice. We also discussed with specialists the potential of arranging auxiliary lighting lines for classes that employed virtual reality (VR) and whether it would improve communication between educators and students. The length of interviews for all participants is between 45 and 60 minutes.

3.3. Interview Analysis

After the interviews with specialists, the first and third authors extracted thematic codes through an open-coding approach Braun and Clarke (2006); Charmaz (2006). They separately separated, categorized, and organized the comments from specialists in order to develop a collection of mutually exclusive instructional recommendations. Finally, we engaged in discussions to establish a consensus that identified six themes for design requirements on the virtual soundstages.

3.4. Interview Results

The following paragraphs include the report of our findings about six design requirements (R1-R6), and further highlight the quotes from specialists during the interviews.

R1: Lighting Courses Setting on a Virtual Soundstage

Based on interviews with specialists about teaching on real soundstages and their suggestions for virtual soundstage courses, we have come up with the demands of developing a curriculum as follows. Three specialists (E1,2,6) detailed the basic information for the traditional lighting lesson. The courses regarding *"Advanced Lighting Fundamentals"* or *"Advanced Lighting Design"* teach the arrangement, adjustment, and modeling of lighting effects according to the basic setups and lighting configurations. The courses usually lasts one academic year. Each lesson lasts 2-3 hours. Cinematography courses usually have fewer than 10 students. Since the venue is small and crowded, classrooms can make it hard for students to see what the teacher is saying, the quality of teaching may go down if there are more than 10 students in a class.

Another crucial question is whether the virtual soundstage can teach the material. Six specialists have praised the virtual soundstage's potential in teaching. E6 said: "*On the virtual soundstage, lighting teaching courses can be interoperable with performing light positioning and light source adjustment. A virtual soundstage can act as a key portion of the entire teaching procedure, which covers one-third of the entire lighting teaching modules. This portion can reduce the reliance on the genuine soundstage.*" E5 commented: "*The virtual studio can be more intuitive for real-time viewing of lighting adjustments. The effect of light and corresponding shadow changes in the character, improving the efficiency of lighting teaching and learning.*" E2 summarized: "*I think the virtual soundstage can help with basic lighting shooting training, such as 1) learning how to use lighting equipment and adjust lighting; 2) using lamps and lanterns to accomplish the basic shooting with a lighting layout considering multitudinous aspects, including the use of primary light, auxiliary light, and finishing light; and 3) recreating the common shooting scenes, such as day and night scenes, regardless of daytime or nighttime.*" When the lighting course involves complex or large-scale needs or unique lighting situations, teaching using a physical soundstage is also necessary, i.e., the complementing use of virtual and physical soundstages. E3 speculates on the limitations of virtual soundstages and the teaching modules that should be taught on physical soundstages, such as how to set up lighting for large-scale scenes, some that are more detailed and dramatic, and a scene requiring high levels of precise lighting control, such as a close-up shot of a person's face with large eyesight. It is also vital to give virtual lighting training that focuses on the foundations of light devices and how to utilize them properly, such as employing basic lights to play the main and auxiliary lights, contour lights, and other real-time light effects.

R2: Virtual Scenes and Objects

Recreation of actual studio specifications (lighting design, environment design) in virtual environments is necessary, and thus we have to include scenes and objects in a realistic manner, including applied lighting, interoperable items, (virtual) avatars, cameras, and viewfinders, LED walls, studio field lights, to name but a few. More importantly, the importance of realism on virtual soundstages is recognized by all six specialists. E3 highlights that "*Virtual Studio instruction must be a realistic process; otherwise, it would be only a reference tool or a gaming experience without many educational values.*" E1 shares similar views but recognizes the benefits of leveraging VR: "*Certain special scenes in the film production rely on a physical studio. Instruction from virtual studios enables students to adapt and learn the fundamental studio procedures in advance.*" In other words, the students can spend their time on fundamental principles, concepts, and even simple trials in VR, and the lectures with the physical soundstage will go with more advanced content. E1 continued: "*Therefore, the most important aspect of virtual studios is the accurate replication of studio situations.*" Consequently, virtual scenes and objects are an indispensable element for the virtual studio, considering that the virtual studio must be a realistic representation of a real soundstage scenario.

R3: Visual Cues in Lighting Education

The primary objective of virtual studio-based cinematography instruction, according to all specialists, is the operation of lighting that is highly relevant to the viewfinder and camera. Lighting and camera operations are interconnected elements of realistic shooting. The location, color, and texture of the lighting directly impact the realism of the movie experience created lighting. We list the specialists' viewpoints as follows. R2 thinks visual cues, such as auxiliary lines illustrating the lighting effects, are the basic requirements for practical filmmaking on virtual soundstages. Meanwhile, E5 mentioned that the location, color, and texture of the light have a direct correlation with whether or not the lighting experience is authentic. E2 also notes that "*in actual studio instruction, lighting position is taught in two primary ways: where the light should be set and how far away it should be from the subject, and in what direction the light should beam.*" As such, the lighting configuration in virtual studios should emulate the effects in physical studios, thus offering educational values to teachers and students. In addition, "*Understanding the qualities of lighting, such as the movement of lighting equipment, setting up, adjusting the angle of the light, fine-tuning the color temperature of the light, and so on, is essential for students' mastery before the actual shooting begins.*" as highlighted by E4.

R4: Simultaneous Interaction with Multiple Users

Practical requirements and interactive situations are discussed in the interviews with E1, E2, E4, and E6, including the interactivity demands in the classrooms, the viewable auxiliary lines of lighting effects, and the viewfinder supporting multiple users simultaneously. E1 first pinpoints that "*Real-time display sharing is crucial, as the view sharing of studio layout is highly dependent on the viewfinder's imagery.*" Also, E4 mentioned that most studio instruction requires the instructor first to demonstrate the setup to the students. The students pick up knowledge through the teacher's lighting display/viewfinder and explanation of the outcomes shown in the viewfinder. This opinion connects to E6's viewpoint: "*In fact, in real soundstage teaching, due to the limited size of the studio, each teaching session needs to be limited to 20 people, and it is not easy for students to observe the detailed lighting process in real-time through the viewfinder/display in physical studios. In contrast, the virtual might resolve this issue if more people could share the teacher's perspective in the same virtual space.*" The issue of students not being able to observe in depth in the physical venue may be remedied if numerous individuals could share the teacher's vision in real-time on the virtual soundstage. We conclude that a design space exists for improving communication and classroom interaction by appropriately leveraging virtual environments.

R5: Virtual Assets and Lighting Effects

Virtual soundstages should include various luminaire equipment to replicate diverse light appearances at different times and in different locations. E4 mentioned "*The emphasis of the instructional training is relevant to testing the light effects supported by various luminaires, as well as evaluating the features of photography equipment. Since the effect of various luminaries can only be evaluated in the physical studio, students can learn and experience in a reasonably effective way. As such, the virtual studio should give a reasonable emulation of the physical environment for students learning through a series of testing and evaluation.*" Also, E3 aligns with E4's comments and emphasizes: "*The training in the virtual studio training might accommodate the demand for a variety of equipment alternatives using interactive VR technology.*" E2 further pinpoints the advantages of virtual studios by leveraging the adaptive time and place among diversified virtual environments that impact the lighting effects differently. E2 also said that "*I feel that virtual soundstages have the edge over actual soundstages. It enables various scene changes, seasonal adjustments, and quick access to lighting components.*" To sum up, the virtual environments of cinematography should contain a variety of virtual lighting assets.

R6: AI-driven Learning and Virtual Production

Three interviewed specialists (E3, E4, and E6) brought up the prospect of using artificial intelligence (AI) to support human instructors in the virtual classroom. E4 mentioned how instructors are hard to come by in the film industry due to their limited time and busy schedule. As such, how AI-based cinematography instruction may help alleviate this problem, such as reducing the workload from highly repetitive tasks and standard learning content. E6 proposes a futuristic vision toward virtual-physical blended production. Soundstage and lighting modules in a virtual world should include virtual characters and environments that can be displayed in real-time, e.g., facilitating learning through trial-and-error. After settling on their tools, students should be able to cast their virtual productions and pick their scenarios. Changes in the virtual environment may be made instantly to the actors' performances and potentially physical environments. That is, the outcome is an automatic short film. Within this process, the AI should flag any issues with the recording and provide the students with various solutions to implement.

4. System Design

Art Mirror enables instructors and students to complete the cinematography lighting education in VR environment by providing a virtual soundstage.

4.1. Methodology

The below paragraphs elaborate the analysis and design process for the proposed system.

4.1.1. Analyzing Process

According to the interviews with specialists, we outlined the top six needs for creating lighting education modules in a computer-mediated environment. Over the course of two months and weekly discussions (over 17 hours) among the authors, we analyzed the soundstage's physical space, and collected the relevant research on VR-based teaching. We take what we've learned from the six requirements and translate it into four design considerations: lighting on scenes and characters, lighting control design, auxiliary visual signals of lighting, and collaborative design for cinematography. R1 is the foundational requirement for building the system and virtual lesson arrangements. Lighting on Scenes and Characters fits the needs of R2 and R5, whereas Auxiliary visual signals of Lighting meet the needs of R3 and R4. Remarkably, the Lighting of Scenes and Characters is emphasized by R2, R4, and R5 professionals. Collaborative Design for Cinematography also takes into account the suggestions made by R4. AI-enabled training and AI-driven adaptive manufacturing, however, are beyond the purview of the present study. We recognize its critical function in large-scale learning but will not go deeper into this aspect at this phase.

4.1.2. Design Process

We designed Art Mirror in two stages. First, we implemented a lo-fi prototype before the interview (Section 3). We built and collected models that could reflect the environment of a physical soundstage. All models were built according to the reference photos of the real soundstage. The kitchen scene was chosen as the default scene because it was a common and classic scene. For interaction, users can manipulate and rotate different parts of the lights. For example, users can grab the bottom of the light for placement and the joint of the light stand for height adjustment.

Then, we iteratively designed and improved the prototype according to the result of the interview (Section 3). To better support communication and teaching, we provided visual cues for lighting education. Adapted from visual guidance from the commercial game engines and 3D modeling tools, e.g., Unity[10] and Blender[11], we visualized the shape of the light and camera. Also, we added angles of the light for students and teachers to communicate and reference. Furthermore, to provide accurate positioning and angle tuning, we used the thumbstick on the VR controller instead of grabbing it for the control. For example, after selecting a light, users can move the light on the floor by moving the thumbstick up, down, left, or right.

4.2. System Walkthrough

We describe our system walkthrough regarding four design components: (1) lighting on scenes and characters, (2) lighting control design, (3) auxiliary visual cues of light, and (4) collaborative design for cinematography.

4.2.1. Lighting on Scenes and Characters

The absence of standards amongst film studios in the majority of colleges and universities is the greatest obstacle where that cinematography education is facing today. As a vital component of the film industry, film studios play a significant role in film production. However, it is difficult for most novices in the film industry to reach the physical working environment of a typical film studio at first. In order to provide novices with a better understanding of the studio working environment, we recreated a normal film studio in virtual environments. The studio was first constructed as a result of the creator's need to control the lighting and weather of the shooting scene. To the best of our knowledge, the film studio of the earliest age was a transparent shed constructed from a glass house with the intention of allowing adequate sunshine into the shooting location.

In today's film industry on-site shooting environment, many film studio shooting tends to combine physical shooting with high-definition LED backdrop shooting. For instance, when the latest Batman series is released in 2022, the vast majority of this film's shooting footage is shot on the soundstage, driven by the combined effects of physical characters and LED backdrops. Therefore, our proposed system also integrates the popular film industry production process with the addition of LED backdrops to the VR

[10]https://unity.com

[11]https://www.blender.org

virtual shooting scenarios. The user may alter the LED background to match the real scene being filmed.

To better combine the effect of LED screen shooting, we searched for kitchen scenes from a classic movie (see Figure 3). This movie has a large number of kitchen scenes shot at different times (i.e., from daytime to night-time). We aim to offer better training modules to potential learners to enhance their lighting ability. As such, we create a 1:1 model of this kitchen in virtual reality, and the kitchen displays changing times for the sake of more realistic training scenarios, i.e., adjusting the lighting based on the time. As

Figure 3: A LED screen and the kitchen scene in *Art Mirror* (Left) and the auxiliary (white) lines for lighting cues (Right), inspired by the Unity.

the actor shooting is the main component of a film's creation, our proposed system is concerned with the lighting reflected on the face of the character and the corresponding lighting effects produced in the film. Therefore, in the virtual environment of the shooting scene, we created virtual people that allows the teachers and students to evaluate various setups of illuminations on the face of (virtual) characters, i.e., avatars, as well as the effects of environmental lighting on the avatars (see Figure 4).

4.2.2. Lighting Control Design

As the core of the soundstage, the lighting plays a decisive role in the creation of the shooting, so the wise choice of lighting will greatly help the producer and creator to complete the desired imagery. The common lighting equipment used on the soundstage scenes are tungsten lamps, HMI lights, and LED light bulbs, such as Arri and SkyPanel series. From the texture of lighting, we primarily divide the illumination types into soft light (scattered

Figure 4: Two virtual characters in *Art Mirror*.

light) and hard light (direct light), and the lighting in the virtual soundstage needs to meet the requirements of these two categories in real-life operations.

In the daily soundstage shooting, lamps and lanterns of the SkypPanel series (see Figure 5) is a compact and intensive LED light sources featured with soft light. It also enables a wide range of color temperature adjustments. Meanwhile, lamps and lanterns of the HMI series (see Figure 6) serve as a representative of direct lighting. It owns strength in the color rendering of cinematography due to its effect being highly similar to daylight lighting effect, so it is commonly picked in soundstage shooting.

After compiling interviews with experts and reviewing the literature, we decided to employ two lamps and lanterns above as the virtual teaching lamps and lanterns and emulate their physical characteristics to the maximum extent in the VR teaching scenes. The reason endorsed by experts is that they can simulate the commonly used lights for teaching.

Figure 5: The SkyPanel series lights in *Art Mirror*.

Luminaires (lamps and lanterns), principally HMI and SkyPanel, are available in a wide variety of types. The primary distinction between these types is the variation in light output and size. In the real work environment,

Figure 6: The HMI series lights in *Art Mirror*.

the vast majority of producers and creators simply employ individual models participating in the actual filming. In addition, the creation is not considerably impacted by the use of various models of the same kind of lighting. Therefore, in our system's virtual landscape, lights and lanterns are simplified into only two sizes — large and small. The two sizes are adequate to let the students comprehend the function of lamps and lanterns.

In VR settings, the luminaire model, according to the specialists' recommendations, have to achieve the same motion characteristics as actual physics. That is, the models should move, rotate, tilt, and lift like the physical world. Consequently, virtual scenarios, our luminaires, relevant to HMI and SkyPanel, are produced with the exact same operability as the studio shooting, especially with the exact same realism of operability. For instance, if we need to elevate the luminaire to a very high position, we can call the accessories of supporting lighting brackets at the high cost of resource and time in the physical setup. In contrast, we can easily accomplish any height control by modifying the height of the lighting bracket in virtual scenarios.

4.2.3. Auxiliary visual cues of Lighting

In the physical-world shooting scenes, lighting does not have auxiliary lines to assist the configurations. As such, everyday lighting operators and creators alter and optimize the lighting cloth based mostly on their rule of thumb as well as their experiences acquired from various real cinematography circumstances. In real-life studio shooting, photographers usually use a laser pointer to indicate the adjustment of illumination and the positions. The laser beam from the laser pointer serves as the key communication cue and interactive medium with the lighting director, producers, and other creative staff. Although the laser-pointing method can successfully reduce the communication gap between the operators in the studio, such a communication cue highly relies on experience, gut feelings, and industry jargon instead of quantitative measurements. This severely restricts the mastery of lighting skills and cultivating the novices.

We leverage the concepts of the aforementioned laser beam in the physical soundstage in the virtual shooting scene of our proposed system. We change the interactive cues of the laser beam to a virtual line of light auxiliary. This change of interactive cues is commonly employed during the establishment of virtual scenes in the Unity engine. The purpose of the auxiliary line is to help novice operators, and creators better determine the range and location of illumination. As such, the operators can adjust and evaluate the placement and settings of the lighting model in an intuitive manner (see Figure 7). Therefore, the proposed virtual soundstage is equipped with

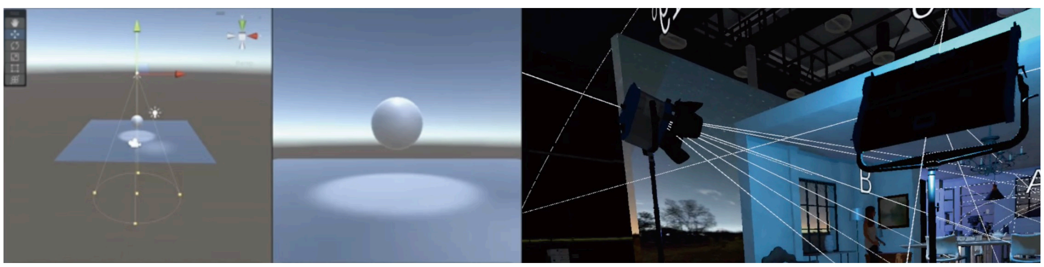


Figure 7: The auxiliary visual cues of lighting in *Art Mirror* inspired by the Unity.

lamps and lanterns with auxiliary lines. The auxiliary lines include the direction and pointing of the lamps and lanterns, lighting irradiation range, and the changes in the brightness when the distance of lamps or lanterns is altered. These three quantitative outcomes may assist novices in gaining a better knowledge of lighting, and in order to quantify the light adjustment parameters in real-life shooting practice. Remarkably, the pitch and rotation angles and degrees of all lights are visualized by appropriate annotation in our VR system. In virtual shooting instruction, the accurate annotation of degree, clear auxiliary line, and illumination range may aid novices in gaining a better understanding of lighting configuration, in theory, to the maximum extent.

4.2.4. Collaborative Design for Cinematography

Art Mirror supports simultaneous access by multiple users, both teachers and students (see Figure 8).

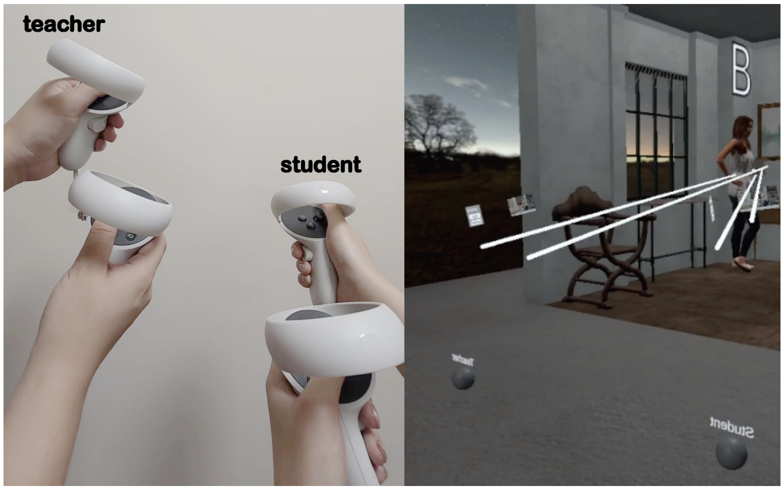


Figure 8: The Collaboration among Teacher and Student within *Art Mirror* in a One-on-one Manner.

It is crucial to provide students with hands-on experience regarding the operations from the instructor's perspective as well as the lighting setup outcomes based on the camera display during the teaching process. As we examine the connection between teaching and learning in a collaborative setup, we have configured the system to allow the teacher and students to simultaneously view the camera display after the flexible yet adaptive illumination setup in virtual reality. Meanwhile, we configured two camera positions (see Figure 9) within the system. One is dedicated to facilitating teaching effectiveness by offering real-time assessment by providing a fixed machine position, but also for the teachers and students to conduct experiments of adjusting variables (angle and position) in the virtual setup. As such, students are able to complete the test assessment through the lighting configuration of the camera position. Another camera is characterized by moveable locations to make demonstrations with versatile locations. As such, the teacher can inspire the students and enable students to learn diversified lighting configurations.

In the design and implementation of the Art Mirror system's lighting scenarios, the camera response on the right-hand side (see Figure 9) helps the users to adjust the real outcomes of the imagery, while the camera on the left-hand side has a fixed location for real-time display sharing that enables seamless collaboration between the teacher(s) and students.

Figure 9: Two camera positions within *Art Mirror*.

4.3. Implementation

We implemented *Art Mirror* using Unity, a common 3D game engine for building VR applications. We adapted the light model from Unity for light simulation. We used Unity Multiplayer Networking for networking between different users. A local server is hosted, and a join code is generated and provided to users to join using Meta Quest 2[12]. Unity Multiplayer Networking enabled the application to transfer spatial information of different virtual objects and world data to all users for synchronization. Models including the soundstage, the large LED display, objects in the kitchen, lights, and the camera were built using Blender. The source code is available at `https://github.com/metaartmirror/artmirror`.

5. User Study

This section describes the design of the user study and the evaluation results through *Art Mirror*.

5.1. Participants

We recruited 16 participants with good vision. Eight participants are teachers (ages 26-41, 6 males and 2 females). The remaining eight participants are students (ages 18-20, 3 males and 5 females). The combination of teachers and students can emulate the teaching and learning routine in physical soundstages. Student participants have recently graduated from

[12]`https://store.facebook.com/quest/products/quest-2/`

high school and are preparing to enter an art college to study cinematography as well as have relevant interests and learning experience, while teacher participants have at least 3 years of teaching experience with physical soundstages and cinematography (range: 3–9 years; average teaching experience: 5 years). Five of the eight students had VR experience, and the other three did not, whereas six of the eight teachers had VR experience and two did not. In the pre-experiment briefing, we allowed 5 to 10 minutes for students and instructors to get familiar with the Oculus Quest 2, a VR headset, so that they could comprehend its fundamental functions. Then, after a brief pause of no more than ten minutes, we began our experimental teaching. Approximately 35 minutes were necessary to wear the headset during the evaluation session. Participants can take a brief pause if they feel uncomfortable during the task, like if they get motion sickness. All sixteen participants were allocated in random order and further assigned into eight teaching groups that consisted of one teacher and one student. After the experiment, each participant receives a remuneration of $25 USD.

5.2. Procedure

Our user studies were conducted face-to-face in the field, with each participant group needing to complete a roughly 40-minute experiment followed by an interview. Each experiment is one teacher to one student. The whole experiment was videotaped with authorization and user consent. Meanwhile, users were encouraged to think aloud during the experiment.

Introduction (around 10mins): We first introduced the study background and procedure. Then, we showed the teachers and students the outline for the foundational lighting lesson designated for the experiment. Based on the usual practice, the lighting course on the real soundstage takes about 2 to 3 hours due to the heavyweight and bulky volume of the lighting equipment. In contrast, after the removal of such physical constraints, it only takes 30 to 35 minutes to complete the learning and practice on the virtual soundstage.

Step 0: Pre-training (5mins):

At this stage, we brought everyone inside *Art Mirror*'s virtual soundstage and showed them how to use the VR device's equivalent of a soundstage.

Step 1: Lighting Teaching and Learning Evaluation (around 30mins): The teacher would then work with the student on the virtual soundstage for teaching and learning in a one-on-one manner (Figure 8). A video of teaching and learning demonstration is available in the supplementary materials, according to the outline in Appendix A 12.

Step 2: Follow up interview (around 15mins): After the training on the virtual soundstage, we conducted follow-up interviews with each pair of teachers and students, allowing them to discuss and elaborate on their answers with one another. Our primary goals in these interviews were to observe and probe the actual experiences of teachers and students in the proposed system.

Step 3: Questionnaires (around 10mins): After conducting the interview, we distributed a questionnaire of thirteen questions that covered five topics: usability[13], sense of agency Jicol et al. (2021), realism Pei et al. (2022), presence Louis et al. (2019); Yassien et al. (2020), and collaboration Prasolova-Førland et al. (2021); Jin et al. (2022); Drey et al. (2022). Each question employs a seven-point scale. The first topic reflects the usability of our system, while the other four topic questions are commonly asked in virtual reality studies.

5.3. Study Results and Analysis

After the user study, we collected the quantitative data from 16 questionnaires and analyzed the qualitative data from the interviews with four authors meeting and discussing over 10 hours. In this subsection, we report our study results on both qualitative results and quantitative results.

5.3.1. Qualitative Results

Generally, from the perspective of 8 teacher users (T1-T8), all of they agreed using *Art Mirror* can improve soundstage teaching efficiency. T1, who had nine years teaching experience on cinematography commented that *"This system is very efficient and convenient, and I am satisfied with the lighting effects and experimental results achieved during the teaching process."* T3 also pointed out that *"The virtual soundstage allows for more possibilities than the real one."* From the perspective of 8 student users (S1-S8), all of them lauded the usability of *Art Mirror* as easy to learn and use. S2 praised that *"This virtual soundstage is interesting and fun, the scene is very real."* S7 noted that *"Art Mirror makes it simple to adjust the angle of all lights, allowing easy lights movement."*

[13] `http://www.measuringux.com/SUS.pdf`

5.3.2. Quantitative Results

As shown in Figure 10, we present our result in terms of usability, realism, presence, sense of agency, and (multi-user) collaboration. All related questionnaires and the rating result are provided in the supplementary materials. The below paragraphs report the details of our evaluation results.

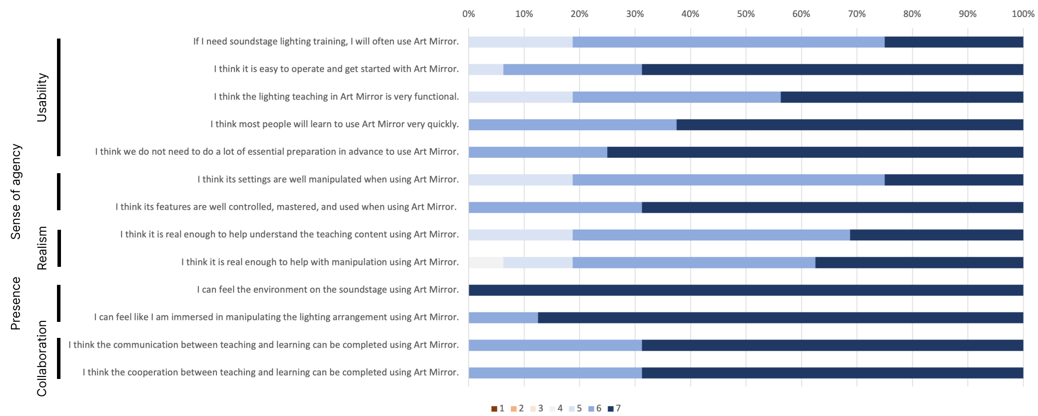


Figure 10: This figure shows the ratings of the participants on usability, realism, presence, sense of agency, and collaboration. (1 = Strongly disagree, 7 = Strongly agree)

Usability: In general, all participants, regardless of teachers and students, reflected their score no less than 5 (out of 7) in usability. All participants agreed that the system is easy to learn and easy to use. Participants reflected that they strongly agreed that *Art Mirror* is easy to start with (median=7, mean=6.63, std=0.619), learn quickly (median=7, mean=6.63, std=0.5), and do not require a lot of essential preparation (median=7, mean=6.75, std=0.447). Moreover, all participants showed agreement and positive attitudes about the usability of *Art Mirror*: "If I need soundstage lighting training, I will often use Art Mirror." (median=6, mean =6.06, std=0.680), and "I think the lighting teaching in *Art Mirror* is very functional" (median=6, mean=6.25, std=0.775). In summary, the *Art Mirror* system is deemed entirely functional for teaching lighting, is simple to learn and use, and does not require a great deal of fundamental understanding to operate.

Sense of agency: As for the sense of agency, the sixteen participants made 5 points or above on both two questions. The participants strongly agreed that the *Art Mirror*'s configuration (panel, virtual scenes, and virtual objects) are easy-to-operate (median=6, mean=6.06, std=0.680), and the corresponding functions are adaptive yet intuitive, hence achieving low learning costs (median=7, mean=6.69, std=0.479). In particular, the participants agreed that the virtual studio supports the free exploration of lighting effects, which is analog to self-exploration in the physical (open-)world.

Realism: All participants agreed that the system was real enough for education purposes (median=6, mean=6.13, std=0.719) and manipulation (median=6, mean=6.13, std=0.885), showing satisfaction with the virtual studio consistently. Interestingly, we discovered that participants had varying requirements for realism.

We discovered that P7 (T4) gives a score of 4 for the question "*Art Mirror* is realistic enough to aid in operations," and they also commented: "Walk through the wall is necessary to increase the efficiency of the deployment of lights in the virtual studio, so they do not need such realistic partition that leads to unnecessary travels around the walls and other surfaces." In addition, P6 (T3) suggested that "when the light board at the ceiling can be turned 360 degrees, it will be a bit too convenient to use with an unrealistic sense." P2 (T1) also made a perfect score for both realism questions, supported by comments like "all the props are movable". Therefore, an understanding of the system's degree of realism should be a topic deserving in-depth research and debate.

Presence:

Regarding the presence, nearly all participants strongly agreed that they were presented in the soundstage (median=7, mean=7, std=0) and immersed in lighting manipulation (median=7, mean=6.88, std=0.342).

Remarkably, the question "I can feel the environment on the soundstage using *Art Mirror*." has resulted in a perfect score, i.e., 7 out of 7. The results demonstrate that the *Art Mirror* settings and accessories can bring a sense of presence through realistic and immersive experiences during the assigned cinematography training tasks.

Collaboration:

The scores for both questions on collaboration are no less than 6. The questions reflect the participants strongly agreed that communication and collaboration in cinematography learning (median=7, mean=6.69, std=0.479) and teaching could be accomplished with *Art Mirror* (median=7, mean=6.69, std=0.479). The teachers and students show agreement on effective learning and interaction in the virtual studio. P7 (T4) and P11 (T6) both mentioned that the virtual studio could replicate the interactive behavior of the physical studio and the corresponding design communication, such as the changes in lighting effects, color change, distance, intensity adjustment, and so on. As such, virtual and real soundstages achieve similar behaviors and hence save manpower and setup time.

5.4. Gallery

During the user study, each student finished a lighting configuration, and each teacher gave remarks on the lighting effect (see Figure 13, Appendix B). We demonstrate one work among the student participants (Figure 11) from P2 (student 1) as a gallery example, while the full list of lighting work and participants' comments, including teachers' comments on their paired students' work and students' learning experiences with *Art Mirror*, are available in Appendix B (Figure 13).

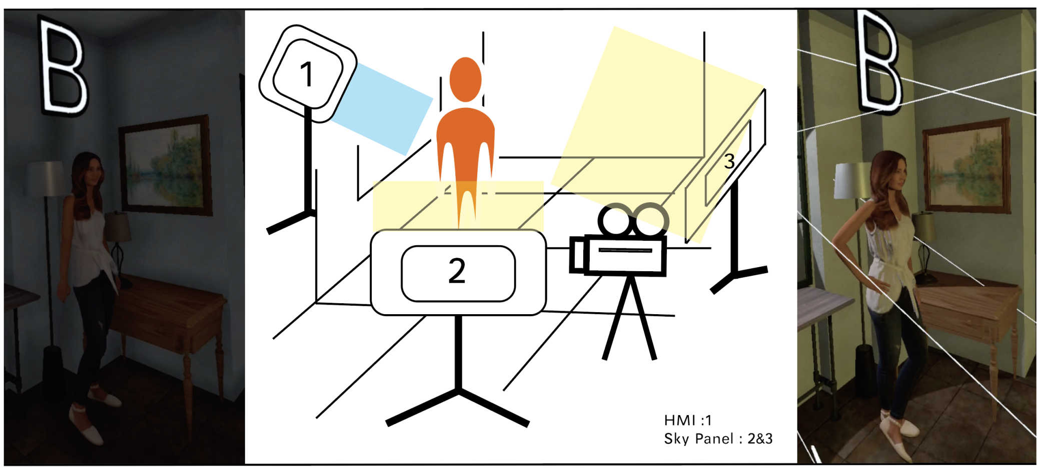


Figure 11: The lighting training by using *Art Mirror*: The leftmost picture refers to the before-lighting setup; The middle picture shows the lighting setting process by P2 (student 1) using two SkyPanel lighting devices and one HMI lighting device to achieve a lighting effect of an indoor night scene; The rightmost picture indicates the after-lighting outcomes.

6. Discussion

After illustrating the evaluation results, we summarize our notable findings and highlight design implications for VR Cinematography Education System reflected by the user study with *Art Mirror*. Next, we discuss the limitations and highlight future work.

6.1. Adapt VR to Cinematography Education

VR education is believed to aid instruction, encourage active participation, and pique the interest of students in learning Berns et al. (2019); Brondi et al. (2015); Wei et al. (2023); Xu et al. (2023); Wei et al. (2024b,a). Meanwhile, with the help of the VR environment, both the cost of teaching scenarios and the risk of experimenting can be cut down Drey et al. (2020); Potkonjak et al. (2016). Our investigations have shown that cinematography education in virtual reality, a type of virtual environment in the Metaverse, is a feasible and efficient method that can be utilized in addition to traditional classroom instruction, i.e., extending virtualization on top of physicalization Ren and Hornecker (2021). Specialists from the user study and in-depth interviews confirmed that *Art Mirror* provided hands-on experiences for lighting training and is suitable for virtual soundstage teaching. Furthermore, learners are able to acquire the fundamental concepts of lighting Fielding (2013) and basic lighting methods in a VR environment through utilizing virtual settings and lighting components that closely mimic the physical studio. A digital twin of physical studios has demonstrated the feasibility of virtual reality cinematography education. Remarkably, the participants with *Art Mirror* gained enhanced awareness of lighting configurations and the corresponding effects through a series of trials and practice in the virtual soundstage. In addition to tertiary education, *Art Mirror* can potentially be extended to general education. The contents of *Art Mirror* can serve as the basic lighting education as an interactive introduction to raising the students' interests in cinematography, including general art colleges, vocational art education schools, film, and television-related education groups, and so on. Also, *Art Mirror* enables the selection of notable film sequences and the illustration of their lighting setup. Consequently, the audience can recognize the significance of lighting in cinematography. In other words, *Art Mirror* also assists spectators in comprehending and appreciating how the film's light design was done, bringing the public audience closer to the film production.

Art Mirror can potentially serve as a tool for planning of lighting design in an intuitive and low-cost manner Brown (2014). Meanwhile, before shooting, Art Mirror can also be given to the crew as a lighting layout, which can be more accurate than drawing the light positions on paper traditionally. In particular, novice creators can begin their first works with *Art Mirror* through a number of trial-and-errors and make a lighting plan without high barriers from equipment and venues. We anticipate that *Art Mirror* will become a good addition to the authoring tool in the metaverse.

6.2. Design Implications

The following paragraphs discuss the design implications of realism and quantitative measurements for lighting education.

6.2.1. Strike a balance between realism and functionality for learning effectiveness.

In a learning environment supported by virtual reality (VR), it is essential to consider the extent to which realism can aid teaching and learning depending on the scenario and the unique application.

As a result of our study, we have revealed that the requirement for realism is counterintuitive. Among most prior virtual reality studies, the higher the level of realism, the better the learning experience and user satisfaction Tlili et al..

In contrast, the required level of realism should be considered case-by-case based on the purpose of virtual scenes and user context. To streamline operational accuracy in the virtual soundstage, the props and lighting should preferably be as realistic as possible. Also, it is recommended to maintain a high level of detail for configuring the lighting devices. For instance, the jointed knobs of the lights should be made to rise and drop more accurately.

As mentioned in digital visual theory Darley (2002); Prince (2011), the greater the realism of these models, the more effective learners, and users will be able to learn to engage efficiently or to interact directly with activities.

However, we also found that instead of excessively seeking realism, we have to strike a balance between realism and functionality, and consider the relaxation of physical constraints for facilitating collaboration among users, such as allowing the users to walk through the walls to enhance the efficiency of the user's activities in the virtual soundstage.

This is crucial for lighting education since it eliminates the preparation time of preparing physical scenes and setups Burum (2007), and thus achieves resource allocation and productivity over more conventional methods of instructing on cinematography.

6.2.2. Visualize quantitative measurements for lighting learning.

The auxiliary lines in the virtual soundstage serve as an important visual cue of reflecting the lighting effects. We treat this as an opening of quantitatively delivering the cinematography education scenarios.

Cinematography education always contains quantitative aspects Nykvist et al. (2003); Fielding (2013); Keating (2009). It is possible to make well-documented records in physical soundstage for various aspects, such as aperture, light meter, color temperature, and to name but a few. The quantitative measurements of the light's angle and range are regarded as hard-to-quantify variables that have not been quantified on the physical soundstage.

With the assistance of the auxiliary line in the virtual soundstage, the system can present the quantified results to the angle and range of the light. The outcomes shed light on applying other novel approaches for teaching lighting in which learners and instructors achieved enhanced communication of lighting education.

During the lighting process, the auxiliary line, supported by the *Inverse Square Law* Adelberger et al. (2007) stating *'The intensity of the radiation is inversely proportional to the square of the distance'*, gives a reference for improving the lighting effects by adjusting the device locations. For example, based on the *Inverse Square Law*, auxiliary lines are available to mark the light's location, distance from the photographed object, and the actual luminous area. It is worth noting that the rigorous auxiliary lines should also achieve different reflections depending on the objects of different materials to achieve a detailed and realistic reference. In particular, the majority of the participants agree that auxiliary lines improve their learning experiences.

Meanwhile, participants suggested that we should provide selective popups based on the user context and accentuate the annotation of lighting areas when the lighting effects encounter a new material to adjust the properties of auxiliary lines. Moreover, *Art Mirror* can serve as a playground for introducing the effects of lamp power to the lighting distance Burum (2007); Fielding (2013).

Also, novice learners can get the concepts, including the relationships among lighting ranges, angles, and distance. Also, *Art Mirror* can serve as a playground for introducing the effects of lamp power to the lighting distance Burum (2007); Fielding (2013). In summary, the design probe of visualizing quantitative measurements by auxiliary lines in lighting effects for cinematography education not only helps novice learners acquire the basic concepts, such as the relationships among light ranges, angles, and distance, but also improves the communication between the instructors and students and teaching efficiency by this quantitative education.

6.3. Potential for Remote Education

An additional consideration is the significant impact that virtual environments can have on remote education. Although not the focus of our main study, the *Art Mirror* system holds substantial potential for application in remote learning contexts. By leveraging VR technology, students can access immersive cinematography training without the need to be physically present in a studio or classroom. This accessibility is particularly beneficial for learners who are geographically dispersed or for institutions with limited resources to set up physical soundstages. The virtual environment enables real-time interaction between instructors and students, facilitating collaborative learning experiences similar to those in traditional settings. Moreover, the scalability of VR platforms allows for standardized training modules to be distributed widely, ensuring consistent educational quality across different locations. Incorporating *Art Mirror* into remote education could enhance learning outcomes by providing engaging, hands-on experiences that bridge the gap between theoretical concepts and practical application in cinematography.

7. Limitation and Future Work

In this section, we discuss the limitations and highlight and future work.

7.1. Limitation

First, we did not conduct a longitudinal study to assess the long-term impact of VR-based instruction on memory retention and problem-solving skills Radianti et al. (2020); Freina and Ott (2015). The effects of virtual environments on these cognitive aspects remain uncertain and require extended monitoring and validation.

Second, the effectiveness of *Art Mirror* relies heavily on the availability and quality of high-end VR hardware, such as advanced headsets and controllers. Institutions or users without access to such equipment may experience a suboptimal learning experience, which could affect the system's overall utility.

Third, while *Art Mirror* simulates many aspects of a physical soundstage, it lacks the tactile feedback that comes from handling real equipment. This limitation might be significant for certain aspects of cinematography training that depend on physical interaction and haptic sensations.

Fourth, our requirements analysis relied heavily on interviews with six experts selected based on their relevance to the field. This introduces a potential selection bias, as these experts may hold specific views or experiences that do not fully represent the diversity of opinions within the cinematography community.

Fifth, the present user experience is limited by computational resources. Rendering realistic lighting effects and auxiliary lines demands significant computational power. Consequently, certain lighting phenomena—such as accurate light dispersion, reflections at specific angles, and shadows influenced by the sun's movement—are not fully represented. Although *Art Mirror* can distinguish between brightness and darkness, it cannot fully capture the subtleties of the three sides (light, gray, dark) and five tones (highlights, shadows, mid-tones, projections, reflections) Brown (2016). We acknowledge these limitations in lighting expressiveness; however, discussions with participants during user study interviews indicated that these did not significantly impact their understanding of the cinematography learning modules.

Sixth, the system is not entirely consistent with physical reality regarding the reflection qualities of various materials. The limitations in rendering the lightness, purity, and saturation of colors mean the virtual scenes lack industrial-level precision.

Seventh, the vergence-accommodation conflict Hoffman et al. (2008) inherent in current head-mounted displays limited the realism of *Art Mirror*. Due to the fixed focal length, participants experienced eye fatigue when trying to focus on the camera display (**??**; right), hindering the experience of using a shoulder-mounted camera as in reality. We believe that advancements in VR headset technology will alleviate this issue.

Despite these limitations, our primary objective—to enhance novices' knowledge of studio scenes and lighting equipment, and their understanding of fundamental operations—was not significantly impacted. In VR lighting education, the precision of digital twins and the exact imitation of physical effects are less critical. Our system, without requiring specialized settings or industrial-level accuracy, can satisfy basic educational needs by focusing on the essential concepts and practices of cinematography.

7.2. Future Work

7.2.1. Scene and Lighting Library

First, we intend to add new scenarios and lighting accessories to the library to enrich the variety of material and modeling options.

Art Mirror should have a wider range of lighting instructions and more virtual scenes and objects that reflect the environment. For example, the space stations commonly featured in sci-fi movies, futuristic scenes of city architecture with a cyberpunk style (e.g., purple, blue, and dark color tones), or other natural scenes such as jungles in the Amazon's rain forest. The learners may receive cinematography education with quick scene switching to enhance their awareness of shooting and lighting training in the new events that are difficult to construct and realize in real life, such as space capsules, historical buildings or cultural heritage, and so on.

Second, the present version of *Art Mirror* only implements the fundamental types of two luminaires. Thus, to further contribute to a more realistic lighting setup and effect examination, it is necessary to include more lighting kits. Some things that can be in the extra lighting kits are black shades, soft white light sheets, light shade buckets, different colored papers, shades of tailor-made shapes, and so on. Also, as work continues, more scenes, avatars, and other models will be added to the asset library, along with an extra lighting kit, to meet the needs and training goals of teaching lighting in different scenes.

7.2.2. Collaboration

Since lighting education often involves collaboration among learners and their instructors, a virtual soundstage, enabling many users to work together, may be useful and convenient Duval and Fleury (2009); Holm et al. (2002). *Art Mirror* can facilitate collaboration among learners and instructors in diversified scenarios, albeit our current evaluation only contains a kitchen scenario. It is worthwhile to note that the virtual soundstage can potentially adapt to other collaborative scenarios among learners and instructors. It is often feasible for the instructor to establish a virtual assignment for numerous individuals to work together. As such, our proposed solution would be an excellent approach to fulfill the demands of the teacher to set the assignment and a promising way of designing assignments. Additionally, in such a collaborative environment of cinematography learning, the instructor can regulate the learners' roles and grant the right according to their role Nebeling et al. (2021). As such, the instructors on virtual soundstages can achieve easier classroom management than their physical counterparts, e.g., safety management and preventing damage to high-cost equipment due to improper usage. Also, other rights of instructors include "stopping all activities" in the virtual demonstration and managing shared information and viewpoint.

7.2.3. AI Coach with Immersive Technology

Art Mirror can be integrated with functionalities driven by artificial intelligence. The rise of AI agents sheds light on combining AI and virtual environments for better teaching. The HCI research community can further explore user experiences and potential ways of interaction with AI coaches. Finally, the participation of the instructor is an essential aspect of lighting education. It will be interesting to see the hybrid mode of content delivery used by human and AI coaches. We anticipate that the AI can focus on repetitive tasks and minimize the system's need for teachers. The AI coaches may help students understand how lighting works in virtual reality scenarios and take part in basic lighting instruction, while the human instructor can lead a deep discussion to get the students thinking and coming up with new ideas.

8. Conclusion

This work explores how to support collaborative cinematography for lighting education on a virtual soundstage in the metaverse era. Our in-depth interviews with six cinematography specialists highlight six important dimensions of virtual soundstage design. Due to the scope of our study, we considered the first five factors for the establishment of a virtual soundstage, namely *Art Mirror*. Through our evaluation with sixteen participants, *Art Mirror* is easy to use and realistic, characterized by flexible environments and a strong sense of presence, which supports collaboration between instructors and learners in cinematography education.

References

Adelberger, E., Heckel, B.R., Hoedl, S., Hoyle, C., Kapner, D., Upadhye, A., 2007. Particle-physics implications of a recent test of the gravitational inverse-square law. Physical Review Letters 98, 131104.

Alton, J., 2013. Painting with light. Univ of California Press.

Bahng, S., Kelly, R.M., McCormack, J., 2020. Reflexive vr storytelling design beyond immersion: facilitating self-reflection on death and loneliness, in: Proceedings of the 2020 CHI conference on human factors in computing systems, pp. 1–13.

Bernard, H.R., Bernard, H.R., 2013. Social research methods: Qualitative and quantitative approaches. Sage.

Berns, C., Chin, G., Savitz, J., Kiesling, J., Martin, F., 2019. Myr: A web-based platform for teaching coding using vr, in: Proceedings of the 50th acm technical symposium on computer science education, pp. 77–83.

Braun, V., Clarke, V., 2006. Using thematic analysis in psychology. Qualitative research in psychology 3, 77–101.

Brelsford, J.W., 1993. Physics Education in a Virtual Environment. Proc. of the Human Factors and Ergonomics Society Annual Meeting 37, 1286–1290.

Brondi, R., Alem, L., Avveduto, G., Faita, C., Carrozzino, M., Tecchia, F., Bergamasco, M., 2015. Evaluating the impact of highly immersive technologies and natural interaction on player engagement and flow experience in games, in: International Conference on Entertainment Computing, Springer. pp. 169–181.

Brown, B., 2012. Motion picture and video lighting. Routledge.

Brown, B., 2014. The Filmmaker's Guide to Digital Imaging: For Cinematographers, Digital Imaging Technicians, and Camera Assistants. Routledge.

Brown, B., 2016. Cinematography Theory and Practice: Imagemaking for Cinematographers & Directors. Routledge.

Burum, S.H., 2007. American cinematographer manual. volume 1. American Cinematographer.

Charmaz, K., 2006. Constructing grounded theory: A practical guide through qualitative analysis. sage.

Chen, Z., et al., 2021. Learning from home: A mixed-methods analysis of live streaming based remote education experience in chinese colleges during the covid-19 pandemic, in: Proc. of the 2021 CHI Conf. on Human Factors in Comp. Sys., ACM, NY, USA.

Chung, J.J.Y., Shin, H.V., Xia, H., Wei, L.y., Kazi, R.H., 2021. Beyond show of hands: Engaging viewers via expressive and scalable visual communication in live streaming, in: Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems, pp. 1–14.

of Cinematographers, A.S., 2022. American cinematographer. https://ascmag.com/.

Darley, A., 2002. Visual digital culture: Surface play and spectacle in new media genres. Routledge.

Drey, T., Albus, P., der Kinderen, S., Milo, M., Segschneider, T., Chanzab, L., Rietzler, M., Seufert, T., Rukzio, E., 2022. Towards collaborative learning in virtual reality: A comparison of co-located symmetric and asymmetric pair-learning, in: Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems, Association for Computing Machinery, New York, NY, USA. URL: https://doi.org/10.1145/3491102.3517641, doi:10.1145/3491102.3517641.

Drey, T., Jansen, P., Fischbach, F., Frommel, J., Rukzio, E., 2020. Towards progress assessment for adaptive hints in educational virtual reality games, in: Extended Abstracts of the 2020 CHI Conference on Human Factors in Computing Systems, pp. 1–9.

Duval, T., Fleury, C., 2009. An asymmetric 2d pointer/3d ray for 3d interaction within collaborative virtual environments, in: Proceedings of the 14th international Conference on 3D Web Technology, pp. 33–41.

Fabris, C.P., et al., 2019. Virtual reality in higher education. Inter. J. of Innovation in Science and Mathematics Education 27, 69–80.

Fielding, R., 2013. The technique of special effects cinematography. Routledge.

Freina, L., Ott, M., 2015. A literature review on immersive virtual reality in education: state of the art and perspectives, in: The international scientific conference elearning and software for education, pp. 10–1007.

Garrison, D.R., Anderson, T., Archer, W., 1999. Critical inquiry in a text-based environment: Computer conferencing in higher education. The internet and higher education 2, 87–105.

Getuli, V., Capone, P., Bruttini, A., Sorbi, T., 2021. A smart objects library for bim-based construction site and emergency management to support mobile vr safety training experiences. Construction Innovation .

Higgins, S., et al., 2012. Multi-touch tables and collaborative learning. British J. of Educational Technology 43, 1041–1054.

Hoffman, D.M., Girshick, A.R., Akeley, K., Banks, M.S., 2008. Vergence–accommodation conflicts hinder visual performance and cause visual fatigue. Journal of vision 8, 33–33.

Holm, R., Stauder, E., Wagner, R., Priglinger, M., Volkert, J., 2002. A combined immersive and desktop authoring tool for virtual environments, in: Proceedings IEEE Virtual Reality 2002, IEEE. pp. 93–100.

IMDb, 2022a. Battleship potemkin (1925), directed by sergei eisenstein. https://www.imdb.com/title/tt0015648/.

IMDb, 2022b. The blue angel (1930), directed by josef von sternberg. https://www.imdb.com/title/tt0020697/?ref_=fn_al_tt_1.

Jicol, C., Wan, C.H., Doling, B., Illingworth, C.H., Yoon, J., Headey, C., Lutteroth, C., Proulx, M.J., Petrini, K., O'Neill, E., 2021. Effects of Emotion and Agency on Presence in Virtual Reality, in: Proceedings of the 2021 CHI Conf. on Human Factors in Computing Systems, Association for Computing Machinery, New York, NY, USA. pp. 1–13. URL: https://doi.org/10.1145/3411764.3445588, doi:10.1145/3411764.3445588.

Jin, Q., Liu, Y., Yarosh, S., Han, B., Qian, F., 2022. How will vr enter university classrooms? multi-stakeholders investigation of vr in higher education, in: Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems, Association for Computing Machinery, New York, NY, USA. URL: https://doi.org/10.1145/3491102.3517542, doi:10.1145/3491102.3517542.

Jing, A., Gupta, K., McDade, J., Lee, G., Billinghurst, M., 2022. Near-gaze visualisations of empathic communication cues in mixed reality collaboration, in: ACM SIGGRAPH 2022 Posters, Association for Computing Machinery, New York, NY, USA. URL: https://doi.org/10.1145/3532719.3543213, doi:10.1145/3532719.3543213.

Jing, A., May, K.W., Naeem, M., Lee, G., Billinghurst, M., 2021. Eyemr-vis: Using bi-directional gaze behavioural cues to improve mixed reality remote collaboration, in: Extended Abstracts of the 2021 CHI Conference on Human Factors in Computing Systems, Association for Computing Machinery, New York, NY, USA. URL: https://doi.org/10.1145/3411763.3451844, doi:10.1145/3411763.3451844.

Jong, M.S.Y., Tsai, C.C., Xie, H., Kwan-Kit Wong, F., 2020. Integrating interactive learner-immersed video-based virtual reality into learning and teaching of physical geography. British Journal of Educational Technology .

Kasapakis, V., Dzardanova, E., Nikolakopoulou, V., Vosinakis, S., Xenakis, I., Gavalas, D., 2021. Social virtual reality: Implementing non-verbal cues in remote synchronous communication, in: Virtual Reality and Mixed Reality: 18th EuroXR International Conference, EuroXR 2021, Milan, Italy, November 24–26, 2021, Proceedings, Springer-Verlag, Berlin, Heidelberg. p. 152–157. URL: https://doi.org/10.1007/978-3-030-90739-6_10, doi:10.1007/978-3-030-90739-6_10.

Kavanagh, S., et al., 2017. A systematic review of virtual reality in education. Themes in Sci. and Tech. Education 10, 85–119.

Keating, P., 2009. Hollywood lighting from the silent era to film noir. Columbia University Press.

Kim, J., Choi, Y., Xia, M., Kim, J., 2022. Mobile-friendly content design for moocs: Challenges, requirements, and design opportunities, in: CHI Conference on Human Factors in Computing Systems, pp. 1–16.

Kim, S., Lee, G., Huang, W., Kim, H., Woo, W., Billinghurst, M., 2019. Evaluating the combination of visual communication cues for hmd-based mixed reality remote collaboration, in: Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems, Association for Computing Machinery, New York, NY, USA. p. 1–13. URL: https://doi.org/10.1145/3290605.3300403, doi:10.1145/3290605.3300403.

Krueger, R.A., 2014. Focus groups: A practical guide for applied research. Sage publications.

Lan, X., Wu, Y., Shi, Y., Chen, Q., Cao, N., 2022. Negative emotions, positive outcomes? exploring the communication of negativity in serious data stories, in: CHI Conference on Human Factors in Computing Systems, pp. 1–14.

Landau, D., 2014. Lighting for cinematography: a practical guide to the art and craft of lighting for the moving image. A&C Black.

Lee, L.H., Braud, T., Zhou, P., Wang, L., Xu, D., Lin, Z., Kumar, A., Bermejo, C., Hui, P., 2021. All one needs to know about metaverse: A complete survey on technological singularity, virtual ecosystem, and research agenda. ArXiv abs/2110.05352.

Li, J.V., Kreminski, M., Fernandes, S.M., Osborne, A., McVeigh-Schultz, J., Isbister, K., 2022. Conversation balance: A shared vr visualization to support turn-taking in meetings, in: Extended Abstracts of the 2022 CHI Conference on Human Factors in Computing Systems, Association for Computing Machinery, New York, NY, USA. URL: https://doi.org/10.1145/3491101.3519879, doi:10.1145/3491101.3519879.

Lieux, M., et al., 2021. Online conferencing software in radiology: Recent trends and utility. Clinical Imaging 76, 116–122.

Lin, P., Van Brummelen, J., 2021. Engaging teachers to co-design integrated ai curriculum for k-12 classrooms, in: Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems, pp. 1–12.

Liu, Z., Yan, S., Lu, Y., Zhao, Y., 2022. Generating embodied storytelling and interactive experience of china intangible cultural heritage "hua'er" in virtual reality, in: Extended Abstracts of the 2022 CHI Conference on Human Factors in Computing Systems, Association for Computing Machinery, New York, NY, USA. URL: https://doi.org/10.1145/3491101.3519761, doi:10.1145/3491101.3519761.

Louis, T., Troccaz, J., Rochet-Capellan, A., Bérard, F., 2019. Is it real? measuring the effect of resolution, latency, frame rate and jitter on the presence of virtual entities, in: Proceedings of the 2019 ACM International Conference on Interactive Surfaces and Spaces, Association for Computing Machinery, New York, NY, USA. p. 5–16. URL: https://doi.org/10.1145/3343055.3359710, doi:10.1145/3343055.3359710.

Lu, Y., Xu, Y., Zhu, X., 2021. Designing and Implementing VR^2E^2C, a Virtual Reality Remote Education for Experimental Chemistry System. Journal of Chemical Education 98, 2720–2725.

Ma, S., Zhou, T., Nie, F., Ma, X., 2022. Glancee: An adaptable system for instructors to grasp student learning status in synchronous online classes, in: CHI Conference on Human Factors in Computing Systems, pp. 1–25.

Mascelli, J.V., 1965. The five C's of cinematography. volume 1. Grafic Publications.

Millerson, G., 2013. Lighting for TV and Film. Routledge.

Nebeling, M., Lewis, K., Chang, Y.C., Zhu, L., Chung, M., Wang, P., Nebeling, J., 2020. Xrdirector: A role-based collaborative immersive authoring system, in: Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems, pp. 1–12.

Nebeling, M., Rajaram, S., Wu, L., Cheng, Y., Herskovitz, J., 2021. Xrstudio: A virtual production and live streaming system for immersive instructional experiences, in: Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems, pp. 1–12.

Nykvist, S., Bertolucci, B., Mastoianni, M., 2003. Making pictures: a century of European cinematography. Harry N. Abrams.

Ogunseiju, O.O., Akanmu, A.A., Bairaktarova, D., 2021. Mixed reality based environment for learning sensing technology applications in construction .

Pei, S., Chen, A., Lee, J., Zhang, Y., 2022. Hand interfaces: Using hands to imitate objects in ar/vr for expressive interactions, in: Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems, Association for Computing Machinery, New York, NY, USA. URL: https://doi.org/10.1145/3491102.3501898, doi:10.1145/3491102.3501898.

Petersen, G.B., Mottelson, A., Makransky, G., 2021. Pedagogical agents in educational vr: An in the wild study, in: Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems, Association for Computing Machinery, New York, NY, USA. URL: https://doi.org/10.1145/3411764.3445760, doi:10.1145/3411764.3445760.

Piumsomboon, T., Lee, Y., Lee, G., Billinghurst, M., 2017. Covar: A collaborative virtual and augmented reality system for remote collaboration, in: SIGGRAPH Asia 2017 Emerging Technologies, Association for Computing Machinery, New York, NY, USA. URL: https://doi.org/10.1145/3132818.3132822, doi:10.1145/3132818.3132822.

Potkonjak, V., Gardner, M., Callaghan, V., Mattila, P., Guetl, C., Petrović, V.M., Jovanović, K., 2016. Virtual laboratories for education in science, technology, and engineering: A review. Computers & Education 95, 309–327.

Pottle, J., 2019. Virtual reality and the transformation of medical education. Future healthcare journal 6, 181.

Prasolova-Førland, E., McCallum, S., Estrada, J.G., 2021. Collaborative learning in vr for cross-disciplinary distributed student teams, in: 2021 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW), pp. 320–325. doi:10.1109/VRW52623.2021.00064.

Prince, S., 2011. Digital visual effects in cinema: The seduction of reality. Rutgers University Press.

Radianti, J., Majchrzak, T.A., Fromm, J., Wohlgenannt, I., 2020. A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda. Computers & Education 147, 103778.

Rahman, Y., Asish, S.M., Khokhar, A., Kulshreshth, A.K., Borst, C.W., 2019. Gaze data visualizations for educational vr applications, in: Symposium on Spatial User Interaction, Association for Computing Machinery, New York, NY, USA. URL: https://doi.org/10.1145/3357251.3358752, doi:10.1145/3357251.3358752.

Rajaram, S., Nebeling, M., 2022. Paper trail: An immersive authoring system for augmented reality instructional experiences, in: Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems, Association for Computing Machinery, New York, NY, USA. URL: https://doi.org/10.1145/3491102.3517486, doi:10.1145/3491102.3517486.

Ren, H., Hornecker, E., 2021. Comparing understanding and memorization in physicalization and vr visualization, in: Proceedings of the Fifteenth International Conference on Tangible, Embedded, and Embodied Interaction, Association for Computing Machinery, New York, NY, USA. URL: https://doi.org/10.1145/3430524.3442446, doi:10.1145/3430524.3442446.

Salt, B., 1977. Film style and technology in the forties. Film Quarterly 31, 46–57.

Shoufan, A., 2019. What motivates university students to like or dislike an educational online video? a sentimental framework. Computers & education 134, 132–144.

Speicher, M., Hall, B.D., Nebeling, M., 2019. What is mixed reality?, in: Proceedings of the 2019 CHI conference on human factors in computing systems, pp. 1–15.

Suzuki, R., Kazi, R.H., Wei, L.Y., DiVerdi, S., Li, W., Leithinger, D., 2020. Realitysketch: Embedding responsive graphics and visualizations in ar through dynamic sketching, in: Proceedings of the 33rd Annual ACM Symposium on User Interface Software and Technology, pp. 166–181.

Tlili, A., Huang, R., Shehata, B., Liu, D., Zhao, J., Metwally, A.H.S., Wang, H., Denden, M., Bozkurt, A., Lee, L.H., Beyoglu, D., Altinay, F., Sharma, R.C., Altinay, Z., Li, Z., Liu, J., Ahmad, F., Hu, Y., Salha, S., Abed, M., Burgos, D., . Is metaverse in education a blessing or a curse: a combined content and bibliometric analysis 9, 24. URL: https://doi.org/10.1186/s40561-022-00205-x, doi:10.1186/s40561-022-00205-x.

Velev, D., Zlateva, P., 2017. Virtual Reality Challenges in Education and Training. International J. of Learning 3, 33–37. doi:10.18178/IJLT.3.1.33-37.

Wei, Z., Chen, Y., Tong, W., Zong, X., Qu, H., Xu, X., Lee, L.H., 2024a. Hearing the moment with metaecho! from physical to virtual in synchronized sound recording, in: Proceedings of the 32nd ACM International Conference on Multimedia, Association for Computing Machinery, New York, NY, USA. p. 6520–6529. URL: https://doi.org/10.1145/3664647.3681004, doi:10.1145/3664647.3681004.

Wei, Z., Jin, S., Tong, W., Yip, D.K.M., Hui, P., Xu, X., 2024b. Multi-role vr training system for film production: Enhancing collaboration with metacrew, in: ACM SIGGRAPH 2024 Posters, pp. 1–2.

Wei, Z., Xu, X., Lee, L.H., Tong, W., Qu, H., Hui, P., 2023. Feeling present! from physical to virtual cinematography lighting education with metashadow, in: Proceedings of the 31st ACM International Conference on Multimedia, pp. 1127–1136.

Wickens, C.D., 1992. Virtual reality and education. IEEE International Conference on Systems, Man and Cybernetics .

Winkler, R., et al., 2020. Sara, the Lecturer: Improving Learning in Online Education with a Scaffolding-Based Conversational Agent. ACM, NY, USA. p. 1–14.

Xu, X., Tong, W., Wei, Z., Xia, M., Lee, L.H., Qu, H., 2023. Cinematography in the metaverse: Exploring the lighting education on a soundstage, in: 2023 IEEE conference on virtual reality and 3d user interfaces abstracts and workshops (VRW), IEEE. pp. 571–572.

Xu, X., Yang, L., Yip, D., Fan, M., Wei, Z., Qu, H., 2022. From 'wow'to 'why': Guidelines for creating the opening of a data video with cinematic styles, in: CHI Conference on Human Factors in Computing Systems, pp. 1–20.

Yalow, E., Snow, R.E., 1980. Individual Differences in Learning from Verbal and Figural Materials. Technical Report. Stanford Univ Calif School of Education.

Yassien, A., ElAgroudy, P., Makled, E., Abdennadher, S., 2020. A design space for social presence in vr, in: Proceedings of the 11th Nordic Conference on Human-Computer Interaction: Shaping Experiences, Shaping Society, Association for Computing Machinery, New York, NY, USA. URL: https://doi.org/10.1145/3419249.3420112, doi:10.1145/3419249.3420112.

Youngblut, C., 1998. Educational uses of virtual reality technology. .

Zhang, L., Oney, S., 2020. Flowmatic: An immersive authoring tool for creating interactive scenes in virtual reality, in: Proceedings of the 33rd Annual

ACM Symposium on User Interface Software and Technology, Association for Computing Machinery, New York, NY, USA. p. 342–353. URL: https://doi.org/10.1145/3379337.3415824, doi:10.1145/3379337.3415824.

Zhang, S., Liu, Q., 2019. Investigating the relationships among teachers' motivational beliefs, motivational regulation, and their learning engagement in online professional learning communities. Computers & Education 134, 145–155.

Zhao, Y., Jiang, J., Chen, Y., Liu, R., Yang, Y., Xue, X., Chen, S., 2022. Metaverse: Perspectives from graphics, interactions and visualization. Visual Informatics 6, 56–67.

Zhou, R., Wu, Y., Sareen, H., 2020. Hextouch: Affective robot touch for complementary interactions to companion agents in virtual reality, in: 26th ACM Symposium on Virtual Reality Software and Technology, Association for Computing Machinery, New York, NY, USA. URL: https://doi.org/10.1145/3385956.3422100, doi:10.1145/3385956.3422100.

9. Appendix A

	Foundational Lighting Lesson Outline (30 minutes in total)
1 (two minutes) Introduction by Teacher	Enter the Art Mirror and check the surrounding area. The instructor describes the setting and pertinent details.
2 (two minutes) Demonstration by Teacher	Demonstrate the features and specialized applications of two types of lighting in an open soundstage space. 2.1. Instructing the light's location to shift 2.2 Instruction in the tilt, left-to-right, and up-and-down motions of the light head 2.3 Instruction in light and dark color adjustment 2.4 Adjustment Instructions for the Camera Display
3 (ten minutes) Teaching by Teacher	Detailed lighting directives Simulation of the dusk light effect at sunset lighting Step 1: Identify the location of the primary light source, position the appropriate lamps and lanterns, and adjust the height, angle, and other relevant factors. The remote monitor can display the camera's screen light effect changes in real-time. Step 2: Layout the house's distributed lighting, position the appropriate lights, and adjust the height, angle, and other relevant factors. The remote monitor may show the camera location and screen light effect changes in real-time. In Step 3: the position of the auxiliary light source is determined, the associated bulbs are placed, and the height, angle, and other relevant parameters are adjusted. The remote monitor may show the camera's screen light effect changes in real time. In Step 4: the location of the trim light source is determined, the matching lamps and lanterns are placed, the height, angle, and other relevant parameters are adjusted, and the remote monitor may show the change in the light effect of the camera position screen in real-time. The instructor will explain the function and significance of the primary light, auxiliary light, dispersed light, and finishing light during the demonstration.
4 (ten minutes) Training by Student	Students handle their own indoor night scene lighting Simulate the effects of sunset and dusk illumination Step 1: Determine the location of the primary light source, position the appropriate lights, and adjust the height, angle, and other relevant characteristics. The remote monitor may show the camera's screen light effect changes in real time. Step 2: Layout the house's distributed lighting, position the appropriate lights, and adjust the height, angle, and other relevant factors. The remote monitor may show the camera location and screen light effect changes in real-time. In Step 3: the position of the auxiliary light source is determined, the associated bulbs are placed, and the height, angle, and other relevant parameters are adjusted. The remote monitor may show the camera's screen light effect changes in real time. In Step 4: the position of the trim light source is determined, the associated lights are placed, and the height, angle, and other relevant parameters are adjusted. The remote monitor may show the real-time alteration of the camera location screen's light effect.
5 (three minutes) Remarks by Teacher	Teacher's remarks

Figure 12: A foundational lighting lesson outline in the user study by using *Art Mirror*

10. Appendix B

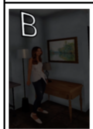
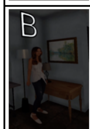
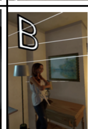
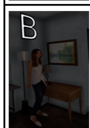
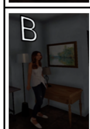
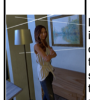
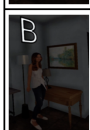
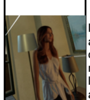
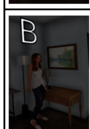
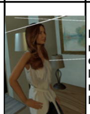
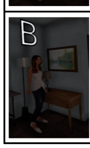
Before-Lighting Setup	After-Lighting Setup	Teacher's Comments on the Student's Work	Student's Feedback Regarding Learning Experiences
		**P1 (T1)** The lighting arrangement for the indoor night scene is completed to a high precision, and it is possible to differentiate between outdoor and indoor light due to the difference in light source and color changes. However, when the scenario comes to the outdoor lighting being chosen, the HMI lighting height is insufficient, and the simulated moonlight light irradiation angle is a bit unrealistic. Simply seeing the light on a person's body is acceptable, but the angle of outside light irradiation is difficult to restore when considering the light of the person's surroundings further. Overall, the way of lights are set up inside gives a good impression, but the color of the lights is too yellow and doesn't match the setting.	**P2 (S1)** The simulator made me feel like I could use these lights much faster in virtual reality than in real life, and that I had a better understanding of lighting, which I thought was very clever and more effective than traditional ways of learning.
		**P3 (T2)** The lighting is well-managed. There is a clear distinction between warm and cool light, and the light control on the character's face is well balanced. The usage of LED as an outdoor light source, the light's brightness, and its color may be subtly adjusted. The ambience of the inside night scene is likewise well-controlled. This instance of indoor environment lighting is quite effective.	**P4 (S2)** The system is much simpler to use than conventional learning since we can manage as many luminaires as we like inside the system, modifying the characteristics of each light, and the guide lines and angle markers allow me to manipulate the light's direction, location, and intensity.
		**P5 (T3)** This lighting outcomes has a significant flaw, since interior light is often provided by internal artificial light sources, such as table lamps, floor lights, dining room chandeliers, candles, living room fireplaces, etc. The blue light in the interior of this lighting example resembles the impression of moonlight but is overly strong, resulting in an interior that does not have a true nighttime feel. The benefit is that the choice of light color and lighting angle are quite precise.	**P6 (S3)** I personally found learning lighting methods in VR to be quite intriguing. Compared to conventional schooling, I found it simpler to comprehend the complexity of lighting, and I was able to create scenes that I liked using these tools. Future skill development will include continued usage of this virtual lighting tool.
		**P7 (T4)** The light control is excellent, with a distinct differentiation between warm and cool light. The lighting ratio of the character's face is managed appropriately. The brightness, hue, and angle of the outside lighting source may be precisely adjusted. The brightness of the interior illumination is well managed. The ambience of the interior night setting is nicely crafted. This example of interior environment effect lighting is effective.	**P8 (S4)** After knowing how to use the VR equipment, I was able to rapidly create my own images using the lighting offered in the VR virtual training situations. The system was simple to use and accomplished the majority of the features we needed for our investigations.
		**P9 (T5)** There are three lighting issues with this pupil. The color of moonlight that is mimicked outside is inaccurate. The color is very blue, which detracts from the overall aesthetic. Second, the outside region is too bright while the inside light is too dim, preventing the characters in the indoor area from producing substantial shifts in light and shadow and preventing them from modeling the light. Finally, the difference between the main and secondary light on the face of the figure is unclear.	**P10 (S5)** This method works well for my training and observation needs because the operation is easy to understand and the information can be reviewed after class, even if the class didn't learn it the first time.
		**P11 (T6)** This student's illumination was excellent. Using LEDs to imitate the appearance of a flame light source, he created a more realistic light source effect on both the face and torso of the figure by simulating the impact of a fireplace in a night scenario. In addition, he distinguished clearly between the warm and cold light effects on the figure. The light ratio adjustment on the face of the figure was accurate, and the simulation of moonlight outside was convincing.	**P12 (S6)** In Art Mirror, I felt like I was operating in a genuine studio due to the realistic lighting and environments. I felt so gratified after finishing a course. When I'm in a real studio, I'm certain I'll be able to do the essential tasks.
		**P13 (T7)** There are two lighting issues with this pupil. The hue of the moonlight represented outside is wrong and too green, thus detracting the viewing experience as a whole. Another problem is that the interior lighting finished the lighting, making the area brighter, but did not enable the figures in the room to make substantial variations in light and shadow, thus preventing the lighting from being modeled.	**P14 (S7)** This virtual studio configuration is extremely enjoyable! Before I knew it, a lesson had passed, and I believe that it was an enjoyable and instructive experience that made me eager for future studio sessions. In the meantime, I'd like to use Art Mirror in my spare time to work on lighting setups and operations.
		**P15 (T8)** The lighting control of this student was poor, and although the color difference between inside and outdoor light was attained, the constract between indoor and outdoor light was too low, resulting in no discernible shift in the light on the characters' faces. The total lighting was too uniform and lacked significant contrast, which resulted in this light only illuminating the surroundings and not modeling them with the luminaires.	**P16 (S8)** Even though the auxiliary lines are extremely helpful and the light movement operations helped my understanding, I believe I still need further practice to acquire the sense of lighting setup.

Figure 13: Gallery for user study feedback from 16 participants (eight students and eight teachers). The first column on the left is the before-lighting setup. The second column is the after-lighting setup; from top to bottom, are the lighting setup effects done by Student 1 to Student 8 after the foundational lighting lesson and training. In the third column, from top to bottom, are the comments from teacher 1 to teacher 8 on the lighting effects of the student's work. The fourth column, from top to bottom, is from S1 to S8's feedback regarding learning experiences.