Beyond CAVEs and Domes:
Creating Accessible Multi-User Virtual Installations for Immersive Learning

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Abstract
New opportunities for immersive learning on campuses with high fidelity installations like CAVEs and domes have been made possible by the development of various technologies like virtual reality, motion capture, projection mapping, and more. These high fidelity installations have been created by commercial companies, primarily for marketing, exhibitions, and events. However, there is still a demand for accessible and reasonably priced immersive installations in educational settings. By planning, building, and implementing a low-cost, substantial multi-user virtual installation for cooperative immersive learning and presentation of student VR/AR media, this project intends to close this gap. Key design elements have been identified and integrated into an immersive exhibit using more readily available technologies like projection mapping and VR by comparing current immersive educational environments such as CAVEs and domes. The design and development techniques used to build this immersive learning environment while preserving cost effectiveness will be covered in this article. Some early implementations of educational programs are introduced that employ the big multi-user immersive installation's early learning that includes use in giving student created virtual tours connected to tourism education and immersive storytelling. Through this study, we show the learning potential of immersive installations in learning environments while making them more accessible to more institutions, allowing students to collaborate and learn while utilizing the most recent immersive technologies.

Keywords: Immersive Learning, Virtual Reality, Augmented Reality, Virtual Tour Installations

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Introduction

In the aim of supporting immersive learning activities and programs, ones that employ technologies like virtual and augmented realities, there is a growing variety of specialized technologies that are deployed in learning spaces. These can include computing hardware and software, virtual reality head-mounted displays, augmented reality glasses, depth/3D cameras, holographic displays, CAVEs, and other equipment. There is a growing combination of these technologies that are combined to create installations to facilitate immersive learning, in schools, museums, universities, and other informal learning environments (Dede, 2009; Mikropoulos & Natsis, 2011). These installations have tended to have been experimental, highly calibrated, and/or highly specialized to the learning task. One example of this is the CAVE. The CAVE is a cube with display-screen faces surrounding the viewer; as the viewer moves within the bounds of the CAVE, the correct perspective and stereo projections of the environment are displayed. A CAVE is a space that submerges one or more people into a projected virtual environment. There are many types of CAVEs but a popular one uses small see-through spectacles akin to those used in a movie theater, the virtual environment is often viewed in stereoscopic 3D. A 3D mouse and these glasses are used to monitor objects in space. Users are now able to move their hands and heads naturally to explore and engage with the virtual environment (Cruz-Neira et al., 1992; Manjrekar et al., 2014). This can make the learning benefit in relation to the cost, time, and expertise high, creating a barrier to more widespread use.

As these technologies become more accessible, and simultaneously immersive learning practices become more practical, it would be beneficial research to seek more standardized, low-cost, and approachable multi-user installations. The widespread adoption of immersive visualization systems in educational settings has been hindered by several factors. First and foremost, the high initial system cost has been a significant barrier. Both the hardware and software required for these systems have traditionally been expensive, making it difficult for many institutions to afford them. Secondly, the high cost of operation has been a deterrent. These systems require specialist support staff and ongoing maintenance, adding to the overall cost of ownership. Thirdly, accessibility has been a challenge. Only a few systems are available, and they are typically accessible to a relatively small number of users. Fourthly, the software complexity associated with these systems has been a hurdle. There are only a few 'off-the-shelf' applications available, and custom application software development is often required for most new applications. Fifthly, ease of use issues have been a concern. Special effort is needed to use these systems, and they are not well integrated into workflows except for a few specialized problem domains. Lastly, human factors issues have been a hindrance. User fatigue, 'simulator sickness,' and the need to wear special viewing apparatus are just a few of the issues that have made it challenging to use these systems. In summary, the high costs, limited accessibility, software complexity, ease of use issues, and human factors challenges have all contributed to the slow adoption of immersive visualization systems in educational settings (Manjrekar et al., 2014; Parke, 2005).

The U Theatre project is an innovative initiative that seeks to make immersive learning environments more accessible to a broader audience. Recognizing the challenges and limitations of traditional immersive installations, the U Theatre project aims to provide a cost-effective and user-friendly alternative. The centerpiece of the project is a 180-degree immersive screen, designed to create a multi-user virtual installation for cooperative immersive learning and presentation of student VR/AR media. With a length of approximately five meters, the screen can accommodate between five and ten people, making it ideal for group activities and collaborative learning experiences. The U Theatre project utilizes readily available technologies such as projection mapping and virtual reality to create an immersive learning environment. The project also involves the careful calibration and blending of multiple projectors to cover the entire screen and create a seamless and immersive visual experience. One of the key goals of the U Theatre project is to make immersive learning environments more accessible to educational institutions. By using affordable and readily available technologies, the project aims to lower the barriers to entry and make it easier for schools and universities to incorporate immersive learning into their curricula. The U Theatre project represents a significant step forward in making immersive learning a reality for more students and educators.

This study will also explore the integration of practical learning tools, applications, and implementations to enhance the utility and flexibility of installations like the U Theatre in educational contexts. By incorporating augmented reality, virtual tours, and immersive storytelling, the U Theatre can be transformed into a dynamic and interactive learning environment. Students can engage in experiential design projects, creating augmented reality experiences that can be showcased within the U Theatre. Virtual tours, connected to tourism education, can be developed and presented, allowing students to explore and learn about different locations and cultures in an immersive setting. Immersive storytelling can be employed to create engaging narratives that captivate the audience and enhance the learning experience. These practical tools and applications not only enrich the educational value of the U Theatre but also provide students with hands-on experience in using immersive technologies for various purposes. By connecting these practical learning tools to the U Theatre, this study aims to demonstrate the potential of immersive installations as versatile and adaptable learning environments that can cater to a wide range of educational needs and objectives.

Background

The construction of immersive installations for learning, training, and other educational contexts has a long and researched history. From the use of flight trainers for military pilots to surgical models for medical simulations, to VR virtual field trips (Cheng, 2022; Hawkinson, 2022; Hemman, 2005; Valverde, 1968). Many of these systems were very expensive, the cost being justified as the alternative to live training was even more expensive and very dangerous. Later researchers and developers identified these justifications for deploying more costly virtual simulations for training as DICE. DICE is an acronym to define some times when virtual reality is most appropriate to use for learning and stands for Dangerous, Impossible, Counterproductive, and Expensive (Bailenson, 2018). The examples of flight trainers and medical simulators fall into these DICE criteria very well. But as the installations become more affordable and accessible, a larger variety of simulations and learning activities becomes cost effective to deliver. This could allow for further research into new implementations of immersive learning and expand/renew as the rationale evolves from DICE as the costs get less expensive.

There are many approaches to mixing digital and real content, simulation and practical scenarios for learning, and thus a variety of approaches to designing spaces to facilitate a mixed, virtual, and augmented reality for educational contexts. The following are examples of three fields which have research to show how such learning spaces have been deployed, a simple compare and contrast helped to form much of the approach to the design of the immersive space featured in this study.

Design Study: Medical Simulations

Virtual reality (VR) is being used in medical education to enhance the training and acquisition of procedural skills, particularly in emergency medicine. VR provides a realistic and interactive environment for medical students and practitioners to practice and refine their technical expertise in medical procedures. It allows learners to practice procedures that are infrequently encountered in clinical practice or have a potential risk to patients when performed by less skilled practitioners. VR technology has been successful in training for procedures that are already screen-based, such as endoscopic surgical techniques. Instructional theories and skill acquisition play a crucial role in medical procedure training. Strategies such as deliberate practice and spaced repetition have been shown to enhance learning and skill retention. VR offers a safe and controlled environment for learners to practice procedures without the risk of harming real patients. It allows learners to make mistakes, learn from them, and improve their skills in a realistic and immersive setting. Ongoing research and advancements in VR technology will continue to shape the future of medical education (Hemman, 2005; Schild et al., 2018; Wang et al., 2008). Although VR has been a focus of medical training research and development, the uses of VR have largely been ‘task training’ where learning focuses on one skill, procedure, or scenario. This points to using VR as a step in the training process, and spaces designed to deploy a mixture of digital and real interactions have been designed to provide more dynamic and flexible simulations. These environments look like emergency or surgical rooms and deploy a mix of digital display, human actors, and live scenarios to give learners an environment that benefits from both simulated and real-life components, the Mayo Clinic, Multidisciplinary Simulation Center is an example of this (Eagle et al., 2010; Levine et al., 2013). The design of these learning spaces fit the learning content as doctors will be expected to cope with a variety of patients and situations.

Design Study: Flight Simulators

Simulators are also used in flight training to improve pilot skills, decision-making abilities, and overall safety. Simulators provide a realistic and immersive training environment that allows pilots to gain valuable experience and practice critical flight scenarios without the risks associated with real-world flying. In contrast to medical training and the role of ‘task training’, where specific skills and procedures are vital but secondary to the dynamic human interactions in emergency rooms, tasks are many times the primary focus of training pilots. Simulators focus on equipment, procedures, resource management, and instrument flight training (Cross et al., 2022; Valverde, 1968). Instrument flight training in particular is interesting to design simulations for as the simulator can be very close to the real thing, as you are trained to fly solely based on information given from cockpit instruments. So the design of immersive simulators can focus more on the replication of physical cockpits and how they would display information in different situations, much easier to digitally and physically replicate than dynamic human/biological interactions as in medical training (Aldrich, 2005).

Design Study: Tourism Studies

Another design approach in immersive learning is an ultra-low cost and highly accessible one. Virtual field trips became popular for schools and classrooms as low cost 360 viewers were deployed using Google Cardboard and applications like Expeditions and Google Street View. This allowed for learners to use smartphones or tablets to simulate standing in other locations around the world. WIth the help of software like Google Expeditions, entire classrooms could simulate a trip to historical and cultural locations together. This allowed for connecting more traditional classroom activities with short immersive elements (Alizadeh & Hawkinson, 2021; Parsons et al., 2019). Other related low-cost solutions for virtual travel have used popular software platforms like Minecraft and Roblox (Meier et al., 2020), and student virtual tour creation platforms like the 'My Hometown Project' (Alizadeh & Hawkinson, 2021; Hawkinson, 2022). Digital Twins have also allowed for virtual visits to locations in the past like ancient Rome or impossible to reach places like Mars (Hancher et al., 2009).

The spectrum of learning designs above suggest, as does research specific to learning space design, that alignment to learning goals and curriculum is a key pedagogical issue in effective deployment (Parsons et al., 2019).

Design and Development of the U Theatre

As past research suggested, a learning needs analysis was undertaken and curriculum support opportunities were explored to base the design of an immersive installation in a university laboratory. The installation was named the 'U Theatre' for both its shape and focus on interactivity.

Planning and Conceptualization

The planning and conceptualization of the U Theatre at the Kyoto University of Foreign Studies were driven by the university's curriculum, emphasizing global studies, tourism studies, digital literacy, and language education. Recognizing that students had low to moderate technology skills, primarily using smartphones with little to no programming experience, the design aimed to create an immersive learning environment that was both supportive of the curriculum and accessible to students with varying technological expertise.

Drawing inspiration from medical simulations, flight simulators, and tourism studies, the U Theatre was designed as a flexible and adaptable space for both individual exploration and group collaboration. Unlike traditional VR setups, the U Theatre intentionally avoids the use of VR headsets, which can hinder in-person collaboration. Instead, it employs cutting-edge immersive tools that allow students to engage with digital content in a more humanistic and empathetic way. The design process considered the need for a mix of digital and real interactions, incorporating elements from low-cost virtual field trips. Overall, the U Theatre was designed to provide a versatile immersive learning space that supports the university's curriculum and accommodates students with varying levels of technological expertise.

The physical space itself was a major design factor, looking to maximize the space to the number of simultaneous participants but also allow for flexibility and immersive content. The space allocated by the university was previously a computer lab and learning commons. It was mainly used for individual study and housed banks of desktop computers. The maximum space was about 100 square meters with some small rooms and storage areas for network servers and other equipment. The space could be comfortably occupied by about 30 students or more in its previous design.

The design space suggested that one large virtual immersive installation could facilitate more simultaneous participants, more so than allocating more space for VR headsets, which needed more allocated space per headset than the previous computer desks.

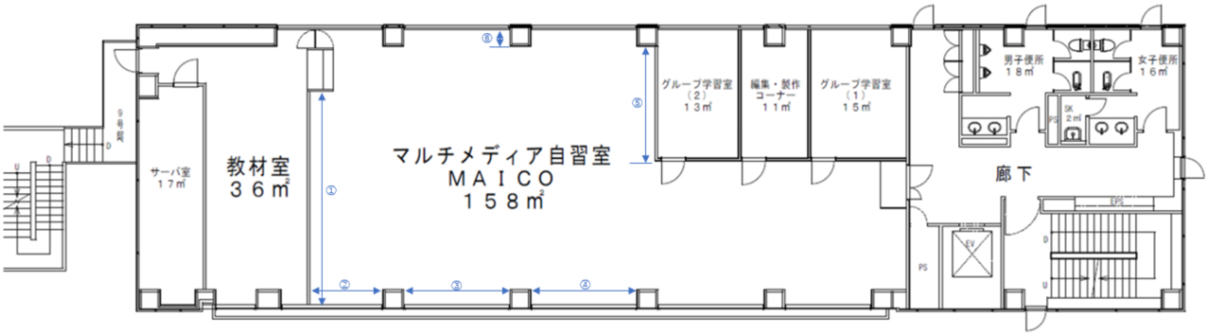

Figure 1: Space Allocated for the U Theatre

Design and Installation

The space allocated to the laboratory helped determine the overall size of the U Theatre. A U shape pointing in from a corner. Giving an angle of the U shape from a corner would allow for maxim viewing from the participants while having the smallest footprint in the room, also allowing for the largest viewing screen possible. With the position, angle, and allocated space decided. It was determined that a half circle screen with a 5 meter diameter could be placed at an angle in a corner of the space. With the basic shape decided, the next key factor was determining an optimal array of projectors that would cover most of the shape, which from initial simulations suggested 3 short throw projectors mounted near the top center of the half-cylinder shape. Next, further design elements were considered, such as height, curve, extension of sides into a U shape, supporting structure like overhead mounting for the projectors, stands, and lighting attachments.

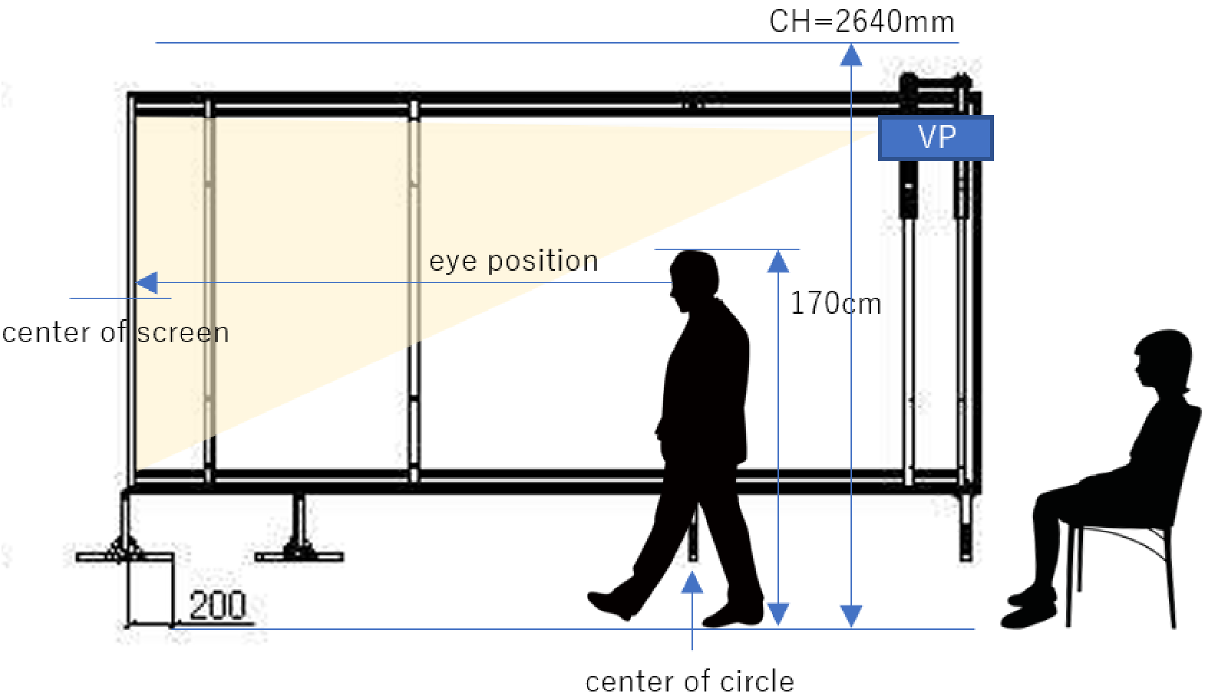

Figure 2: Viewing and projection angles of preliminary design of U Theatre

Using design tools like StetchUp and projection mapping simulators, an initial design to have a 1.5 meter projection area centered for eye level was created. Viewers of the installation could not block the light from the projectors, but also be as far inside the installation to have some of the screen in peripheral vision. Also, considering seated and standing viewers, or both for maxim occupancy or simultaneous viewers was considered. It was estimated that 10 to 15 could view the space at the same time while being inside the radius of the cylinder.

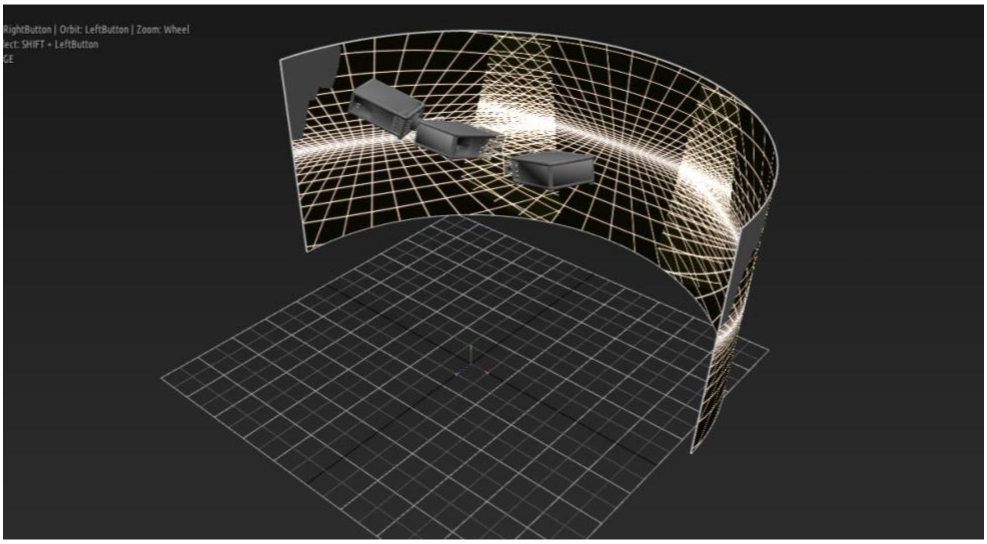

Figure 3: Projection Mapping Simulation of Screen

The design decisions that perhaps had the most variables to consider are the projectors, angles, distance, resolution, brightness, and coverage of the viewing angle. Each of these variables seemingly could be improved only at the cost of scaling back on the others. Further distance from the screen would improve coverage but reduce brightness and resolution. Moving the angles of the projectors so they wouldn't be blocked as much by viewers meant more distortion and lower resolutions. Other considerations like the resolution of each projector, the ability for a server to render and map all of the projectors, and the size of each pixel as it is represented on the screen all were affected by even slight changes to the design. Even after installing the screen these angles and positions needed to be re-simulated and adjusted as the build specifications of the screen were not exact to original designs and thus fine tuning needed to be done.

In the end, a balance was found between brightness, resolution, and projection size. The projection size was lowered so as to not cover the entire U shape to favor brightness and resolution after initial testing. Black borders were installed on each end of the U shape to mask the additional screen space that was not being projected onto.

Educational Implementations

During the design stages of the installation, considerations were made to the kinds of immersive learning that was both already taking place in coursework and student projects, and possible future integrations. Curriculum alignment was seen as a key factor in the implementation and use of the installation. There were already several learning activities in mind before designing the installation, such as a student project in virtual tour making by tourism studies programs and Model United Nations simulations that were experimenting with virtual reality (Hawkinson, 2022; Mcgregor & Hawkinson, 2022). These programs were planned to utilize the U Theatre in future iterations. Other ideas and events were also introduced, as the university is looking to possibly start studies and activities into eSports and data science.

Course	Learning Activities
Game, Interaction, and Experience Design	AR Location Based Game Design
Immersive Technology Workshop	Virtual Reality Tour Design and Presentation
Global Engagement	Model United Nations Simulations
eSports Fundamentals	Gaming Design and Events
MICE Tourism	Travel Simulations / Tour Design
Introduction to Data Science	Data Visualization

Table 1: U Theatre and Curriculum Alignment

Using the U Theatre in Tourism Studies

The "My Hometown Project," initiated in 2016 as a vocational training program at the School of Global Tourism at Kyoto University of Foreign Studies, aimed to enable students to design and share virtual reality tours of their hometowns. Adapted for online learning during the global pandemic, the project expanded to include an online course, website, app, and platform, allowing participants worldwide to create and explore curated personal stories and tours of small places and rural areas. Virtual travel, while not a replacement for real travel, offers unique benefits such as reducing overcrowding at popular tourist destinations and promoting sustainable tourism. It also fosters empathy by allowing individuals to experience different cultures and perspectives. The U Theatre has already been used by teachers and students to show, share, and experience student created tours as a part of this project. I has allowed small groups of students to present virtual reality tours with each other.

eSports and Game Design Studies

An immersive eSports event honoring the early days of competitive electronic gaming was organized at Kyoto University of Foreign Studies. The event focused on "Spacewar!", one of the first video games in terms of design and competitive play. Spacewar! was first conceived of as a simulator for prospective astronauts rather than a game, during the space race of the early 1960s. Students were given the chance to interact with the game, experiencing its straightforward controls and brief gameplay sessions that usually lasted between thirty and sixty seconds, in addition to short lectures about the history of the game. Due to its simplicity of use, it was perfect for novice competitions. The historical importance of Spacewar! was emphasized, emphasizing its function as a conduit for the spread of eSports and its ultimate development into the competitive gaming sector that exists today. Along with honoring the past, the occasion also made references to upcoming events. The next significant event was the launch of "Space Invaders" on the Atari 2600, which led to the first-ever worldwide video game competition. The use of the U Theatre in this way showed promise in deploying it for eSports events and eSport event remote viewing.

Open Campus

The university was also interested in using the space as a piece for promotion and display of student projects and to give visitors of open campus a chance to experience immersive technology in an easy as accessible way. The U Theatre was made a point of interest in a campus tour and visitors were given short lectures, shown student virtual tours, and allowed to try student created video and games. During this event individuals were given the opportunity to try VR headsets as well, and this showcased the differences in using VR headsets and a group immersive installation like the U Theatre. It was observed that managing multiple VR headsets can be challenging. The event showcased the novelty effect of VR and AR technology, attracting a diverse audience with varying opinions on its potential applications. It was noted that the perception of the technology's usefulness varied widely among attendees, including high school students, junior high students, younger students, and parents.

Conclusion

The U Theatre offers a unique platform for collaborative learning, allowing multiple users to interact with each other and the virtual environment simultaneously. This feature is particularly advantageous for group-based learning activities and simulations that require teamwork and communication. The potential impact of the U Theatre on immersive learning and education is immense. By providing a more accessible and cost-effective alternative to traditional CAVEs and domes, the U Theatre can help bridge the gap between institutions with varying resources. This democratization of immersive technologies can lead to more widespread adoption of virtual installations in educational settings, ultimately benefiting a larger number of students. Furthermore, the U Theatre's versatility in accommodating different types of simulations and studies makes it a valuable tool for institutions looking to diversify their educational offerings. By making immersive technologies more accessible to institutions, the U Theatre project has the potential to revolutionize the way we approach immersive learning and education.

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