Exploring Stage Lighting Education in Metaverse

Wai Tong
Texas A&M University
College Station, Texas, USA
wtong@tamu.edu

Meng Xia
Texas A&M University
College Station, Texas, USA
mengxia@tamu.edu

Huamin Qu
The Hong Kong University of Science and Technology
Hong Kong SAR, China
huamin@cse.ust.hk

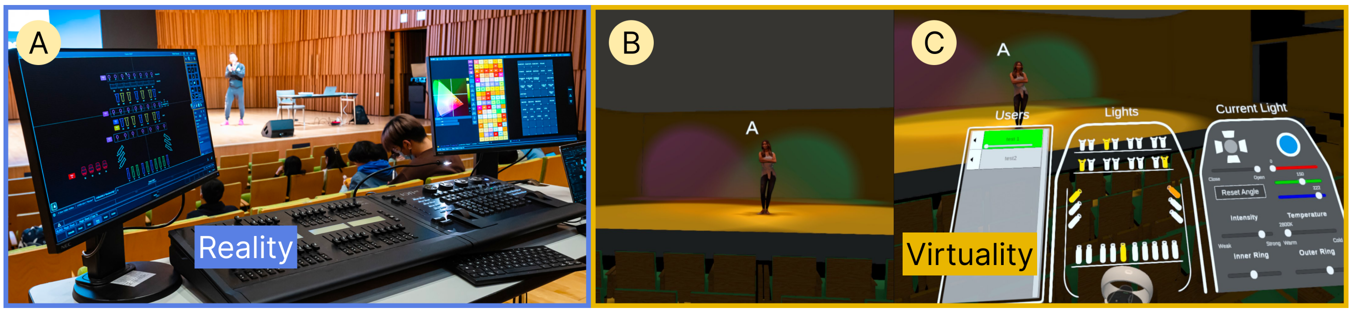

Figure 1: We developed a VR prototype for stage lighting education. The real-world stage lighting scenarios (a) are mimicked by a virtual auditorium (b) for learning purposes while providing a user-friendly but non-realistic user interface and interaction for efficient controls (c).

ABSTRACT

This paper investigates stage lighting education in the metaverse from a practical perspective. We conducted participatory design with practitioners and stakeholders from a local university to develop a VR-based stage lighting system for the Technical Theater Arts course. Over six months, we derived a list of design requirements (e.g., Level of realism serves the purpose of learning) and developed a prototype VR system for stage lighting education. Our contributions include the establishment of design requirements for stage lighting education in the metaverse, the development of a prototype system, and insights from integrating VR in course development. This research paves the way for further exploration and refinement of VR applications in educational settings.

CCS CONCEPTS

• **Human-centered computing** → **Virtual reality**; • **Applied computing** → **Education**; **Performing arts**.

KEYWORDS

Stage lighting education, virtual reality, participatory design

ACM Reference Format:
Wai Tong, Meng Xia, and Huamin Qu. 2024. Exploring Stage Lighting Education in Metaverse. In *Extended Abstracts of the CHI Conference on Human Factors in Computing Systems (CHI EA '24), May 11–16, 2024, Honolulu, HI, USA.* ACM, New York, NY, USA, 6 pages. https://doi.org/10.1145/3613905.3650924

CHI EA '24, May 11–16, 2024, Honolulu, HI, USA

ACM ISBN 979-8-4007-0331-7/24/05
https://doi.org/10.1145/3613905.3650924

1 INTRODUCTION

Metaverse has emerged as a prominent and transformative influence in education, offering innovative solutions to address challenges associated with resource-intensive learning environments and physical limitations that hinder student access. This paradigm shift allows for the scaling up of educational experiences, providing learners with immersive opportunities previously constrained by cost or logistical feasibility.

The ongoing evolution of immersive technologies, coupled with the exploration of the Metaverse, has led to a diverse range of studies investigating the impact of VR on various learning scenarios. From health-related [1, 21] and foreign language learning [12, 14] to computer science [6, 15] and science education [8, 13], VR has demonstrated notable advantages, including increased student motivation, enjoyment, and understanding compared to traditional methods [10]. A recent study by Villena *et al.* [18] highlighted the efficacy of immersive VR in promoting greater student learning. Beyond motivational benefits, VR addresses physical limitations in traditional learning environments, offering innovative opportunities, such as teaching cinematography in the Metaverse [19, 20]. However, much of the existing research has been confined to one-time lab sessions/experiments for a particular learning task, necessitating a comprehensive examination of VR in designing an actual course perspective.

This work aims to bridge this gap by exploring the use of VR in real-world practice, providing valuable insights for educators and stakeholders seeking to harness the full potential of VR in education. We focus on stage lighting education since it is in demand in the real world from a local university. First, students from different campuses could not access the auditorium that provided the stage and lighting equipment for learning. Second, the auditorium might be occupied by other events, which limits the usage and practice of students. Third, instructors worry about causing damage to professional equipment while teaching and learning, limiting the hands-on experience for students to learn.

As a result, we cooperate with the university to work with instructors and staff from the media technology center to implement stage lighting education (a major part of the Technical Theater Arts Course) with VR technology. Employing a participatory design approach, a multidisciplinary team, including the course instructor of stage lighting, a practitioner of stage lighting, and the director and the head of the media technology center, engaged in a six-month iterative development process for the Technical Theater Arts Course scheduled in Spring 2024. This collaborative effort resulted in design requirements encompassing efficacy in learning assessment, the importance of realism, the need for seamless communication, and the centrality of usability. Guided by these criteria, a VR prototype system was developed to meet the design requirements for virtual stage lighting education. We further discussed the lessons learned during the co-design and development between different stakeholders. Due to the late-breaking nature of this work, one more iteration on system development with the participation of students and the comprehensive evaluation will be covered in future work. In conclusion, the contributions of this late-breaking work are:

- a set of design requirements for stage lighting education distilled from a multidisciplinary team with different stakeholders
- a prototype VR system for stage lighting education based on the design requirements
- lessons learned in developing course with VR technology

2 RELATED WORK

The intersection of VR and education has become a focal point in recent years, capturing the attention of researchers and education practitioners [10]. The ongoing evolution of immersive technologies drives this heightened interest. Within this landscape, there is a growing exploration of how the Metaverse can significantly impact various learning scenarios, ranging from health-related [1, 21], foreign language learning [12, 14] to computer science [6, 15] and science education [8, 13].

Notable advantages of leveraging VR in education are increased students' motivation, enjoyment, and understanding compared to traditional methods [10]. For example, a recent study by Villena *et al.* [18] concluded that immersive VR can promote greater student learning compared to control conditions by analyzing 21 studies from 2010 and 2021. Moreover, a recent work by Zhu *et al.* [21] demonstrated that VR improves situated awareness in health-related education. They showed that VR data stories can promote situated awareness by enhancing people's connection to risky situations in public health education compared to 2D data stories. Moreover, a fully immersive VR experience with a head-mounted display offers a higher sense of presence than a 3D desktop application [16], which might possibly increase memory [3] and support better skill learning [5] and embodied learning [9]. The immersive nature of VR has the potential to transform the learning experience, making it more dynamic and participatory for students. These benefits are a promising aspect of the Metaverse's role in education.

Moreover, VR presents a solution to physical limitations that traditional learning environments may face, such as resource constraints or the inherent risks associated with certain places. For instance, researchers [19, 20] have delved into the exploration of teaching cinematography in the Metaverse, highlighting the platform's ability to transcend traditional constraints and create innovative learning opportunities. The irrelevant to the physical world promotes distance learning, which allows students to access learning materials and resources anytime and anywhere.

However, it is important to note that much of the existing research on education in the metaverse, especially lighting-related education, has been conducted in controlled laboratory settings, often focusing on specific aspects of course design. This narrow scope limits our understanding of the practical deployment of VR technology in real-world course practices. To address this gap, we aim to study how to utilize VR in the course from a practical view. This includes building the learning platform, supporting communication between instructors and students, and enabling the evaluation of the learning outcome. Many practical considerations have been covered, including the realism of the scene and interactions. We aim to contribute valuable insights for educators and stakeholders looking to harness the full potential of VR in education.

3 PARTICIPATORY DESIGN AND DESIGN REQUIREMENTS

To better design a system that fits into and enhances the existing practice and gather more practical insights, we adopt participatory design research practise [17]. We co-designed with different stakeholders in the university and iteratively discussed and developed the prototype for the Technical Theater Arts Course that will be taught in the Spring of 2024, starting in February. This approach ensures that the VR system for stage lighting education aligns with the specific needs and workflows of the educational environment, enhancing its effectiveness and relevance.

3.1 Context

Our context is stage lighting education. It is one major part of the Technical Theater Arts Course at the local university. It is conducted in the hall of the auditorium on the main campus. This course was designed for students interested in stage management, lighting, sound, and video setup.

3.2 Participants

We worked closely with four key stakeholders: the course instructor of stage lighting, a stage lighting practitioner, the director, and the head of the media technology center.

3.3 Methods and Timeline

Over six months, we engaged in a co-design process to develop the VR system for theater lighting education. To accommodate the diverse schedules and locations of our participants, we alternated between in-person and remote meetings, convening bi-weekly to ensure consistent progress and engagement. Each session was planned to focus on specific aspects of the system's design and functionality, allowing us to gather targeted feedback and insights. At the same time, our development approach was iterative, emphasizing the importance of regular input and feedback from our stakeholders. This iterative process helped refine the system's features and usability and ensured that the final product closely aligned with the real-world needs and expectations of those in the field of stage lighting education.

3.4 Result

We adopted thematic analysis [2] on the feedback from the biweekly meetings and discussions. The analysis consists of two steps. First, two authors independently open-coded [4] the feedback (excluding technical details such as bug reports and UI design) from the biweekly meetings and discussions. When there was confusion or conflict regarding any code, the coder would explain the code, and then two coders would discuss it until they reached a consensus before modifying the code. We generated seven codes (flexibility, safety, learning assessment, realism, communication, usability, and replacement of learning in reality). Second, we further discussed and organized them into three themes: motivation & educational benefits, design requirements, and evaluation of learning outcomes.

3.4.1 Motivation & Educational Benefits. The primary motivation for utilizing VR in stage lighting education stems from its flexibility and safety. VR enables students to learn at any time and place without needing access to a physical theater or equipment, which might be otherwise engaged. This virtual environment allows for extensive experimentation and exploration without the risk of damaging expensive professional equipment.

3.4.2 Requirements. Requirements can be summarized in learning assessment, realism, communication, and usability.

- **Support teaching mode and assessment mode in VR (R1)**: The VR platform should support both the teaching mode and the assessment mode. In teaching mode, it enables communication between the teacher and students and also among students. The teacher can better demonstrate lighting and instruct students. It also enables group activities in the metaverse. In assessment mode, students can practice themselves without receiving help from instructors or peers so that their performance can be assessed. Extra functions should be provided to facilitate assessment, e.g., recording for homework.
- **Level of realism serves the purpose of learning (R2)**: Researchers generally seek highly realistic VR rendering and interaction for better user experience. However, in education, the level of realism of the components serves the purpose of learning.
  Certain elements require high fidelity for learning purposes (R2-1) The physical structure of lights, including barn doors and hangers, and the interaction mechanisms for rotating lights and adjusting their degrees of freedom should be as realistic as possible. The graphics, particularly light effects, are crucial for an authentic learning experience. The space and the layout of the seats and lights should match the real-world setting to facilitate the transfer of learning from the metaverse to the real world. For these aspects, if realism cannot be achieved due to technical constraints, the information should be conveyed to the learners clearly to avoid misunderstanding and confusion in learning. For example, the system should communicate the limitations of the virtual environment, such as the constraint of having only eight lights operational simultaneously in Unity.
  Other aspects that need not be highly realistic (R2-2) Aspects like the texture and fine-grained details of objects, such as the performers on stage and background scenes, need not be highly realistic, though they should be easy for the learners to recognize. Moreover, the interaction mechanism could be non-realistic. In a real auditorium, some lights need to be pulled down to the ground from the ceiling to adjust the angle. The control panel is also only set in a specific location. However, in the metaverse, these interactions could be optimized for learning purposes and designed to be anti-physic for easy manipulation. For example, every student has a control panel beside their controller, and they can adjust the angle of every light using the control panel anywhere.
- **Offer channels for natural communication (R3)**: To facilitate teaching activities and the communication between the instructors and the students, as well as students and students, the system should provide channels for natural communication in VR, such as gesture and voice. Rather than typing, gesture and voice may introduce less cognitive load during the learning process.
- **Provide user-friendly user interface (R4)**: The user interface (UI) must be intuitive, facilitating effective learning outcomes. An example is a light control panel that allows students to adjust light properties and observe the effects in real-time, familiarizing them with the characteristics of theater lighting equipment.

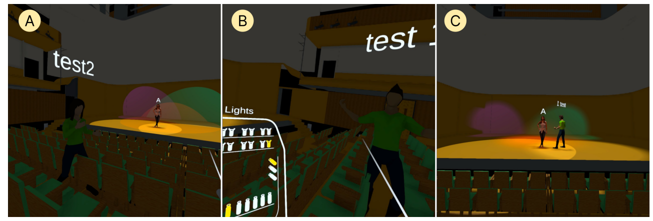

Figure 2: This figure shows the shared virtual auditorium with two users. (a) the point of view from the user named "test 1". (b) the point of view from the user named "test 2". (c) user "test 2" is observing the light effect with user "test 1" on stage with the animated avatar.

3.4.3 Evaluation of Learning Outcomes. The ability of the VR system to represent learning outcomes in the real world is a key consideration. While the metaverse can accelerate the acquisition of stage lighting knowledge by providing unlimited access to virtual space and equipment, VR cannot entirely replace learning in reality, as students still need hands-on experience with physical equipment to fully acquire the necessary skills. The ultimate role of VR in stage lighting education is to quickly impart knowledge and concepts before students proceed to actual practice.

4 SYSTEM

We iteratively developed a prototype based on the requirements distilled. In this section, we provide a comprehensive overview of the design and functionality of our immersive educational platform, followed by the implementation details of the prototype.

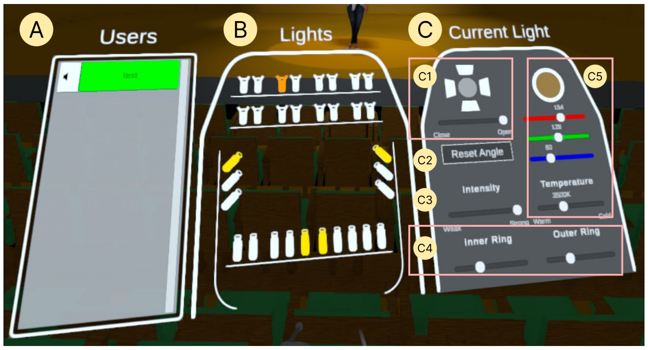

Figure 3: This figure shows the user interface for the VR stage lighting education system. (a) the user list panel that shows a list of current users in the shared virtual space. (b) the light plan panel that shows the 2D map of the lights' location and its corresponding state. (c) the control panel of the currently selected light. It can modify values including (c1) barn doors control, (c2) reset angle button, (c3) intensity slider, (c4) inner and outer ring angles, and (c5) color and temperature.

4.1 Teaching and Assessment

The system accommodates both teaching and assessment modes, harmonizing collaborative teaching and individualized assessment. A focal point on seamless teacher-student interactions affords versatility for diverse instructional tasks, encompassing one-to-many teaching and individual assessment.

Teaching Mode: Within the teaching mode, the system establishes a shared environment conducive to teaching scenarios (R1), as shown in Figure 2. This mode is specifically designed to facilitate synchronous interactions and the state of the lights between instructors and students, fostering real-time engagement, discourse, and shared exploration of stage lighting effects. As such, all light settings are shared between instructors and students. The changes made by one user are immediately affected and reflected by other users. *Communicative Features.* To allow teacher-student and student-student communication, voice chat is provided (R3). Moreover, to facilitate the visibility of different users in the same room and the usage of body language during teaching, we provided full-body avatars for each user.

Assessment Mode: Conversely, the assessment mode is designed to cater to individualized assessments (R1). This mode provides a dedicated space for students to engage in self-directed learning and undertake assignments independently. Teachers can assign tasks and assignments to students individually, instead of collaboratively in the teaching mode. *Recording.* We utilized the built-in recording and screenshot functions provided by the headset for assignment recording (R1).

4.2 User Interface and Interactions

To allow students to set up and observe lights for a stage, we implemented a user interface and interactions for users to control different light settings and navigate the virtual environment.

4.2.1 Interface Design. The system presents a familiar WIMP-style user interface for users to control the light settings (R4). The UI is attached to the user's left-hand controller; thus, users can freely edit the light setting regardless of their current location in the virtual auditorium. The interface is divided into three panels: the **user list panel**, **light plan panel**, and the **control panel** (Figure 3).

To facilitate easy communication, we create a **user list panel**, as shown in Figure 3(A), for users to be aware of the current users in the room and whether they are speaking or not. The user list panel will be displayed on the left side of the light plan panel only when users enter teaching mode. From there, users can adjust the volume of other participants using the sliders or mute their voices in the room by clicking on the mute icon button.

A **light plan panel**, as shown in Figure 3(B), is provided on the UI for users to learn the position of the lights. The light plan is arranged in rows and columns, depicting individual stage lights with distinct icons. The icons are color-coded, suggesting different types or states of lighting status, i.e., white for off, yellow for on, and orange for selected. This panel also serves as a selection interface, where a user can choose specific lights to control or inspect instead of picking the light on the ceiling.

Once a light has been selected, the **control panel** opens on the right, as shown in Figure 3(C), which exhibits a more detailed set of controls for manipulating the selected light. This panel includes sliders and buttons that allow for the adjustment of various light properties, including: **Shape.** Users can also adjust the barn doors' openness of each light to create different light shapes, as shown in Figure 3(C1). Each light has four barn doors; users can use the icon on the top left corner to select one door for adjustment. Users can use the slider below to adjust the opening angle of the selected barn door. All barn doors are opened by default. **Rotation.** Users can change the rotation of the light by using the thumbstick on the controller. A "Reset Angle" button is presented in the UI (Figure 3(C2)) to reset the positioning of the selected light to a default state. **Intensity.** Intensity affects the lights' brightness. A slider allows the user to modify the brightness of the light from 'Weak' to 'Strong' Figure 3(C3). **Field Angle and Focus.** Users can adjust the field angle by modifying the outer ring angle of the light. Operating with the inner ring angle slider can adjust the focus of the light, resulting in a different presentation of the shadow. These operations could be done using the sliders at the bottom as shown in Figure 3(C4). **Color.** We include three slides for users to adjust the RGB value of the current light selected light color on the top right corner of the control panel (Figure 3(C5)). Moreover, we introduce *temperature* as a dynamic element influencing light color (R2). It incorporates domain-specific terms, enriching the overall learning experience in real-world scenarios. Users can use the sliders to change the color from "cold" to "warm".

4.2.2 Locomotion. Users can teleport to any floor, including the stage, in the virtual auditorium using the trigger button of the controller. To allow users to observe the stage lighting effect from the perspective of audiences, we placed several rows of seats for users to teleport to experience the actual effect in different locations.

4.3 Real-world Scenario Integration

The background scene is crafted using the actual layout of the physical stage and supplemented with real-world objects, including animated performer models (R2; Figure 1). This approach enables students to bridge the gap between virtual and real-world applications, promoting a deeper understanding and practical application of theoretical knowledge.

4.4 User Awareness of Limitations

Our VR application comes with a prompt system, ensuring users are aware of the limitations inherent in the virtual environment (R2). A warning is displayed to the user when more than eight lights are turned on, as additional lights would have no effect due to system limitations. This feature is essential for clearly understanding the differences between reality and virtual reality, enabling students to apply knowledge in the real world with informed expectations.

4.5 Implementation

The prototype system is developed for users to use with Meta Quest Pro, a state-of-the-art standalone VR head-mounted display with high rendering and computation power. The system is developed using the Unity game engine, selected for its versatility and suitability on mobile and standalone VR devices. We used Unity Netcode to facilitate networking features, ensuring seamless collaborative interactions. The voice communication is supported by Vivox service in Unity. The 3D scene is constructed using a Building Information Modeling (BIM) model of an actual auditorium and simplified (for example, removing fine-grained details, merging identical objects, and reducing the number of polygons) through the 3D modeling tool Blender to deliver a familiar and smooth virtual environment.

5 DISCUSSIONS

Supporting Dynamic Level of Realism for Learning Purpose. Our participatory design process with stakeholders and practitioners suggests that the level of realism of the components serves the purpose of learning, echoing Xu et al.'s findings [20]. We identified more detailed requirements that, on the one hand, the virtual elements closely related to learning goals should be as real as possible. For example, our prototype design emphasizes realistic light effects and accurate spatial layouts to enhance learning transfer. If technical constraints limit the realism of visual elements related to learning performance, the system needs to communicate this limitation to learners, such as Unity only supports eight lights simultaneously, to avoid confusion when they switch on more than eight lights. Other aspects not closely related to learning goals can be abstracted without much negative impact, for example, the performers' details (e.g., facial expressions). Moreover, sometimes VR environments can loosen physical-world constraints to accelerate learning. For example, the students can manipulate light much easier with a UI interface following the students than with reality. However, during the meetings with the stakeholders, they mentioned stage lighting safety instruction learning could be one of the potential course content. The requirement for realism would be different for this topic; instead of focusing on the lighting effect, the manipulation of lights should be as realistic as possible. Lastly, it might also be helpful to consider collaborative learning scenarios where students have different roles or learning goals to be achieved. Realism could be dynamic for different students to fit their learning goals in the VR environment for personalized learning.

Transfer Learning from Metaverse to Reality. It is important to think about whether the effectiveness of the learning in the VR system can mirror real-world learning outcomes. The metaverse offers a significant advantage in teaching theater lighting by allowing unrestricted access to virtual spaces and tools. The instructor and stakeholders mentioned that while VR is excellent for conveying theoretical knowledge and concepts, it cannot replace the practical, hands-on experience required in stage lighting. The tactile and sensory aspects of working with real light equipment are crucial for complete stage lighting skill development. In this context, VR serves as a valuable precursor to hands-on practice, efficiently imparting foundational knowledge. Therefore, a suggested future direction is to explore the optimal distribution of VR and reality-based courses, ensuring that students learn theoretical concepts in the virtual auditorium and apply them in real-world scenarios. This approach aims to harness the strengths of both environments, addressing VR's limitations by integrating practical experiences. Another direction would be enhancing the tactile experience in VR, as discussed by Levac et al. [11]. Finding ways to simulate hands-on practice within VR, perhaps through advanced haptic feedback or realistic equipment interactions, can bridge the gap between virtual and real-world learning.

6 CONCLUSION AND FUTURE WORK

In this paper, we conducted a participatory design with practitioners and stakeholders to explore utilizing stage lighting education in a course. We derived a list of design requirements from a practical view and developed a prototype system to reflect the design requirements. For the next steps, we will explore more novel educational interactions in VR rather than simulating the auditorium [7] and conduct long-term studies in the course to measure the effectiveness of skills and knowledge acquired in the VR environment when applied in real-world stage lighting setups. In addition, we will evaluate the effectiveness of VR-based assessments compared to traditional methods to understand the potential of VR environments in standardized testing and certification within technical education fields.

REFERENCES

[1] Marie-Stéphanie Bracq, Estelle Michinov, and Pierre Jannin. 2019. Virtual reality simulation in nontechnical skills training for healthcare professionals: a systematic review. *Simulation in Healthcare* 14, 3 (2019), 188–194. https://doi.org/10.1097/SIH.0000000000000347
[2] Virginia Braun, Victoria Clarke, Nikki Hayfield, and Gareth Terry. 2019. *Thematic Analysis.* Springer Singapore, Singapore, 843–860. https://doi.org/10.1007/978-981-10-5251-4_103
[3] Lénaïc B Cadet and Hanna Chainay. 2020. Memory of virtual experiences: Role of immersion, emotion and sense of presence. *International Journal of Human-Computer Studies* 144 (2020), 102506. https://doi.org/10.1016/j.ijhcs.2020.102506
[4] Kathy Charmaz. 2006. *Constructing Grounded Theory: A Practical Guide through Qualitative Analysis.* Sage, Thousand Oaks, CA, USA.
[5] Simone Grassini, Karin Laumann, and Martin Rasmussen Skogstad. 2020. The use of virtual reality alone does not promote training performance (but sense of presence does). *Frontiers in psychology* 11 (2020), 553693. https://doi.org/10.3389/fpsyg.2020.01743
[6] Birte Heinemann, Sergej Görzen, and Ulrik Schroeder. 2023. Teaching the basics of computer graphics in virtual reality. *Computers & Graphics* 112 (2023), 1–12. https://doi.org/10.1016/j.cag.2023.03.001

[7] Jim Hollan and Scott Stornetta. 1992. Beyond being there. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Monterey, California, USA) *(CHI '92)*. Association for Computing Machinery, New York, NY, USA, 119–125. https://doi.org/10.1145/142750.142769

[8] Xiaoxia Huang, Jeanine Huss, Leslie North, Kirsten Williams, and Angelica Boyd-Devine. 2023. Cognitive and motivational benefits of a theory-based immersive virtual reality design in science learning. *Computers and Education Open* 4 (2023), 100124. https://doi.org/10.1016/j.caeo.2023.100124

[9] Mina C Johnson-Glenberg, Hannah Bartolomea, and Elena Kalina. 2021. Platform is not destiny: Embodied learning effects comparing 2D desktop to 3D virtual reality STEM experiences. *Journal of Computer Assisted Learning* 37, 5 (2021), 1263–1284. https://doi.org/10.1111/jcal.12567

[10] Sam Kavanagh, Andrew Luxton-Reilly, Burkhard Wuensche, and Beryl Plimmer. 2017. A systematic review of virtual reality in education. *Themes in Science and Technology Education* 10, 2 (2017), 85–119.

[11] Danielle E Levac, Meghan E Huber, and Dagmar Sternad. 2019. Learning and transfer of complex motor skills in virtual reality: a perspective review. *Journal of neuroengineering and rehabilitation* 16 (2019), 1–15. https://doi.org/10.1186/s12984-019-0587-8

[12] Iolie Nicolaidou, Petros Pissas, and Dimitrios Boglou. 2023. Comparing immersive virtual reality to mobile applications in foreign language learning in higher education: A quasi-experiment. *Interactive Learning Environments* 31, 4 (2023), 2001–2015. https://doi.org/10.1080/10494820.2020.1870504

[13] Jocelyn Parong and Richard E Mayer. 2018. Learning science in immersive virtual reality. *Journal of Educational Psychology* 110, 6 (2018), 785. https://doi.org/10.1037/edu0000241

[14] Bruno Peixoto, Rafael Pinto, Miguel Melo, Luciana Cabral, and Maximino Bessa. 2021. Immersive virtual reality for foreign language education: A PRISMA systematic review. *IEEE Access* 9 (2021), 48952–48962. https://doi.org/10.1109/ACCESS.2021.3068858

[15] Johanna Pirker, Andreas Dengel, Michael Holly, and Saeed Safikhani. 2020. Virtual Reality in Computer Science Education: A Systematic Review. In *Proceedings of the 26th ACM Symposium on Virtual Reality Software and Technology* (Virtual Event, Canada) *(VRST '20)*. Association for Computing Machinery, New York, NY, USA, Article 8, 8 pages. https://doi.org/10.1145/3385956.3418947

[16] Yu Shu, Yen-Zhang Huang, Shu-Hsuan Chang, and Mu-Yen Chen. 2019. Do virtual reality head-mounted displays make a difference? A comparison of presence and self-efficacy between head-mounted displays and desktop computer-facilitated virtual environments. *Virtual Reality* 23 (2019), 437–446. https://doi.org/10.1007/s10055-018-0376-x

[17] Clay Spinuzzi. 2005. The methodology of participatory design. *Technical communication* 52, 2 (2005), 163–174.

[18] Rafael Villena-Taranilla, Sergio Tirado-Olivares, Ramon Cozar-Gutierrez, and José Antonio González-Calero. 2022. Effects of virtual reality on learning outcomes in K-6 education: A meta-analysis. *Educational Research Review* 35 (2022), 100434. https://doi.org/10.1016/j.edurev.2022.100434

[19] Zheng Wei, Xian Xu, Lik-Hang Lee, Wai Tong, Huamin Qu, and Pan Hui. 2023. Feeling Present! From Physical to Virtual Cinematography Lighting Education with Metashadow. In *Proceedings of the 31st ACM International Conference on Multimedia* (Ottawa ON, Canada) *(MM '23)*. Association for Computing Machinery, New York, NY, USA, 1127–1136. https://doi.org/10.1145/3581783.3612580

[20] Xian Xu, Wai Tong, Zheng Wei, Meng Xia, Lik-Hang Lee, and Huamin Qu. 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 Computer Society, Los Alamitos, CA, USA, 571–572. https://doi.org/10.1109/VRW58643.2023.00128

[21] Qian Zhu, Linping Yuan, Zian Xu, Leni Yang, Meng Xia, Zhuo Wang, Hai-Ning Liang, and Xiaojuan Ma. 2024. From reader to experiencer: Design and evaluation of a VR data story for promoting the situation awareness of public health threats. *International Journal of Human-Computer Studies* 181 (2024), 103137. https://doi.org/10.1016/j.ijhcs.2023.103137