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Reconstruction of Industrial and Historical Heritage for Cultural Enrichment Using Virtual and Augmented Reality

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Abstract: Because of its benefits in providing an engaging and mobile environment, virtual reality (VR) has recently been rapidly adopted and integrated in education and professional training. Augmented reality (AR) is the integration of VR with the real world, where the real world provides context and the virtual world provides or reconstructs missing information. Mixed reality (MR) is the blending of virtual and physical reality environments allowing users to interact with both digital and physical objects at the same time. In recent years, technology for creating reality-based 3D models has advanced and spread across a diverse range of applications and research fields. The purpose of this paper is to design, develop, and test VR for kinaesthetic distance learning in a museum setting. A VR training program has been developed in which learners can select and perform pre-made scenarios in a virtual environment. The interaction in the program is based on kinaesthetic learning characteristics. Scenarios with VR controls simulate physical interaction with objects in a virtual environment for learners. Learners can grasp and lift objects to complete scenario tasks. There are also simulated devices in the virtual environment that learners can use to perform various actions. The study's goal was to compare the effectiveness of the developed VR educational program to that of other types of educational material. Our innovation is the development of a system for combining their 3D visuals with rendering capable of providing a mobile VR experience for effective heritage enhancement.

Keywords: cultural enrichment; virtual reality; augmented reality; museum fruition; digital storytelling; serious game; VR game; immersion; learning



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1. Introduction

Augmented reality (AR) is a technology that superimposes digital information, such as images, sounds, and text, onto the real-world environment in real-time [1,2]. It enhances the user's perception of the physical world by adding computer-generated sensory input, such as graphics and sounds, to enhance or augment the real-world environment. Unlike virtual reality (VR), which creates a completely artificial environment, AR overlays information on the existing world. AR can be experienced through various devices such as smartphones, tablets, and AR glasses. It is used in various fields, including entertainment, education, retail, and industry, to provide an immersive and interactive experience for users [3,4].

The social learning process is enhanced by immersion that provides authentic-like experiences [5]. Spatial immersion is achieved by surrounding the user with sights, noises, or other virtual scenarios, giving the user the impression that the virtual environment is "genuine" and "real", according to [6]. Immersive VR relies on the employment of specialized technology, such as smart glasses, head-mounted displays (HMD) and sensor gloves, haptic suits and omnidirectional treadmills as described in [7,8], in order to remove people from their actual surroundings and deliver an immersive experience [9].

It is obvious, that technologies for building reality-based 3D models have been improved and spread over a wide range of applications and research sectors [10]. Because of

digitalization and the fabrication of digital copies based on additive printing, these technologies are highly beneficial for preserving, disseminating, and restoring cultural material. VR and 3D printing have contributed to the growth of a new arena for data collection: museum fruition [11]. As a result, immersive VR technologies are growing in importance, especially for education [12–14].

VR technology is described as a simulation of a realistic virtual environment that is created using interactive software and hardware and can be controlled by body movements [15]. There are two types of VR systems: desktop-based (non-immersive) and head-mounted gear-based (immersive). One of the main advantages of VR as a technology is the ability to involve the user in an interactive virtual environment and simulate the sensations of the user's movement and interaction with this environment [16]. The user's involvement in virtual environments is created by the immediacy provided by the VR hardware used, where no other medium is visible between the user and the visible virtual world, while multimodal interaction involving visual and tactile feedback ensures the feeling of immersion [17]. Multimodality also includes sound that is inextricably linked to place and space, mind and body, cultural context, and emotion as a means of knowledge and experiential involvement [18,19]. Furthermore, depending on the way the VR device is tracked in space, six or three degrees of freedom (DoF) can be provided to interact with the virtual environment [20]. Although observing real-life environments or phenomena rendered in a virtual environment can be engaging, this alone is not sufficient to generate high levels of engagement and perception [21]. In a well-crafted experience, observing the environment in VR can engage at least two sensory modalities, auditory and visual [22]. In such applications, information is conveyed through video and audio, and it depends on the hardware used whether it can create a sufficiently immersive virtual environment with a sense of space that can at least partially deceive the user, making them feel that he is actually in that environment. More advanced applications such as Mav 5.0 Virtual Museum of Ercolano [23,24] include not only auditory and visual sensory modalities, but also fine motor skills and physical actions using various controls through which the user can interact with the virtual environment. This makes the virtual environment experiential and interactive, as the user can perform various actions with the objects in it.

AR has been labelled an emerging technology [25] but there are still barriers for both VR and AR that have to be considered before full-scale adoption will happen [26]. VR and AR applications in multidisciplinary field have been best motivated by the following two scenarios: (1) when a phenomenon or an object cannot be easily recreated, such as already non-existing historical buildings; or (2) when a visit in reality is not possible due to a large distance or state borders. The educational merits of AR are intimately tied to how AR is developed, implemented, and incorporated into formal and informal learning situations [27,28]. The main psycho-educational framework is neuroconstructivism, which holds that cognitive development happens not through passive absorption of external information, but rather through the learner's proactivity in investigating, manipulating, and engaging with their environment [29], which is considered a better practice than passive participation [30].

Mixed reality (MR) is a concept that refers to the blending of virtual and physical reality environments in real-time, allowing users to interact with both digital and physical objects at the same time. MR can be viewed as a continuum that ranges from entirely physical environments to entirely digital environments. MR systems are designed to augment the user's perception of the physical environment by adding virtual objects that are displayed on a display device, such as a head-mounted display (HMD) or a smartphone. This technology allows for the creation of a more interactive and engaging experience for the user. One of the key characteristics of mixed reality is the ability to detect and respond to the physical environment. This is typically achieved through a combination of sensors and software that can detect the user's position and movements in the physical environment, as well as track the location and orientation of virtual objects. This allows for a more immersive and interactive experience, as the user can interact with virtual

objects in a way that is similar to how they would interact with physical objects in the real world. MR applications and technologies have become quite popular nowadays [31,32]. They are used in many areas (e.g., games [33], entertainment [34], education [35], assisted living [36], psychology [37], health and rehabilitation [38,39], etc.). For example, MR gaming applications can allow users to play games that blend virtual and physical elements, such as a game that requires the user to navigate a virtual maze in a real-world environment. MR can also be used in educational and training applications to create immersive learning experiences that simulate real-world scenarios. For example, a MR application could be used to simulate an emergency situation, such as a fire or natural disaster, allowing users to practice their response in a safe and controlled environment.

The MR applications and technologies are becoming increasingly popular, according to [31,32,35]. They are used in a variety of contexts (e.g., games, entertainment, education, etc.). According to [40], cultural heritage offers a wide range of prospects for MR applications. Among these options are storytelling [41] (a means for visitors to learn and remember more information about the exhibitions they visit), gamified presence [42] (an incentivized tool to keep people attentive throughout their stay), and many others. This collaboration has resulted in the creation of a new study subject: virtual cultural heritage [43], with special problems and the main issue being the reconstruction of a 3D virtual model of a real cultural artefact or item [44].

Virtual museums may use game technologies for digital representation of the cultural heritage and industrial sites [40,45]. Cultural heritage sites are good candidates for both detailed multidimensional geometric documentation and realistic interactive visualization in VR applications [26,46,47]. VR and AR simulation technologies create an interactive environment in which individuals may experience and appreciate intangible and physical cultural assets and historical locations [48]. These technologies provide user-centred display and digital access to cultural assets, especially where physical access is limited. VR may be employed as a tool to explore and understand history and heritage [49,50]. As a result, the current tendency is to create an interactive virtual model of presentations of this rich source of information and experiences to make museums more appealing and allow for inspired usage by a larger audience, as well as to overcome young people's lack of interest [43]. VR games are increasingly being included in museums and exhibitions, emphasizing the growing cultural significance of games and the institutionalization of game culture [51]. Serious VR games provide a range of educational benefits, combining education with entertainment and resulting in edutainment [52]. Game engines provide tools for the interactive 3D visualisation of cultural heritage objects [53], enabling a novel kind of information transmission via direct user interactions in the virtual environment. Several research have used VR games to improve visitor experiences in a variety of settings. However, there is not much research in the sector that looks at the advantages and disadvantages of VR gaming [54].

According to Hublin [55], the modelling of historical sites (or objects) should include the possibility of computer simulation of inaccessible sites allowing observation of the object or site's internal structure; the technique of virtual filtering may aid in the reconstruction of the artefact (including corrections of plastic deformations). Often, in order to preserve the values of cultural heritage, there is a common problem: physical objects are not durable, their copies or complete sets have not survived. The physical restoration of such objects is an expensive process, and the result is often unpredictable. Therefore, the question arises: maybe they can be modelled virtually, restoring the smallest details.

Virtual representations of crafts and traditions allow viewers to "time travel", transporting them to the past via 3D reconstructions of cultural landmarks and locations. However, digital resources alone are insufficient for properly presenting cultural heritage. Additional historical background material in the form of anecdotes, virtual reconstructions, and digital artefacts is required. All of this is possible using digital storytelling [16], which is a digital multimedia presentation style.

To date, digital technologies used in cultural heritage have mostly focused on re-creating the original look of artefacts and the museum itself, effectively implementing the notion of a “virtual museum” [56–59]. Aside from a few rare exceptions, museums and cultural organizations in general are hesitant to embrace VR technology since they provide the viewer with a detached view of the art collection without providing any cultural or educational value [60]. Recently, studies on the adoption of new technologies to cultural and historical heritage have mostly focused on technologies that rebuild and narrate the complexity of the territory and its past, such as three-dimensional (3D) scanning, 3D printing, and AR. Some museums and archaeological sites currently employ digital technologies to conserve and promote their legacy, but interactive services that immerse tourists in a more immersive and modern experience are still uncommon. Real-time exploration of 3D VR models provides an interesting approach for a varied audience to connect with multi-disciplinary content. Such added value services can motivate tourists when selecting a travel destination [61].

The following methodologies can be considered for reconstructing historical and industrial heritage sites:

- 3D model that includes time slices of the evolution of an object’s locations (virtual 4D reconstruction) [62] based on source material data (descriptive and pictorial, video, archaeological data, such as topographical plan, layers of the Earth’s surface, maps attached to a 3D model, etc.). The 3D model is a visually oriented base that systematizes the accumulated research material.
- Virtual reconstruction [63,64] as a tool for the representation of objects of historical and cultural heritage and communication based on Internet technologies and the development of virtual tourism [65].

This paper aims to design, develop and explore a VR curriculum that would enable kinaesthetic distance learning [28] in the museum setting. A VR training program has been developed where learners can choose and perform ready-made scenarios in a virtual environment. The interaction in the program is based on the features of kinaesthetic learning. With VR controls, scenarios simulate physical interaction with objects in the virtual environment for learners. Objects can be grasped and lifted by learners and used to complete scenario tasks. Furthermore, in the virtual environment there are simulated devices that learners can also use to perform various actions.

The aim of the study was to compare the effectiveness of the created VR educational program with other forms of educational material. Our novel research provides the creation of a system for documenting current and past historical ages, merging their 3D visuals with rendering capable of providing a mobile VR experience for effective heritage enhancement.

2. Related Works

A variety of approaches have been adopted from other domains as a methodological background to build 3D models of cultural heritage such as building information modelling (BIM) [59]. A VR model has been developed for a charcoal mini-blast furnace plant in Brazil [66], an industrial museum and cultural centre in the region of Thessaloniki [58], an exhibition of the historical relics in the Mawangdui Han dynasty tombs in China [67], a Taitung old railway station in Taiwan [68], a 3D reconstruction of the Roman forum of Fanum Fortunae in Italy [69], Nikola Tesla’s laboratory in Long Island (Wardenclyffe), New York, NY, USA [70], underwater archaeological sites in Italy [71], Stoa of Attalos in Athens, Greece [57], Selimiye mosque in Edirne, Turkey [72], Brasov’s history museum [73], Sant’Angelo cave church [74], the Virtual World of Caen [56], inaccessible monuments of the cities of Lecce and Catania [75], the fortress Al Zubarah in Qatar [76], and the Museum of Preclassical Civilizations of the southern Murgia in Ostuni [77].

Castagnetti et al. [78] uses the approach at the Massaciucoli archaeological complex, one of the best preserved Roman sites in the Versilia Area (Tuscany, Italy). The project’s tasks included: (1) creating a virtual tour of the site in its existing configuration using spherical photos augmented with texts, graphics, and audio guides to provide both an

immersive and distant visitor experience; (2) a 3D reconstruction of historical structures in their current condition for documentation and preservation reasons based on a thorough metric survey performed by laser scanning; (3) a 3D virtual reconstructions of the key historical eras based on historical studies and data analysis.

Longo et al. [79] aimed to develop a distinctive multi-device application built around the concept of an intelligent serious game (ISGs). Serious games' (SGs') and intelligent agents' (IAs') combined educational potential will lead to the evolution of the played scenario in accordance with the initial user profiling and the sequence of events produced during the museum tour, which will foster the development of new patterns and strategies for the dissemination and realization of cultural content.

Madsen and Madsen [80] reported the creation of two installations for the viewing of a 3D reproduction of a castle chapel, which functions autonomously during open hours in a castle museum setting. Currently on tablets, they show a convincing 3D representation that runs at interactive frame rates. The tablet is either hand-held to allow for translational flexibility in the chapel or linked to a big screen TV for an immersive experience. During museum hours, both installations are available for unsupervised use. However, the results showed that users only spent a short time using the program and did not completely explore the visual area of the chapel.

Okanovic et al. [81] provided an introduction to the methodologies and analysed several methods for promoting engagement in digital storytelling apps for virtual cultural heritage presentations, and demonstrated how eXtended Reality (xR, i.e., VR + AR) applications for cultural assets enable natural engagement and interaction. Users will find the stories offered by these apps to be both educative and amusing. The authors assessed user edutainment and presented user reactions to the interactions using user-experience research.

Chrysanthakopoulou et al. [7] showed the preliminary findings of a suggested methodology for emphasizing and understanding a historic event using an immersive and interactive VR experience and the user's many senses. The use of a treadmill for navigation and haptic gloves for interactions, in conjunction with the rich 3D models, heightens the sensation of immersion. The findings suggest that engaging multimodal and visual manipulation in an immersive 3D environment may successfully increase visual realism and inspire a stronger feeling of presence, hence magnifying the instructive and informative experience in a museum.

Chen and Lan [82] explained the temporal restoration, spatial restoration, and immersive experience of VR technology, as well as the basic study of VR technology in museums, the platform display, and the possibility of cultural communication. They investigated the development trend and application prospects of somatosensory interaction technology by researching the somatosensory interaction technology's working theory, the state of the somatosensory interaction device Kinect, and the programming algorithm, with the hope to advance the design and production of interactive exhibits in science and technology museums. In the exhibit design, by using Unity3D as the engine to create the interaction platform and a webcam and other interactive devices to realize the somatosensory interaction, improve the design of interactive science exhibits, and engage in innovative scientific exploration, a prototype system of human-machine interaction was made possible.

Finally, the readers are referred to useful surveys of AR, VR and MR for cultural heritage presented in [60,83,84].

3. Methods

3.1. Cognitive Aims of VR Application

The developed VR application aims to provide a mobile and engaging learning experience that allows learners to explore the history and culture in a way that is both memorable and effective. By achieving these cognitive aims, learners will be able to develop a deeper understanding of historical events and cultural heritage and its impact on the world, as well as the skills needed to think critically and spatially about complex historical and cultural phenomena.

The cognitive aims to be achieved by the VR application are as follows:

- Knowledge acquisition: The VR application aims to provide learners with a rich and detailed understanding of history, culture, art, and architecture. This includes learning about the key events, figures, and innovations of cultural and historical significance.
- Critical thinking: The VR application aims to encourage learners to think critically about historical events, and to challenge assumptions and preconceptions about the culture and society of that time. This includes encouraging learners to analyse and evaluate the historical evidence and to develop their own interpretations of history and culture.
- Spatial reasoning: The VR application aims to help learners develop spatial reasoning skills, including the ability to navigate complex 3D environments and to understand the relationships between different elements of a complex environment.
- Interpersonal communication: The VR application aims to encourage learners to communicate and collaborate with others, including other learners and museum staff. This includes engaging in discussions and debates on historic events, as well as working together to solve challenges and complete interactive tasks within the VR environment.

3.2. Technical Requirements for VR application

The technical requirements for any VR application are motivated by the intensity of the information flow through the VR interface close to the intensity of information flow through our senses (and it exceeds any expected boundaries) as it uses all or almost all systems of interaction with the outside world: visual, auditory, tactile [85], gestures [86], etc. One of the main requirements for a VR computer system is the total data transfer rate via the interface with the operator. This speed overcomes the 1 GB line per second (for the visual channel) and will increase with the involvement of other channels of interaction between the subject and VR. The second requirement affecting the characteristics of the computer is to provide a real-time mode: an immediate response of the system to a variety of external events reflecting a continuous change in the operator's state (movement, head turns, torso, limbs, movement of fingers, etc.) is required, and reaction should not exceed the duration of the latent phase to create a sense of continuity of events (in particular, for the visual channel—this is, as you know, at least 1/16 of a second—the physiological frequency limit of the absence of flicker). Creating game-level virtual environments requires designing the environment, objects needed for conducting experiments, and additional objects that add realism to the virtual environments and additional interaction opportunities [87]. Designing the flow of experiments includes finding and identifying objects needed for the experiment, the need for interaction, and rendering the performed actions and results of the experiments with computer graphics. Various hints are necessary to progress in the game. They correspond to a dramatized presentation of the theory. In game levels, hints are represented in textual or visual form by presenting them on virtual instruction sheets. Finding clues can reward the user with various gameplay elements, but their main purpose is to provide information to the user, i.e., how to further progress in the level. In this VR solution, after completing tasks, the user is rewarded with pieces of a code that are required to complete the level of the game.

3.3. Virtual Assistant

This subsection presents the use of the VR assistant in various interactive applications. In real life, when teaching in the classroom, the student always has an assistant who can help them solve tasks or evaluate the learning progress. In distance learning, the student also can consult and receive evaluations from the teacher. A similar scenario is also possible in VR, but it is rarely used. This is due to both the lack of tools and the readiness of teachers to conduct classes in VR. One of the ideas for these problems is the creation of a virtual assistant. A VR assistant [88] is a virtual assistant that uses VR technology to provide users with an immersive experience while interacting with the assistant. Unlike traditional

virtual assistants that operate on a two-dimensional screen, a VR assistant provides a three-dimensional experience by placing the assistant in a virtual environment that users can explore and interact with. A VR assistant can perform a wide range of tasks, such as providing information, answering questions, scheduling appointments, setting reminders, and even controlling smart home devices. The assistant can be designed to look and behave like a human, with natural language processing and speech recognition capabilities that allow users to interact with the assistant using voice commands. The virtual assistant will not only consult and perform assessments, but will also try to keep the learner's attention and motivate them. The virtual assistant subsystem is part of the VR learning program. A virtual assistant in the form of a certain character intervenes and participates in an interactive conversation with the student.

The non-functional requirements for a virtual assistant are:

- The virtual assistant must be a flying character in order to naturally move to any position in the VR scene;
- The virtual assistant must communicate with the student by text, sound (voice) and images, thus conveying information in all ways;
- The virtual assistant must have animations that indicate various states to the student:
- A state where the assistant indicates that communication is about to begin;
- A state where the assistant is speaking and demanding attention;
- A state where the assistant is waiting for student interaction. Several character prototypes were developed during various projects. Their screenshots are given in the images below.

Figure 1 shows the experimental virtual classroom environment where the assistant is designed in the form of an owl. The assistant's states are indicated by dynamic model animations and facial expressions. Information is presented in all ways—images, sound, and text channels.

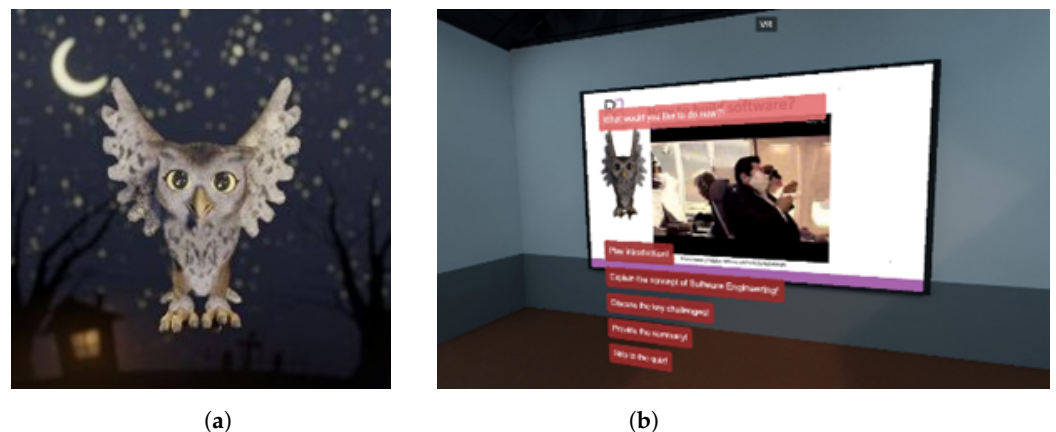


Figure 1. Example of a virtual classroom assistant: (a) an image of the virtual assistant, (b) the use of the virtual assistant for conversation in VR interface.

Virtual assistants were prepared according to the visuals of each project. Sketches of assistants were prepared based on various sample paintings. Later, based on the sketches, their models were created using the three-dimensional modelling program Blender. In the beginning, each assistant was blocked from primitive shapes and iteratively detailed until the right result was obtained. After the models were prepared, the next step was to develop the materials. Materials can be used to specify how the assistant's surfaces will be rendered. Materials are created by specifying material property parameters as values or images as textures. The textures used in the assistant's materials were created with Substance Painter. As in the modelling part, the materials were prepared based on project images. Next, the bone system was created for the assistants. The assistant model was ossified by assigning the vertices of the model to the corresponding bones. Then, by transforming the bones of the skeletal system and creating keyframes for them,

the movements of the assistants' states were animated. Finally, the models of the assistants were exported or images of their animations were generated and used in programs for creating virtual environments.

A virtual assistant is always part of a larger system, considering a complete view of the context which is an important part of the educational process [89]. In addition to virtual assistant functions, the VR system controls the virtual scene and provides learning content in various forms. Furthermore, the VR system provides data to the learning management system (LMS) such as Moodle or similar.

In summary, VR is an interface that uses multiple sensory systems for interacting with a computer. The interface requires high data transfer rates and real-time response to create a sense of continuity. Creating VR environments requires designing objects and interactions for experiments and adding realistic elements for increased interaction. Hints are used to provide information for progress in the game levels, and completing tasks can reward users with code pieces. A virtual assistant can intervene and participate in an interactive conversation with a student, keeping their attention and motivation. The VR system controls the virtual scene, provides learning content, and sends data to a learning management system, e.g., Moodle.

3.4. Designing a VR Learning Program

According to the objective of the work, the VR application being developed must be for learning and must enable a kinaesthetic way of learning. Learners for whom the kinaesthetic learning method is most acceptable absorb information best through personal experiences, self-performed physical activities, experiments and observations of real phenomena related to the educational subject. Therefore, the educational content presented in the virtual environment must be supported by various interactive physical activities and visualizations simulating the phenomena of the educational subject [90].

3.5. Implementation of Interaction in VR Environment

To implement interaction in a VR environment for modelling cultural and historical heritage, the following steps are taken:

- Determine the learning objectives and target audience: Determining the learning objectives and target audience will help in designing a VR program so it meets the needs of the learners.
- Design the virtual environment: Once the learning objectives and target audience have been identified, the next step is to design the virtual environment. The environment should be designed to reflect the cultural and historical heritage being modelled. This can include designing virtual buildings, artefacts, and other elements that reflect the culture and history.
- Incorporate kinaesthetic learning: The VR program should incorporate kinaesthetic learning, which involves physical interaction with the environment. This can include allowing learners to pick up and examine artefacts, walk around the virtual environment, and interact with characters.
- Develop interactive scenarios: Interactive scenarios should be developed to help learners engage with the virtual environment. These scenarios can be based on historical events, cultural practices, or other relevant topics. Scenarios can be designed to encourage learners to explore the environment and interact with objects.
- Use simulated devices: Simulated devices can be incorporated into the VR environment to help learners interact with the environment. For example, learners can use virtual tools to excavate artefacts, perform chemical analysis, or examine objects.
- Test and evaluate the program: Once the VR program has been developed, it should be tested and evaluated to ensure that it meets the learning objectives and is effective in enhancing cultural and historical heritage. The program can be evaluated using surveys, interviews, or other methods to determine learner satisfaction and knowledge retention.

Implementing interaction in a VR environment for modelling cultural and historical heritage involves designing a virtual environment that reflects the culture and history being modelled, incorporating kinaesthetic learning, developing interactive scenarios, using simulated devices, and testing and evaluating the program. By following these steps, a VR program can be developed that is effective in enhancing cultural and historical heritage.

The workflow of VR application development is summarized in Figure 2. The workflow starts with defining project goals and requirements, selecting a VR development platform, designing and developing the virtual environment, creating interactive objects and interactions, testing and iterating on the application, integrating hardware, optimizing performance, and preparing for release. Finally, the VR application is deployed and user feedback is monitored to inform future iterations.

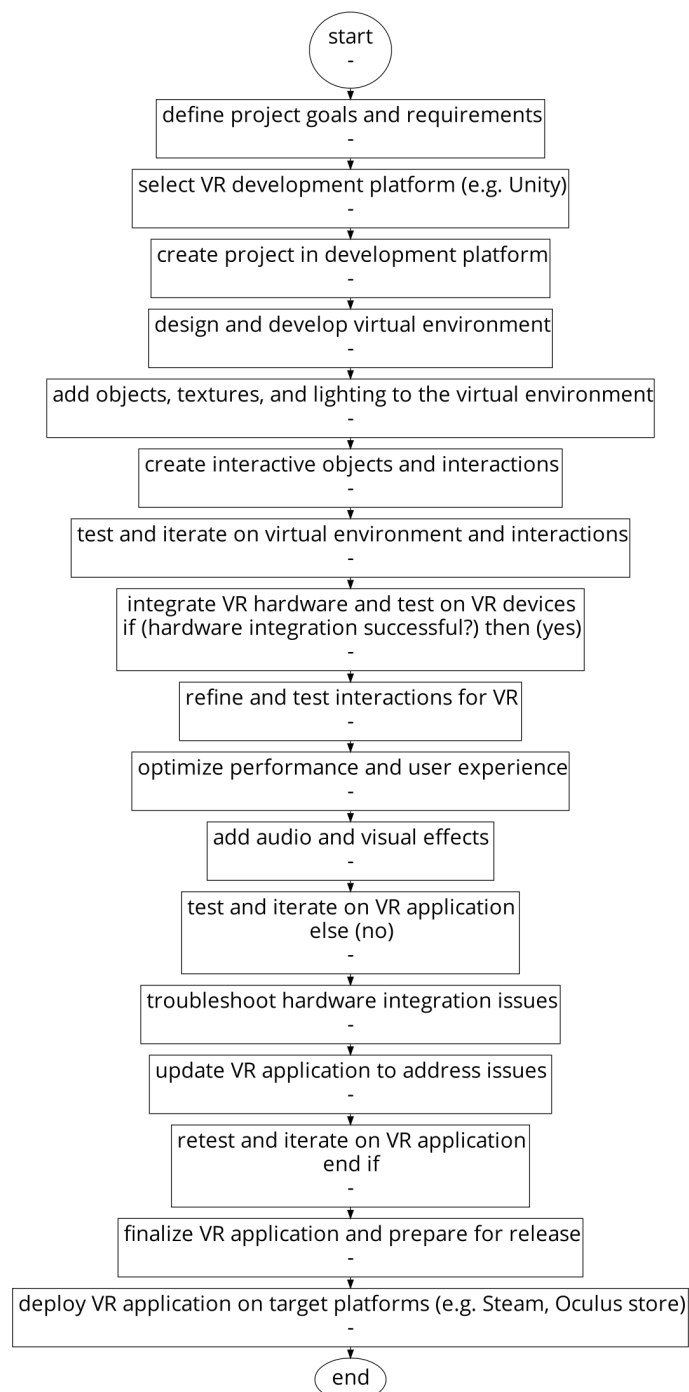


Figure 2. Flowchart of VR application development.

VR Learning App Concept

According to different learning topics, the content in the VR application would be presented in different scenarios of virtual environments. In the program, each scenario would have two types of activities: learning and assessment activities. The virtual environments and types of the scenarios could be chosen by the learners independently or according to the instructions.

Learning is the goal of educational activity-type virtual environment scenarios. In scenarios, learners can freely view and interact with the content presented in the environment. The content provided would be interactive and relevant to the learning topic and objectives. Learners would learn by experimenting with this content and observing the results and consequences of their actions. The results of the actions taken by the learners would be presented through various visualizations.

The content presented in the virtual environments of the evaluative activity-type scenarios would not change from the educational activity-type, but the objectives of these activities would differ. The purpose of this type of assessment activity is to assess the knowledge of the learners. The execution progress of this type of scenario would be predicted by the constraints and evaluated by the accuracy of the tasks performed. The actions of the learner in the virtual environment of the assessment activity should be purposeful, avoiding any experimentation, to obtain the most accurate result as possible within the constraints of the scenario.

The limitations of the evaluation activity would include the flow, instructions and conditions of the virtual environment scenario. The script flow options would control the content of the virtual environment that does not directly depend on the actions of the participant. With these options, contingencies would be simulated in the virtual environment of the scenario. The instruction options would be for task and goal formation in the virtual environment scenario. With these options, it would be possible to specify what the participant has to do in the virtual environment step-by-step, or to form the main goal of the scenario that the participant should achieve by relying on their own knowledge. The condition options would control the various additional conditions that the participant must comply with when performing actions and completing tasks. Among the conditions that can be selected would be a time limit for completing a task or achieving a goal. Constraints for the scenarios to be performed in the assessment activities would be selected from predefined options or randomly from a set of predefined constraints.

The main actions that learners can perform in virtual environments are: movement, interaction with virtual objects, and control of the user interface. Learners could move in two ways, physically and virtually. Physical movement would be rendered based on the data of the VR system. As the learner walks in the real environment, their position would change accordingly in the virtual environment. Virtual movement would be integrated as additional movement that bypasses the limitations of the physical environment area and the active area of the VR system. The program could integrate several methods of virtual movement: teleportation, directional walking, arm swing, reorientation and head direction movement methods. Among these methods, it was chosen to integrate the discontinuous movement method teleportation, as it causes the least discomfort to users [91]. Virtual movement would be performed using VR controllers. When the learner presses a key on the VR controller, a dot in the virtual environment would be displayed to indicate the location of the move. The position of the point could be changed by the learner by aiming with the controller. Releasing the key on the VR controller would instantly transport the learner to the specified location.

Learners would interact with objects in the virtual environment using VR controls. According to them, the positions of the hands in the virtual space would be determined and objects would be used by pressing the button of the controllers. Interactive objects would be of two types: solid objects and device controls. Solid objects would be simulated by the physics engine. These objects can be moved to other locations in the virtual environment. Device controls would simulate various keys and levers. Using them would perform some

actions with virtual devices. Depending on the script, objects can be used to perform some tasks in the script.

The VR application has two user interfaces: the main menu and the script interface (see Figure 3). The main menu provides learners with options to close the program, choose the type of activity, and select the scenario they would like to start. The main menu is presented as a standard graphical user interface with two windows—a main menu window and a script selection menu window. The main menu window has two buttons—the first one opens the script selection window, and the second one closes the program. In the script selection menu window, learners can select a script by pressing the arrow buttons, and the selected scenario is represented by a small icon with a description of the scenario. The cell option allows learners to mark the type of activity they would like to start, and two additional buttons allow them to return to the main menu window or start a script. The user interface can also be presented as a virtual environment where learners can interact with simulated devices through interactive controls to choose the type of activity and scenario they want to start.

The rationale for integrating two menus in the VR application is to provide users with a clear and organized way of selecting and starting different scenarios and activities. The two menus serve different purposes. The main menu interface is the primary interface, where learners can select the type of activity they would like to engage in and choose which scenario to start. This is the initial screen that appears when the application is launched, and it provides the user with the option to start a new scenario or return to the main menu. The script interface, on the other hand, is where learners can select a specific script and start a scenario. It provides a list of available scripts and descriptions of each script, which enables learners to choose the scenario that they find most relevant or interesting. The two menus work together to provide a user-friendly interface that is both easy to navigate and offers a range of options for learners to engage with. By integrating both menus, learners can quickly and easily select the scenarios they want to start and the type of activity they want to engage in, without having to navigate through complicated or confusing menus.

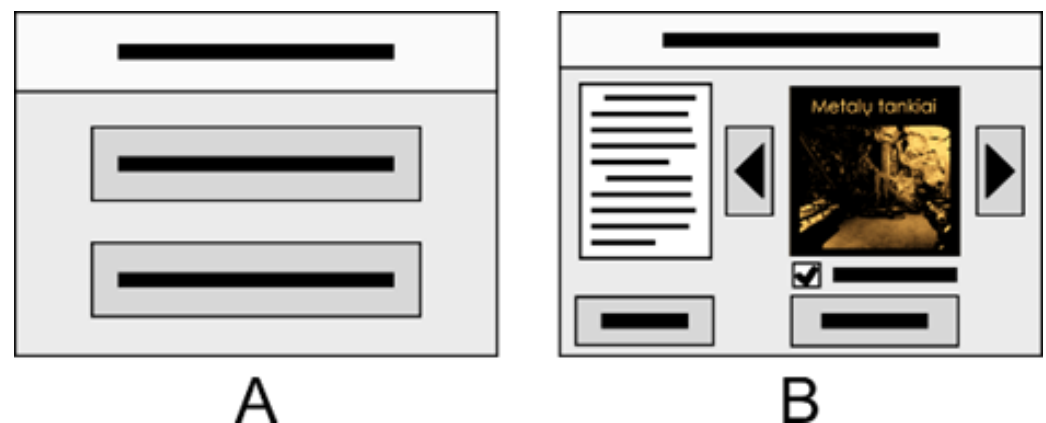


Figure 3. Layouts of the main menu (A) and script selection menu windows (B). The main menu contains the Start and Close buttons. In the scenario selection menu window, general information about the scenario is provided and the optional scenario can be set with the buttons provided.

The script interface would provide help information and a script exit function. This interface would not be visible by itself in the virtual environment, the learner could call it up at any time. The invoked script interface would be rendered next to the learner's virtual hand so that the learner could conveniently change the position of the interface by moving the hand. The interface would be divided into different windows according to the information provided: script description, tasks, task descriptions and script results (see Figure 4). The scenario description window would provide general information about the scenario, what its topic is and the learning objectives, and what will be achieved or

learned after completing the scenario. The Tasks window would list all tasks in the script, along with their progressions, that are required or can be performed in the script. More detailed information about each task would be provided in the task description window. The description would indicate what steps need to be completed in order for the task to be marked as completed. The results of the script would be available only after the script is finished. That is, either completing all tasks in the script or terminating the script due to non-observance of the constraints. The script results window would show how many tasks were completed and various additional information. If the script is run as an assessment activity, the results window would display the resulting assessment. Navigation between interface windows would be possible using the buttons that would appear in the original script user interface window. The learner could press the interface buttons with the other virtual hand. In addition to the window switch buttons, the script's initial user window would have a script exit button to exit the script at any time.

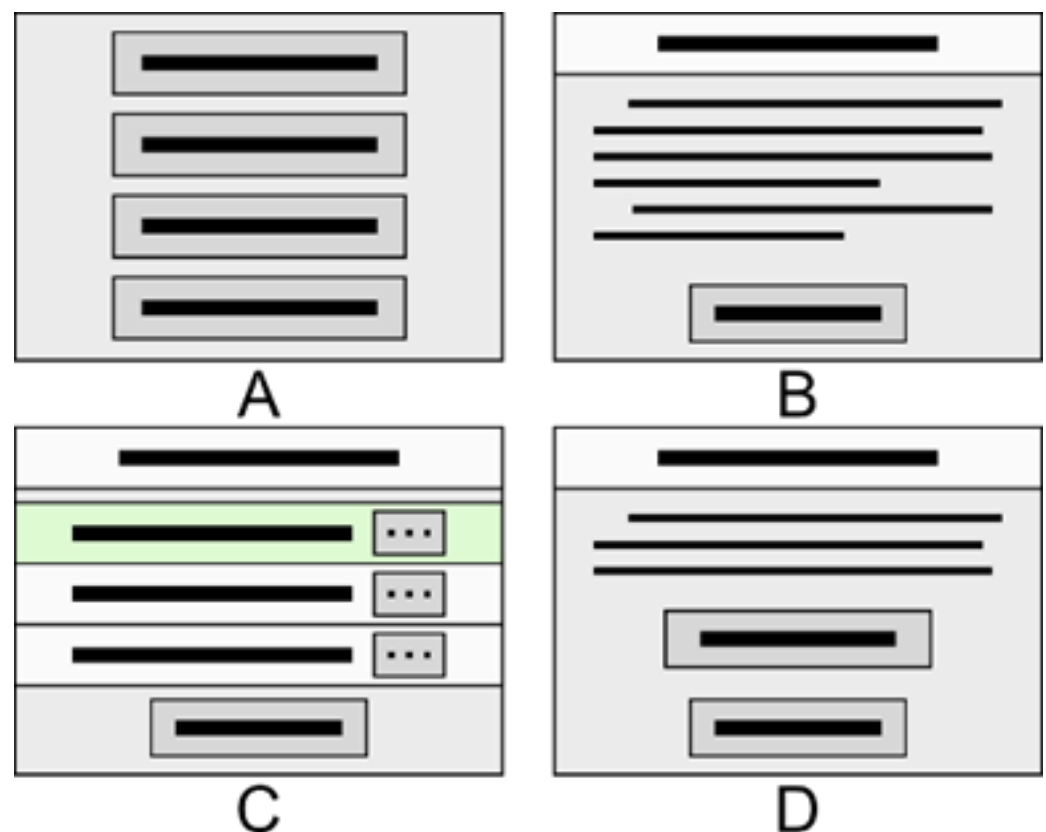


Figure 4. Script UI window layouts. Initial interface window (A), script and task description window (B), task window (C), and results window (D).

The described VR application for mobile learning linked to museum exhibitions integrates two user interfaces: a main menu interface and a script interface. The main menu interface allows learners to select the type of activity and scenario they would like to start, and provides the option to close the program. The script selection menu window allows script selection through arrow buttons and provides information about the scenario. The script interface provides help information and a script exit function and is divided into different windows: script description, tasks, task descriptions, and script results. The example of the discussed interface is presented in Figure 5, which shows the task selection menu. Navigation between interface windows is possible using buttons that would appear in the original script user interface window. Learners can call up the script interface at any time, and it will be rendered next to their virtual hand. The invoked script interface is used for providing additional information about the scenario and task completion status.

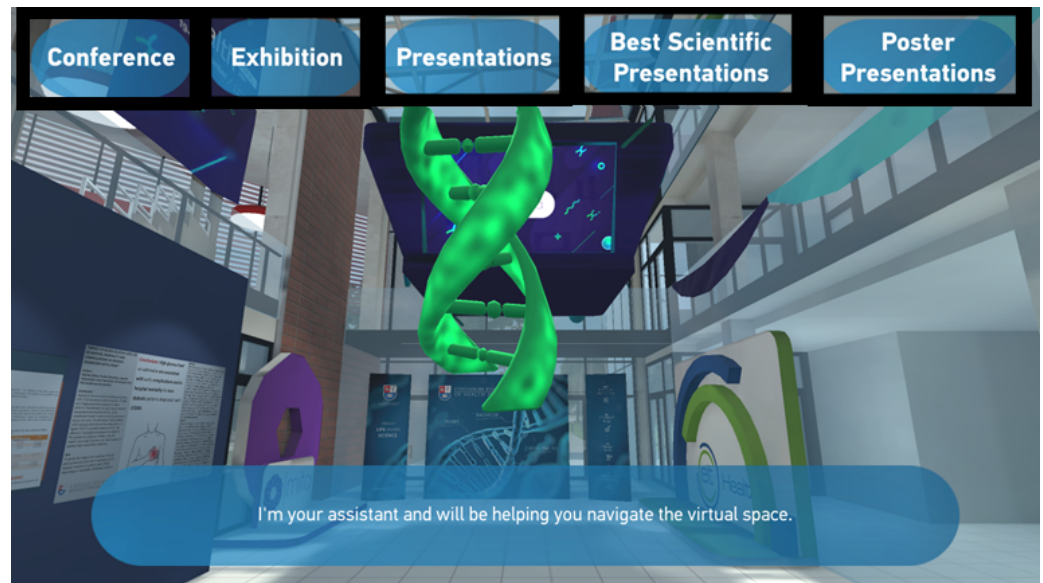


Figure 5. An example of the VR interface. Black frames show the tasks as defined by the UI layout given in Figure 4.

3.6. VR Learning Application Specification

The designed VR program will be divided into two subsystems: menu and virtual environment subsystems. In the menu subsystem, the participant can select the activity scenario and close the VR application. In the subsystem of the virtual environment, the participant can interact with the virtual environment by changing their position, perform actions with objects in the environment, control the course of the scenario, and end the scenario.

Below is a list of the use cases of the menu subsystem:

- Select the type of activity. By pressing the menu button, the participant selects one of two activity types: an educational activity or an assessed activity.
- Select a scenario. The participant must select one scenario of the virtual environment from the presented list by pressing the menu button. Selecting a script enables the virtual environment script.
- Close the program. The participant presses the close button of the program, shutting down the application.

Below is a list of the use cases of the virtual environment subsystem:

- Change position in the virtual environment. By pressing and holding a key on the VR controller, the participant can target planes in the virtual environment. When the participant releases the key, they move to the target position in the virtual environment.
- Interact with an object. The participant can influence objects in the virtual environment using the VR controls. By changing the position of the controller in space, the participant can move virtual objects with it. When the participant holds the controller next to an object and presses the controller key, the object is grabbed or a unique action is performed on it.
- Terminate the script. Through the menu presented to the participant, they can interrupt the running scenario. They can access the script termination function from it.
- Show script menu. A participant can show and hide the user interface.

Behavioural Description of a VR Learning Program

The operation of the VR learning program is detailed with activity diagrams. They represent how to choose a script, how to interact in the virtual environment, and perform tasks using the script interface. The selection and performance of the scenario is carried out by the participant first choosing one of two activity types: an educational activity or an assessment activities. They are then presented with a list of possible scripts to execute

from which they select one. Depending on the type of activity chosen, the participant can independently experiment in the virtual environment or perform the assessed tasks presented to them. The scenario is completed when all the tasks are completed or the is terminated by the participant.

The integrated virtual movement of the teleportation method in the VR learning program would be initiated by the participant pressing a key on the VR controller. By holding down a key, they can select a point on the plane of the virtual environment to which they would like to move. The selection would be controlled by aiming with a VR controller. The location of the selected position would be graphically represented. To move to a selected point in the virtual environment, the participant must release the controller key. If they are allowed to move to the selected place, the participant is moved to it. Otherwise, the move is cancelled.

Picking up solid objects would be performed with a key press on the VR controller. A handshake would be performed when the participant presses the key. It would then check if the virtual hand is near some simulated solid object. If there was no object near the virtual hand the hand is only squeezed. The pick-up can be repeated after releasing the hand. If the object is near the hand during the squeeze then it is attached to the virtual hand. Additionally, after picking up an object, a visual shift is applied, with which the weight of the object is simulated in the virtual environment. The visual offset is continuously updated while the object is held. If the virtual handshake is released after picking up an object, the object is detached from the hand.

Using virtual controls is performed in a similar way to grabbing objects. A participant squeezes a virtual hand with a VR key press. Then it is checked whether the controller is nearby during the handshake. If there is no controller, the hand is only compressed. After releasing the hand, the grab can be repeated again. If the controller is nearby during the handshake, then its grasp is simulated. By grasping the controller, its position can be adjusted. The position of the controller is constantly updated while it is held by the virtual hand. When the controller is released, it is enabled or disabled depending on its previous position.

While in the script, the participant can view the presented content in the script menu. First, the participant uses the VR controller to activate the script interface window in the virtual environment. The visible window contains buttons that the participant can press to view the content of the interface. Clicking on the scenario description, tasks or results button opens the corresponding user interface window where the participant can view the information they need. In the task window, the user can click an additional button that will open a window to provide additional information about the task.

The script is executed by performing actions related to the tasks. After completing one action related to the task, it is checked whether the task is completed with it. If so, then it is then marked as done. Then it checks if the last completed task was the last. If so, then the participant is presented with the results of the scenario execution.

4. Results

4.1. Software and Technical Specifications

The VR solution was developed on a Windows 10 64-bit operating system using the Unity 3D (v2018.3) development environment with HTC Vive and SteamVR (v1.2.3) Utilities. The Blender (v2.8) modelling program was used to create the three-dimensional objects of the virtual environment. Additionally, various ambient sounds were integrated to create more immersive experiences in the virtual environment.

Unity 3D is a powerful and popular game engine that is widely used for VR development. It provides a wide range of tools and features for building immersive virtual environments, including a user-friendly interface, real-time rendering, physics simulation, and asset management tools. Unity also supports a wide range of platforms, including HTC Vive, Oculus Rift, and other VR headsets, making it a versatile choice for VR development.

The Unity Asset Store provides a vast library of assets, plugins, and scripts, which can be easily integrated into Unity projects to accelerate development.

The HTC Vive is a VR headset that provides a VR experience, featuring room-scale tracking, high-resolution displays, and wireless controllers. It uses SteamVR, a software platform developed by Valve, which provides APIs and utilities for VR development. The HTC Vive also features a tracking system that allows users to move around the virtual environment and interact with objects in a natural way.

The following list summarizes the HTC Vive's technical requirements: (a) 4.6×4.6 m tracking space for user operation using two "lighthouse" base stations for tracking the user's movement with sub-millimetre precision by emitting pulsed IR lasers, a pair of screens with a field-of-view of roughly 110 degrees, one for each eye, (b) more than 70 sensors, including a MEMS (microelectromechanical system) gyroscope, accelerometer, and laser position sensors, (c) Front-facing camera for viewing around in the real world to identify any moving or static object in a room as part of a safety system; (d) SteamVR running on the Microsoft Windows operating system; and (e) input from SteamVR tracked wireless motion controllers.

SteamVR is a development platform that provides APIs and utilities for VR development. It includes a range of features, such as locomotion systems, input management, and haptic feedback, that make it easy for developers to create VR experiences. SteamVR also provides tools for testing and debugging VR applications, including a built-in performance profiler, which can help developers optimize their applications for better performance.

Blender is a free and open-source 3D modelling and animation software that can be used for VR development. It provides a wide range of tools for modelling, sculpting, texturing, and animating 3D objects, making it a popular choice for creating assets for VR environments. Blender also supports a wide range of file formats, making it easy to import and export assets from other software tools. Together, these software tools provide a powerful and versatile set of tools for creating VR experiences.

The following describes the minimal necessary computer specifications: Processor Intel Core i5-4590 or AMD FX 8350, graphics card Radeon RX 480 or NVIDIA GeForce GTX 1060, and a visual output. One HDMI 1.4-connection, one DisplayPort 1.2-connection, one USB 2.0-connection, and Windows 7 SP1, Windows 8.1, or Windows 10 as the operating system. The gadget tracks the head's motions with an accuracy of one-tenth of a degree using a gyroscope, accelerometer, and laser position sensor. The user may freely explore virtual things, people, and situations while interacting with them thanks to wireless controllers in each hand and accurate SteamVR tracking.

With simple controls and lifelike haptic feedback, the VIVE controller is made for VR. Any object that has to be photographed is simply captured using photo sensors by the lighthouse system. This is done using two lighthouse stations that sweep structured light lasers over the area to prevent occlusion issues and improve tracking precision.

The virtual environments of the application scripts were created in levels. In the UE4 editor, levels can be loaded with various visual, audio, and logical content from the editor's content window. The main visual details are created from three-dimensional objects, loading them into the scene and changing their transformation according to the environment you want to extract. Created external sets of 3D objects needed to represent virtual environments and the interactive content contained in them were loaded into the project. Objects were created with the 3D modelling program Blender and exported in the FBX (Autodesk Filmbox) format. Collision meshes were created for objects with more complex shapes.

The surfaces of three-dimensional objects are rendered according to the materials assigned to the object, the properties of which are described in the UE4 editor. Material properties can be assigned values or effects, such as textures, that specify some value of the property at each point in the plane. The project used textures from the Substance Source library in the materials of the virtual environment objects.

Prepared visual content was generated into layers of virtual environments and laid out to match the desired look. Next, the class objects needed for the script to work were spawned, such as the participant-controlled MotionControllerPawn and other object classes that provide interactivity.

4.2. Case Study 1

Exhibited in the Vytautas Great War Museum, the purpose of this application was to present historical Lithuanian aeroplanes created in independent Lithuania during the period between the two World Wars (1919–1939) and a couple of other historical vehicles. The purpose of this game was to present the legendary flight over the Atlantic ocean. The game covers a story of two Lithuanian pilots—Steponas Darius and Stasys Girėnas. In 1933 they set out to fly over the Atlantic ocean in a modified plane they called Lituania. They took off in New York and sadly met their tragic fate right before reaching their final destination—landing in the city of Kaunas.

The game includes 10 mini-games and 8 short historical videos that connect the story and mini-games. The videos were taken from historical sources and were pre-processed by increasing the quality and matching the style of the game. The game is dedicated to smart devices (smartphones, tablets) and runs on Android and iOS platforms. The application also includes the AR part which makes use of a magnetic badge depicting the Lituania aeroplane (Figure 6). This application is used in two ways. It is currently being exhibited in a museum and is part of the museum’s educational program.

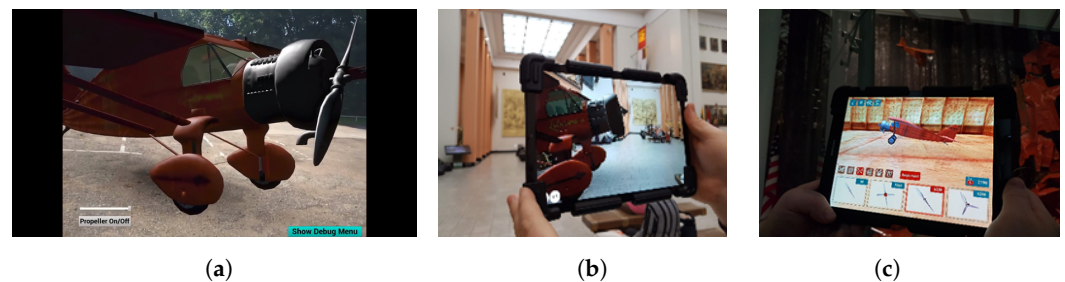


Figure 6. A 3D model of a historical aeroplane “Lituania” in AR: (a) virtual aeroplane image, (b) a demonstration of augmented reality in real-life (museum) context, and (c) a screenshot of a game.

The learning objectives for the historical Lithuanian aeroplanes game include:

- To learn about the historical Lithuanian aeroplanes created during the period between the two World Wars (1919–1939), including their designs, features, and significance.
- To understand the story of two Lithuanian pilots—Steponas Darius and Stasys Girėnas, who attempted to fly over the Atlantic ocean in a modified plane named Lituania, and their tragic fate.
- To engage in interactive and educational gameplay, which can enhance knowledge retention and the learning experience.
- To discover more about the history of Lithuania and its significance in aviation during the interwar period.
- To learn about the technology used to create the game, including AR and video processing techniques.

The learning scenario for the historical Lithuanian aeroplanes game were as follows:

1. The game is introduced to students during a visit to the Vytautas Great War Museum.
2. Students are divided into groups and assigned a mini-game to play. Each mini-game represents a historical event related to the Lithuanian aviation industry between 1919 and 1939.
3. After playing the mini-game, students are asked to watch the corresponding historical video which further connects the story to the mini-game.

4. Once students have completed all 10 mini-games, they are asked to play the final game which covers the story of Steponas Darius and Stasys Girėnas and their flight over the Atlantic ocean.
5. The AR part of the application is introduced, where students can use the magnetic badge depicting the Lituania aeroplane to further explore the details of the plane.
6. A class discussion is conducted to encourage students to share their experiences and learnings from the game. The discussion also includes the importance of Lithuanian aviation history and its impact on the world.
7. As a follow-up activity, students can be asked to create a report or presentation based on their learning from the game and museum visit.

This learning scenario combines interactive gaming with history and technology to create an engaging learning experience for students. It also provides an opportunity to connect historical events to modern technology and encourages students to learn about their country's aviation history.

4.3. Case Study 2

Ką Kaunas? (What is Up Kaunas?) is an art project made in collaboration with a master's student from the Vilnius Academy of Arts. The idea of the project was to make the street art of Kaunas more interesting for tourists by adding visualizations to these art pieces through AR technology (Figure 7).

The project used street art as targets for AR. When a user would face their smartphone's camera towards a piece that was defined within the program various animations and visualizations would appear on top of it. The demonstration of this case study can be seen at <https://www.youtube.com/watch?v=7S7GQxFI4Ss>, accessed on 3 January 2023.

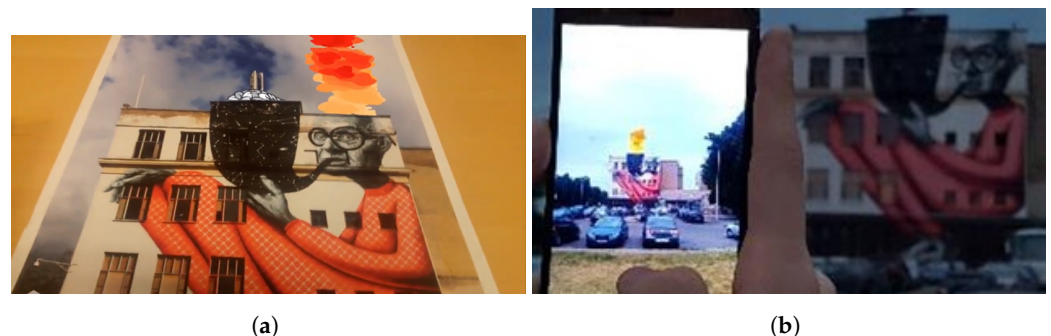


Figure 7. Augmented reality on the historical industrial building of Red October shoe factory in Kaunas (Lithuania): (a) a still video frame of the video sequence, (b) a demonstration of the AR app in real world on site.

The learning objectives for the scenario of “Ką Kaunas?” art project were:

- To increase the engagement of tourists in exploring and appreciating street art in Kaunas through AR technology.
- To enhance visitors' understanding of the cultural and historical significance of street art in Kaunas by adding informative visualizations and animations to the art pieces.
- To encourage tourists to actively participate in discovering and learning about the city's art scene and history.
- To provide a unique and interactive learning experience for tourists to promote curiosity, creativity, and critical thinking skills.
- To promote the use of technology for educational and cultural purposes, and to demonstrate the potential of AR technology in enhancing learning experiences.

The learning scenario for the Ką Kaunas? project were to teach students about art and technology through an interactive and engaging experience. The following steps are included in this learning scenario:

1. Introduce the students to the Ka Kaunas? project and explain the concept of using street art as targets for AR technology. Discuss how technology can enhance the experience of viewing art.
2. Take the students on a field trip to see some of the street art pieces that have been augmented with AR technology. Allow the students to use their smartphones to view the augmented art and experience the animations and visualizations.
3. Engage the students in a discussion about the different techniques and methods used to create street art. Discuss the different styles of street art and the cultural and social implications of this type of art.
4. Ask the students to create their own street art pieces using traditional and/or digital methods. Encourage them to think about how they could incorporate AR technology into their art to make it more interactive and engaging.
5. Provide students with the tools and resources needed to create AR-enhanced street art pieces. Show them how to use AR software to create animations and visualizations that can be superimposed on their art.
6. Allow the students to create their own AR-enhanced street art pieces and share them with their classmates. Encourage them to critique each other's work and provide feedback.
7. Conclude the learning scenario by discussing the importance of art and technology in society. Encourage the students to continue exploring the use of AR technology in art and other fields.

5. Evaluation

5.1. Additional Questionnaires

In order to find out the opinion of the respondents about the educational VR program created at work, they were given an additional questionnaire based on the Web-based Learning Tool (WBLT) Evaluation Scale, the Igroup Presence Questionnaire (IPQ) and the System Usability Scale (SUS). At the beginning of the questionnaire, respondents were also asked to indicate how often they used VR.

WBLT—The rating scale is intended to determine the effectiveness of such learning tools or learning objects. In total, the questionnaire consists of 13 statements. They are divided into three main components of the questionnaire: learning, design and engagement [92]. In each statement, respondents give their opinion about the learning tool by marking the values from 1 to 5, where 1 means “Strongly disagree” and 5 means “Totally agree”. WBLT has been previously used to evaluate VR systems and games in several studies [93–96].

IPQ—The questionnaire is a rating scale designed to measure the user's sense of involvement in virtual environments. The questionnaire consists of a total of 14 statements, which are divided into three main evaluated parts: spatial presence, participation and realism [97]. In the spatial presence, part, the respondents evaluate the sensation they experienced in the virtual environment, that is, whether they felt as if they were actually there. In the participation part, the respondents assess how much attention they paid to the virtual environment compared to the real environment, and how much participation was experienced in it. In realism part, the respondents subjectively assess how realistic the virtual environment seemed to them. Respondents give their opinion in each statement by marking values from 1 to 5.

SUS—The questionnaire is designed to evaluate the usability of the VR program. The standard SUS questionnaire consists of 10 statements. Of these, odd statements are formulated positively, and even statements are formulated negatively [98]. The SUS uses a Likert scale, according to which respondents evaluate each statement by marking values from 1 to 5. A answer of 1 means “Strongly disagree” and 5 means “Strongly agree”.

5.2. Investigation Progress

The research was carried out in the premises of the university. The study was divided into three parts. Before each part of the study, the respondents were informed about the course of the study and what will be conducted.

The first part of the study aimed to determine the way of learning of the respondents. They were given a prepared electronic questionnaire of learning methods. After completing the questionnaire, the second part was started.

In the second part, the respondents were presented with the further course of the research, what they will need to do, what they will need to pay attention to, and what tasks will need to be completed. After the introduction of the procedure, respondents were provided with educational materials in various forms. Each form was given 10 min to review, but respondents could finish the review earlier if they wished. After viewing each educational material, respondents were given a 5 min break. After the break, they had to take a knowledge test and continue to review other learning material. The test took 10 min. According to the forms, the educational material was presented in the following order: visual, audio, textual and kinaesthetic (VR program).

The study used the SteamVR platform, HTC Vive Pro VR glasses and Valve Index controllers to test the VR application. The VR system was run on a PC with the Windows 10 operating system, Intel Core i7-8700K main processor and an NVIDIA GeForce RTX 2080 Ti GPU. In the test room, a space of 3.2×3.2 m was allocated where the respondents could physically move. Before testing the program, the respondents were briefly told how the VR program works, how they can move in the program, interact with its content, and the main script of the program was presented. Before starting the scenario, the respondents could try out the functionality of the program in a prepared initial virtual environment and read the written instructions in it. From the initial virtual environment, respondents could start the main script when they were ready by using the virtual key in the environment. After the scenario ended, respondents were again given a 5 min break and given a knowledge test (Figure 8).



Figure 8. Respondents trying the VR program during the testing of the application, experiencing genuine cross-cultural communication and friendships to transcend differences, stimulating innovative thinking and creative new modes of collaboration to build a more positive, peaceful, and successful society.

At the end, the respondents were given an electronic questionnaire with additional questionnaires of the WBLT rating scale, IPQ and SUS scale designed to determine the respondents' opinion about the VR educational program.

5.3. Data Processing

The research results from the questionnaires and the knowledge test were separated into five data groups: data from the learning methods questionnaire, knowledge test results, WBLT assessment, IPQ, and SUS questionnaire estimates.

5.3.1. Learning Styles Questionnaire Results

Learning styles are different the ways in which individuals prefer to receive, process, and retain information. The concept of learning styles suggests that people have different cognitive strengths and preferences, and that they learn more effectively when information is presented in a way that matches their preferred style. The most common model of learning styles includes visual, auditory, and kinaesthetic/tactile learning, which represent preferences for seeing, hearing, and doing, respectively [99]. While some research supports the idea of learning styles, there is also debate and criticism about their validity and effectiveness in improving learning outcomes [100–103].

After analysing the data of the learning methods questionnaire, the respondents were grouped according to acceptable learning methods. A total of eight groups were distinguished: five groups of multiple learning and three groups of a specific learning method (see Table 1). The largest number of respondents, eight, was assigned to the multi-learning group with a tendency towards all learning methods (VGTK). Five respondents were assigned to the group of multiple learning with a tendency towards the visual and kinaesthetic learning method (VK), two respondents were assigned to the groups of multiple learning with a tendency to the visual, audio and kinaesthetic learning method (VGK) and the group with a tendency to the kinaesthetic learning method. For the rest of the groups, one respondent was assigned to multiple learning with visual, audio and text bias (VGT), multiple learning with visual and audio bias (VA), slight kinaesthetic bias (k) and slight visual bias (v).

Table 1. Number of respondents in the groups according to the acceptable learning methods.

Groups According to the Acceptable Learning Style	Number of Respondents
Multimodal learning with a bias towards all learning styles (VGTK)	8
Multimodal learning with a bias towards visual and kinaesthetic learning (VK)	5
Multimodal learning with an emphasis on visual, auditory and kinaesthetic learning (VGK)	2
Tendency towards a kinaesthetic learning style (K)	2
Multimodal learning with a bias towards visual, audio and text learning (VGT)	1
Multimodal learning with a bias towards visual and auditory learning (VA)	1
A slight tendency towards a kinaesthetic learning style (k)	1
Slight inclination towards a visual way of learning (v)	1

5.3.2. Results of Knowledge Verification Tests

After calculating all the scores of the knowledge test for the participating respondents, the highest average score was obtained from the test prepared for the educational material presented in text form as 9.04 (see Table 2). The second place according to the average score was the test prepared based on the material presented in visual form. The grade point average was 7.49. The worst score was obtained from the test of the material presented in kinaesthetic form as 7. The worst, but similar average score to the average score of the test of kinaesthetic material was obtained from the test prepared according to the educational material in audio form as 6.93.

Judging by the obtained averages of the test results, the kinaesthetically presented educational material was not the most effective. The obtained average was by a small margin higher than the average of the results of the educational material presented in audio mode only. However, given the small number of respondents who might be receptive

to a kinaesthetic learning method, better results could be expected from tests of learning materials presented in other ways.

Table 2. Averages of knowledge test results by the form of learning materials presented.

	Visual Educational Material	Audio Educational Material	Textual Educational Material	Kinaesthetic Educational Material
Score	7.49	6.93	9.04	7.00

Looking at the results and dividing them according to the respondents' potentially acceptable learning methods, differences are found compared to the overall average scores (see Table 3). In the results of the multifaceted VGTK group, it can be seen that the test prepared according to the kinaesthetic form of educational material performed the worst on average, an average score of 6.36. The tests of other forms performed better, the visual form scored 7.53, the audio form scored 6.96, and the text form scored 9.15. The distribution of the test results of the multiple VK group according to the teaching materials is similar to the overall averages. The best performance according to the educational material presented in text form was 8.98, the worst performance for visual material was 8.35, the average score obtained from the test for material presented in kinaesthetic form was 7.85, the worst performed test for material presented in audio form was 7.3. In the multifaceted VGK group, the distribution of the test results also coincided with the overall averages, the best performed text form test was 8.45, the worst performed visual form test was 8.04, the third place according to the average score of the kinaesthetic form test of learning material was 7.73, the worst performed test was based on the material prepared in the audio form 6.85. The respondents of the K group performed the best on the test prepared according to the text form of the material, the average score was 9. The kinaesthetic form test performed worse on the most acceptable form of learning, with an average score of 7.34. An average of 5.68 points was obtained from the audio form of the material, and 5.09 points from the visual form.

Further groups of learning methods may not have been very important, since only one respondent was assigned to them. However, it was observed that the respondent assigned to the multivariate group VG performed best in the tests prepared according to the kinaesthetic and textual form of the material (received 10 points each). Furthermore, the tests of the learning materials in forms acceptable to the respondent performed worse, the test score of the form of visual material was 8.33, and the score of the audio material was 8.67. It was also observed that the respondent of the *k* group performed the worst on the kinaesthetic form material test. The obtained score was 4.37. The best performance on the test based on textual material was 7.83, the poorest performance on the audio test was 7, and the visual test was even worse with 6.33.

Table 3. Averages of the knowledge test results according to respondents' potentially acceptable learning methods and forms of learning materials.

Score	Visual	Audio	Text	Kinesthetic
VGTK score	7.53	6.96	9.15	6.36
VK score	8.35	7.3	8.98	7.85
VGK score	8.04	6.85	8.45	7.73
K score	5.09	5.68	9	7.34
VGT score	6.03	6.08	10	6.14
VG score	8.33	8.67	10	10
V score	8.33	6.56	9	6.28
Control score	6.33	7	7.83	4.37
Total score	7.49	6.93	9.04	7

After reviewing the test results according to the distribution of respondents into groups of potentially acceptable learning methods, it can be seen that the educational material presented in the study in kinaesthetic form is not the most effective. According to the distribution of scores, the best result of the kinaesthetic form test was obtained in one group (VG), three groups had the worst test results (VGTK, v, and k). In the other groups (VK, VGK, VGT) the results did not change from the general distribution. Such ineffectiveness of learning material presented in kinaesthetic form could be due to two reasons. The first reason is the respondents' lack of experience in using VR. Learning materials presented in other formats may have been easier to absorb because they are familiar to many respondents. When learning material is presented in a VR environment, the learner must first adapt to it. This adjustment time depends on each person's experience with VR. The more experience one has with VR technology, the easier it is for individuals to adapt to new virtual environments, and to understand the controls and functions in a VR application. For a VR program to be effective in achieving learning objectives, learners must first be familiar with the technology [104]. This reason is partially confirmed by the data collected in the study and the observations made during the study. When presenting the test results of the kinaesthetic form of learning material according to the frequency of use of VR indicated by the respondents, it can be seen that the increase in the average score is partially dependent on the frequency of use of VR (see Table 4). Respondents who used VR every week received the highest average score of 9.33, respondents who used VR at least once a month of 7.44, and those who used VR at least once a year of 6.23. The difference in experience between the respondents was also observed during the survey. Respondents with more experience easily navigated the virtual environment of the main scenario, confidently moved and managed the content presented in it, and quickly understood the functions of the program. Respondents with less experience spent more time exploring the virtual environment from the starting position, walked more cautiously physically, and had difficulty controlling the content presented in the environment. A few respondents needed extra help using the virtual movement feature.

Table 4. Average knowledge test results depending on the frequency of using VR technology: How often had the respondents used VR?

	Never	At Least Once a Year	At Least Once a Month	Every Week	Every Day
Score average	7.12	6.23	7.44	9.33	3.17
Number of responses	3	8	6	3	1

Daily use of VR was indicated by only one respondent. The table shows that their average score was very low compared to other averages. Although according to the previous statement, it should be the largest. This result may be related to the second reason why the kinaesthetic form of learning material was least effective, which is the poorly prepared content. In the virtual environment of the scenario prepared for the study, the goal was not clearly stated enough. During the research, the respondents were verbally presented with the scenario of the virtual environment, the interactive content in the environment, and reminded of the main goal—to absorb the information presented in the scenario, according to which the task will be performed later. However, some respondents forgot or ignored the goal during the scenario. Other respondents focused too much on the additional task presented in the script, and while trying to complete it, they lost sight of the original learning objective. According to the observations, it can be said that content that is too interactive can distract the learners and prevent them from achieving the set learning goals. In the following scenarios, the content should be prepared in such a way that the main focus is on achieving the main objective of the scenario. This could be achieved by introducing elements of gamification [105]. The learner would not be able to access

the further content of the scenario's virtual environment until some action related to the learning objective had been completed.

It is interesting that those respondents who tried to achieve the set learning goal tried to learn in different ways. Some tried to arrange the cards with the names of chemical elements in the virtual environment according to increasing densities and memorize the arranged sequence. Other respondents tried to memorize the sequence without changing the layout of the cards. After viewing the sequence, some respondents tried to perform an additional task in the script in one of the listed ways. Bearing in mind that the virtual environment used in the study did not contain a lot of interactive content, but it was enough to notice how the respondents approached the task differently. By providing a greater variety of interactive content, learners were given the opportunity to choose how they wanted to solve the problems in the scenario. In this case, the scenarios could be repeated and learners could try to solve problems in a new way each time, comparing which solution method was the most effective. In addition, with a higher amount of interactivity, the involvement of learners in the learning subject can be increased and it would seem more interesting and enjoyable [106,107]. The greater involvement of the respondents in the material presented in the VR program was also observed during the study. Many respondents took advantage of the opportunity to terminate the review of material submitted in other forms earlier than the scheduled time, while only a few respondents terminated the VR review. In the study, respondents seemed satisfied with the immersiveness of the VR app.

5.3.3. Results of the Online Learning Tool Rating Scale Questionnaire

Based on the results of further questionnaires, an attempt was made to determine how the participants evaluated the VR program and its content. According to the results of the WBLT scale (see Table 5) respondents rated the design of the program the best. The resulting normalized score for this section was 0.93. In terms of engagement, the program was rated 0.91. The lowest score of 0.88 was obtained from the learning part. The results of this questionnaire confirm the previous statements. For the respondents, the virtual environment of the VR program was immersive and interesting. However, the program lacks better learning content, as demonstrated by the results of the knowledge tests.

Table 5. WBLT rating scale results.

Learning	Projecting	Inclusion
0.88	0.93	0.91

5.4. Igroup Presence Questionnaire Results

The results of the questionnaire showed that the VR program rated better than the average according to the other parts of this questionnaire (see Table 6). The feeling of spatial presence was rated best, with an average score of 3.31. User engagement in the VR app and its realism were rated lower at 2.48 and 2.21, respectively.

Table 6. IPQ questionnaire results.

Spatial Existence	Engagement	Realism
3.29	2.44	2.21

5.5. System Usability Scale Questionnaire Results

After processing the results of the SUS questionnaire, an estimated score of 89.13 was obtained. According to this rating scale, products with a score of around 80 are considered better than average. Such a high score could be explained by the relatively easy use of the program and the engaging content, which was also reflected in the results of the WBLT rating scale. However, other sources note that respondents' assessment of system usability

may depend on how successful they were in achieving the goals in the program. That is, if the respondent is unable to perform the tasks presented in the program, there is a possibility that he will evaluate the program negatively. If the respondent is successful, he may be inclined to rate the program more highly. Exceptions may be in the case when respondents are not provided with the results of their performance. Respondents may think that they performed the tasks correctly, although there were no such cases. In this study, respondents were not provided with the results of the knowledge tests they took, so the SUS score may have been lower.

We now have a greater understanding of how AR technologies may be used in learning thanks to this study's exploration of their potential and adoption. According to the study's findings, including AR technology into the teaching and learning process helped students become more motivated and successful learners. The majority of the students expressed their satisfaction with the exploratory learning process and felt that the AR tool was helpful in promoting an active learning mindset. The technological acceptability of learners utilizing AR was shown to be greater than that of learners in the control group. More fruitful AR experiences created and produced by instructors at a classroom level will be made possible by continuing to improve and disseminate information about how AR is employed in education. However, safeguards must be provided to prevent accidents during experiencing VR worlds [21].

6. Conclusions

By fusing the benefits of a virtual and authentic landmark visit, AR also has a lot of promise. Additionally, it allows for the digital superimposition of a historic building condition onto the present through on-site monument visits using a smartphone or tablet.

Analysing the results of the study yielded three insights. First, the ready-made VR training program was less effective than the material presented in visual or textual form. Second, it was observed that the results of the test, which was prepared based on the material of the virtual environment, depended on the experience of the respondents with VR. Third, the VR training program was generally evaluated positively. However, according to the results of the surveys, it was observed that the program needs to improve the presentation of learning materials.

After analysing the operating principles of VR technology, it was found that: three degrees-of-freedom (DoF) VR equipment cannot precisely translate physical actions into the virtual space. Therefore, in order to enable kinaesthetic learning based on physical movement in VR, VR equipment that provides six DoF must be used; the capabilities of VR can be expanded using additional interactivity methods such as: virtual movement, which helps to bypass the limitations of the VR space; visual displacement, which helps to simulate haptics and the weight of objects; and physical simulation of objects and interactions with them, supplemented by visual and audio effects, to enhance the involvement of participants. The results of the conducted sociological research showed that 75% of respondents positively evaluate the use of VR in learning. From this it can be concluded that the designed program can be received positively. On the other hand, such a program must help to learn and achieve the set learning goals, so it was decided to create an educational VR program and evaluate its effectiveness through experimental research.

To fulfil the requirements of the kinaesthetic learning method, a VR program was designed and implemented, which provides learners with: free movement, the presentation of naturally performed physical actions, feedback received through sound, text and tactile sensations, conveyed through the image and VR controls.

To evaluate the effectiveness, an experiment was conducted comparing how respondents remember information presented in different forms: visual, audio, textual and kinaesthetic. The VR program was not the most effective compared to the other forms. In the knowledge test prepared according to the content of the VR program, the respondents scored an average of 7.00 points (out of a possible 10), and from the tests of the material presented in visual and textual form, they scored an average of 7.49 and 9.04 points, respec-

tively. It was observed that the test score of the program may depend on the respondent's experience with VR. Respondents who reported using VR more often scored higher on average. Respondents using VR weekly scored an average of 9.33 points, once a month an average score of 7.44, and once a year an average score of 6.23. A VR learning program is likely to be more effective for learners who have more experience using VR. After reviewing the results of the evaluation scale questionnaire of the online learning tool, it was observed that the participants valued the design and inclusion of the program the most (0.93 and 0.91), the learning part was less valued (0.88). After conducting the system usability study according to the SUS methodology, an estimate score of 89.19 was obtained, meaning that the usability of the program was evaluated as better than average. This means that using a VR application is no more complicated than other applications used for learning purposes and can be used for self-study. This is important in distance learning, when the teacher and the learner are not in the same physical environment, and in the cases of problems where the teacher cannot immediately help the learner.

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References

1. Diao, P.H.; Shih, N.J. Trends and Research Issues of Augmented Reality Studies in Architectural and Civil Engineering Education—A Review of Academic Journal Publications. *Appl. Sci.* **2019**, *9*, 1840. [\[CrossRef\]](#)
2. Mystakidis, S.; Christopoulos, A.; Pellas, N. A systematic mapping review of augmented reality applications to support STEM learning in higher education. *Educ. Inf. Technol.* **2021**, *27*, 1883–1927. [\[CrossRef\]](#)
3. Lampropoulos, G.; Keramopoulos, E.; Diamantaras, K.; Evangelidis, G. Augmented Reality and Gamification in Education: A Systematic Literature Review of Research, Applications, and Empirical Studies. *Appl. Sci.* **2022**, *12*, 6809. [\[CrossRef\]](#)
4. Scavarelli, A.; Arya, A.; Teather, R.J. Virtual reality and augmented reality in social learning spaces: A literature review. *Virtual Real.* **2020**, *25*, 257–277. [\[CrossRef\]](#)
5. Coban, M.; Bolat, Y.I.; Goksu, I. The potential of immersive virtual reality to enhance learning: A meta-analysis. *Educ. Res. Rev.* **2022**, *36*, 100452. [\[CrossRef\]](#)
6. Yoon, S.A.; Wang, J. Making the Invisible Visible in Science Museums Through Augmented Reality Devices. *TechTrends* **2014**, *58*, 49–55. [\[CrossRef\]](#)
7. Chrysanthakopoulou, A.; Kalatzis, K.; Moustakas, K. Immersive Virtual Reality Experience of Historical Events Using Haptics and Locomotion Simulation. *Appl. Sci.* **2021**, *11*, 11613. [\[CrossRef\]](#)
8. Pellas, N.; Mystakidis, S.; Kazanidis, I. Immersive Virtual Reality in K-12 and Higher Education: A systematic review of the last decade scientific literature. *Virtual Real.* **2021**, *25*, 835–861. [\[CrossRef\]](#)
9. Litvak, E.; Kuflik, T. Enhancing cultural heritage outdoor experience with augmented-reality smart glasses. *Pers. Ubiquitous Comput.* **2020**, *24*, 873–886. [\[CrossRef\]](#)
10. Kontogianni, G.; Koutsaftis, C.; Skamantzari, M.; Georgopoulos, A.; Chrysanthopoulou, C. Developing and Exploiting 3D Textured Models for a Serious Game Application. In Proceedings of the 2016 8th International Conference on Games and Virtual Worlds for Serious Applications (VS-GAMES), Barcelona, Spain, 7–9 September 2016; IEEE: Piscataway, NJ, USA, 2016. [\[CrossRef\]](#)
11. Clini, P.; Ruggeri, L.; Angeloni, R.; Sasso, M. Interactive immersive virtualmuseum: Digital documentation for virtual interaction. *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.* **2018**, *XLII-2*, 251–257. [\[CrossRef\]](#)
12. Radianti, J.; Majchrzak, T.A.; Fromm, J.; Wohlgenannt, I. A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda. *Comput. Educ.* **2020**, *147*, 103778. [\[CrossRef\]](#)
13. Kamińska, D.; Sapiński, T.; Wiak, S.; Tik, T.; Haamer, R.; Avots, E.; Helmi, A.; Ozcinar, C.; Anbarjafari, G. Virtual Reality and Its Applications in Education: Survey. *Information* **2019**, *10*, 318. [\[CrossRef\]](#)

14. Checa, D.; Bustillo, A. A review of immersive virtual reality serious games to enhance learning and training. *Multimed. Tools Appl.* **2019**, *79*, 5501–5527. [[CrossRef](#)]
15. Coyne, L.; Takemoto, J.K.; Parmentier, B.L.; Merritt, T.; Sharpton, R.A. Exploring virtual reality as a platform for distance team-based learning. *Curr. Pharm. Teach. Learn.* **2018**, *10*, 1384–1390. [[CrossRef](#)] [[PubMed](#)]
16. Zhang, L.; Bowman, D.A.; Jones, C.N. Exploring Effects of Interactivity on Learning with Interactive Storytelling in Immersive Virtual Reality. In Proceedings of the 2019 11th International Conference on Virtual Worlds and Games for Serious Applications (VS-Games), Vienna, Austria, 4–6 September 2019; IEEE: Piscataway, NJ, USA, 2019. [[CrossRef](#)]
17. Sanfilippo, F.; Blažauskas, T.; Girdžiūna, M.; Janonis, A.; Kiudys, E.; Salvietti, G. *A Multi-Modal Auditory-Visual-Tactile e-Learning Framework*; Vol. 1616 CCIS, Communications in Computer and Information Science; Springer International Publishing: Cham, Switzerland, 2022; pp. 119–131.
18. Pietroni, E. Mapping the Soundscape in Communicative Forms for Cultural Heritage: Between Realism and Symbolism. *Heritage* **2021**, *4*, 4495–4523. [[CrossRef](#)]
19. Bellia, A. Towards a Digital Approach to the Listening to Ancient Places. *Heritage* **2021**, *4*, 2470–2481. [[CrossRef](#)]
20. Atsikpasi, P.; Fokides, E. A scoping review of the educational uses of 6DoF HMDs. *Virtual Real.* **2021**, *26*, 205–222. [[CrossRef](#)]
21. Połap, D.; Keşik, K.; Winnicka, A.; Woźniak, M. Strengthening the perception of the virtual worlds in a virtual reality environment. *ISA Trans.* **2020**, *102*, 397–406. [[CrossRef](#)]
22. Miller, H.L.; Bugnariu, N.L. Level of Immersion in Virtual Environments Impacts the Ability to Assess and Teach Social Skills in Autism Spectrum Disorder. *Cyberpsychol. Behav. Soc. Netw.* **2016**, *19*, 246–256. [[CrossRef](#)]
23. Esposito, P. From Accounting to Accountability at the Virtual Museums in Pompeii and Herculaneum. In *Handbook of Research on Management of Cultural Products*; IGI Global: Hershey, PA, USA, 2014; pp. 245–256. [[CrossRef](#)]
24. Saborido, A.E.P.; Castanò, F.; Buono, M. Review on new technologies in Art and Archaeology: The Vesuvian cities. *IOP Conf. Ser. Mater. Sci. Eng.* **2018**, *364*, 012051. [[CrossRef](#)]
25. Dunleavy, M. Design Principles for Augmented Reality Learning. *TechTrends* **2013**, *58*, 28–34. [[CrossRef](#)]
26. Kontopanagou, K.; Tsipis, A.; Komianos, V. A Framework for Exploring Churches/Monuments/Museums of Byzantine Cultural Influence Exploiting Immersive Technologies in Real-Time Networked Environments. *Technologies* **2021**, *9*, 57. [[CrossRef](#)]
27. Wu, H.K.; Lee, S.W.Y.; Chang, H.Y.; Liang, J.C. Current status, opportunities and challenges of augmented reality in education. *Comput. Educ.* **2013**, *62*, 41–49. [[CrossRef](#)]
28. Chang, X.-q.; Zhang, D.-h.; Jin, X.-x. Application of Virtual Reality Technology in Distance Learning. *Int. J. Emerg. Technol. Learn. (ijET)* **2016**, *11*, 76. [[CrossRef](#)]
29. Westermann, G.; Mareschal, D.; Johnson, M.H.; Sirois, S.; Spratling, M.W.; Thomas, M.S. Neuroconstructivism. *Dev. Sci.* **2007**, *10*, 75–83. [[CrossRef](#)]
30. Jang, S.; Vitale, J.M.; Jyung, R.W.; Black, J.B. Direct manipulation is better than passive viewing for learning anatomy in a three-dimensional virtual reality environment. *Comput. Educ.* **2017**, *106*, 150–165. [[CrossRef](#)]
31. Sun, B.; Gao, X.; Chen, W.; Sun, Q.; Cui, X.; Guo, H.; Kevin, C.R.; Liu, S.; Liu, Z. Video Conference System in Mixed Reality Using a HoloLens. *Comput. Model. Eng. Sci.* **2023**, *134*, 383–403. [[CrossRef](#)]
32. Trunfio, M.; Jung, T.; Campana, S. Mixed reality experiences in museums: Exploring the impact of functional elements of the devices on visitors' immersive experiences and post-experience behaviours. *Inf. Manag.* **2022**, *59*, 103698. [[CrossRef](#)]
33. Buzys, R.; Maskeliūnas, R.; Damaševičius, R.; Sidekierskiene, T.; Woźniak, M.; Wei, W. Cloudification of virtual reality gliding simulation game. *Information* **2018**, *9*, 293. [[CrossRef](#)]
34. Wei, W.; Ho, E.S.L.; McCay, K.D.; Damaševičius, R.; Maskeliūnas, R.; Esposito, A. Assessing Facial Symmetry and Attractiveness using Augmented Reality. *Pattern Anal. Appl.* **2022**, *25*, 635–651. [[CrossRef](#)]
35. Pregowska, A.; Osial, M.; Dolega-Dolegowski, D.; Kolecki, R.; Proniewska, K. Information and Communication Technologies Combined with Mixed Reality as Supporting Tools in Medical Education. *Electronics* **2022**, *11*, 3778. [[CrossRef](#)]
36. Vaitkevičius, A.; Taroza, M.; Blažauskas, T.; Damaševičius, R.; Maskeliūnas, R.; Woźniak, M. Recognition of American Sign Language gestures in a Virtual Reality using Leap Motion. *Appl. Sci.* **2019**, *9*, 445. [[CrossRef](#)]
37. Šalkevicius, J.; Damaševičius, R.; Maskeliūnas, R.; Laukienė, I. Anxiety level recognition for virtual reality therapy system using physiological signals. *Electronics* **2019**, *8*, 1039. [[CrossRef](#)]
38. Maskeliūnas, R.; Damaševičius, R.; Blažauskas, T.; Canbulut, C.; Adomavičienė, A.; Griškevičius, J. BiomacVR: A Virtual Reality-Based System for Precise Human Posture and Motion Analysis in Rehabilitation Exercises Using Depth Sensors. *Electronics* **2023**, *12*, 339. [[CrossRef](#)]
39. Janavičiūtė, J.; Paulauskas, A.; Šinkariova, L.; Blažauskas, T.; Kiudys, E.; Janonis, A.; Girdžiūna, M. *Rationale, Design and Validity of Immersive Virtual Reality Exercises in Cognitive Rehabilitation*; Vol. 1665 CCIS, Communications in Computer and Information Science; Springer International Publishing: Cham, Switzerland, 2022; pp. 160–170.
40. Sylaiou, S.; Fidas, C. Virtual Humans in Museums and Cultural Heritage Sites. *Appl. Sci.* **2022**, *12*, 9913. [[CrossRef](#)]
41. Hulusic, V.; Rizvic, S. Story Guided Virtual Environments in Educational Applications. In *Transactions on Edutainment IX*; Springer: Berlin/Heidelberg, Germany, 2013; pp. 132–149. [[CrossRef](#)]
42. Ulmer, J.; Braun, S.; Cheng, C.T.; Dowey, S.; Wollert, J. Gamification of virtual reality assembly training: Effects of a combined point and level system on motivation and training results. *Int. J. Hum.-Comput. Stud.* **2022**, *165*, 102854. [[CrossRef](#)]

43. Hain, V.; Löffler, R.; Zajíček, V. Interdisciplinary Cooperation in the Virtual Presentation of Industrial Heritage Development. *Procedia Eng.* **2016**, *161*, 2030–2035. [\[CrossRef\]](#)
44. Herrmann, H.; Pastorelli, E. Virtual Reality Visualization for Photogrammetric 3D Reconstructions of Cultural Heritage. In *Lecture Notes in Computer Science*; Springer International Publishing: Cham, Switzerland, 2014; pp. 283–295. [\[CrossRef\]](#)
45. Zhou, Y.; Chen, J.; Wang, M. A meta-analytic review on incorporating virtual and augmented reality in museum learning. *Educ. Res. Rev.* **2022**, *36*, 100454. [\[CrossRef\]](#)
46. Krzywinska, T.; Phillips, T.; Parker, A.; Scott, M.J. From Immersion's Bleeding Edge to the Augmented Telegrapher. *J. Comput. Cult. Herit.* **2020**, *13*, 1–20. [\[CrossRef\]](#)
47. Tennent, P.; Martindale, S.; Benford, S.; Darzentas, D.; Brundell, P.; Collishaw, M. Thresholds. *J. Comput. Cult. Herit.* **2020**, *13*, 1–35. [\[CrossRef\]](#)
48. Kuflik, T.; Wecker, A.J.; Lanir, J.; Stock, O. An integrative framework for extending the boundaries of the museum visit experience: Linking the pre, during and post visit phases. *Inf. Technol. Tour.* **2014**, *15*, 17–47. [\[CrossRef\]](#)
49. Egorova, O.; Shcherbinin, D. Creating technical heritage object replicas in a virtual environment. *Front. Mech. Eng.* **2016**, *11*, 108–115. [\[CrossRef\]](#)
50. Rojas-Sola, J.I.; Aguilera-García, Á. Virtual and augmented reality: Applications for the learning of technical historical heritage. *Comput. Appl. Eng. Educ.* **2018**, *26*, 1725–1733. [\[CrossRef\]](#)
51. Pescarin, S.; Pandiani, D.S.M. Factors in the Cognitive-Emotional Impact of Educational Environmental Narrative Videogames. In *Extended Reality*; Springer Nature: Cham, Switzerland, 2022; pp. 101–108. [\[CrossRef\]](#)
52. Taddei, D.M. Digital restoration of the Last Supper by Leonardo Da Vinci and multimedia tools to experience edutainment. *IOP Conf. Ser. Mater. Sci. Eng.* **2018**, *364*, 012034. [\[CrossRef\]](#)
53. Boboc, R.G.; Băutu, E.; Gîrbacia, F.; Popovici, N.; Popovici, D.M. Augmented Reality in Cultural Heritage: An Overview of the Last Decade of Applications. *Appl. Sci.* **2022**, *12*, 9859. [\[CrossRef\]](#)
54. Theodoropoulos, A.; Antoniou, A. VR Games in Cultural Heritage: A Systematic Review of the Emerging Fields of Virtual Reality and Culture Games. *Appl. Sci.* **2022**, *12*, 8476. [\[CrossRef\]](#)
55. Niven, L.; Steele, T.E.; Finke, H.; Gernat, T.; Hublin, J.J. Virtual skeletons: Using a structured light scanner to create a 3D faunal comparative collection. *J. Archaeol. Sci.* **2009**, *36*, 2018–2023. [\[CrossRef\]](#)
56. McCaffery, J.; Miller, A.; Vermehren, A.; Fabola, A. The Virtual Museums of Caen: A case study on modes of representation of digital historical content. In Proceedings of the 2015 Digital Heritage, Granada, Spain, 28 September–2 October 2015; IEEE: Piscataway, NJ, USA, 2015. [\[CrossRef\]](#)
57. Skamantzari, M.; Kontogianni, G.; Georgopoulos, A.; Kazanis, S. Developing a virtual museum for the Stoa of Attalos. In Proceedings of the 2017 9th International Conference on Virtual Worlds and Games for Serious Applications (VS-Games), Athens, Greece, 6–8 September 2017; IEEE: Piscataway, NJ, USA, 2017. [\[CrossRef\]](#)
58. Efstratiou, G.; Michael, T.; Stephanie, B.; Athanasios, L.; Paul, Z.; George, P. New Cross/Augmented Reality Experiences for the Virtual Museums of the Future. In *Digital Heritage. Progress in Cultural Heritage: Documentation, Preservation, and Protection*; Springer International Publishing: Cham, Switzerland, 2018; pp. 518–527. [\[CrossRef\]](#)
59. Karadimas, D.; Somakos, L.; Bakalbasis, D.; Prassas, A.; Adamopoulou, K.; Karadimas, G. Current and Potential Applications of AR/VR Technologies in Cultural Heritage. "INCEPTION Virtual Museum HAMH: A Use Case on BIM and AR/VR Modelling for the Historical Archive Museum of Hydra Greece". In *Communications in Computer and Information Science*; Springer International Publishing: Cham, Switzerland, 2019; pp. 372–381. [\[CrossRef\]](#)
60. Komianos, V. Immersive Applications in Museums: An Analysis of the Use of XR Technologies and the Provided Functionality Based on Systematic Literature Review. *JOIV Int. J. Inform. Vis.* **2022**, *6*, 60–73. [\[CrossRef\]](#)
61. Chatterjee, S.; Majumdar, D.; Misra, S.; Damasevicius, R. The determinants of e-tourism websites for tourists while selecting a travel destination. *Int. J. Electron. Mark. Retail.* **2022**, *13*, 334–359. [\[CrossRef\]](#)
62. Józsa, O.; Börcs, A.; Benedek, C. Towards 4D virtual city reconstruction from lidar point cloud sequences. *ISPRS Ann. Photogramm. Remote Sens. Spat. Inf. Sci.* **2013**, *II-3/W1*, 15–20. [\[CrossRef\]](#)
63. Adami, A.; Pietroni, E.; Capurro, C.; Pletinckx, D. Etruscanning 3D. The Etruscan grave n.5 of Monte Michele in Veii: From the digital documentation to the virtual reconstruction and communication. In Proceedings of the 2013 Digital Heritage International Congress (DigitalHeritage), Marseille, France, 28 October–1 November 2013; IEEE: Piscataway, NJ, USA, 2013. [\[CrossRef\]](#)
64. Haindl, M.; Sedlacek, M. Virtual reconstruction of cultural heritage artifacts. In Proceedings of the 2016 International Workshop on Computational Intelligence for Multimedia Understanding (IWCIM), Reggio Calabria, Italy, 27–28 October 2016; IEEE: Piscataway, NJ, USA, 2016. [\[CrossRef\]](#)
65. Verma, S.; Warriar, L.; Bolia, B.; Mehta, S. Past, present, and future of virtual tourism—A literature review. *Int. J. Inf. Manag. Data Insights* **2022**, *2*, 100085. [\[CrossRef\]](#)
66. Vieira, C.B.; Seshadri, V.; Oliveira, R.A.R.; Reinhardt, P.; Calazans, P.M.P.; Filho, J.B.V. Applying virtual reality model to green ironmaking industry and education: 'A case study of charcoal mini-blast furnace plant'. *Miner. Process. Extr. Metall.* **2017**, *126*, 116–123. [\[CrossRef\]](#)
67. Han, D.; Li, X.; Zhao, T. The Application of Augmented Reality Technology on Museum Exhibition—A Museum Display Project in Mawangdui Han Dynasty Tombs. In *Lecture Notes in Computer Science*; Springer International Publishing: Cham, Switzerland, 2017; pp. 394–403. [\[CrossRef\]](#)

68. Wei, C.C.; Chen, F.; Chen, C.H.; Lin, Y.C. Virtual and Augmented Reality to Historical Site Reconstruction. In Proceedings of the 2018 International Conference on Artificial Intelligence and Virtual Reality—AIVR 2018, Taichung, Taiwan, 10–12 December 2018; ACM Press: New York, NY, USA, 2018. [\[CrossRef\]](#)
69. Clini, P.; El Mehtedi, M.; Nespeca, R.; Ruggeri, L.; Raffaelli, E. A digital reconstruction procedure from laser scanner survey to 3d printing: The theoretical model of the Arch of Trajan (Ancona). *SCIRES-IT—Sci. Res. Inf. Technol.* **2018**, *7*, 1–12. [\[CrossRef\]](#)
70. Vučković, V.; Stanišić, A.; Simić, N. Computer simulation and VR model of the Tesla’s Wardencllyffe laboratory. *Digit. Appl. Archaeol. Cult. Herit.* **2017**, *7*, 42–50. [\[CrossRef\]](#)
71. Bruno, F.; Barbieri, L.; Lagudi, A.; Cozza, M.; Cozza, A.; Peluso, R.; Muzzupappa, M. Virtual dives into the underwater archaeological treasures of South Italy. *Virtual Real.* **2017**, *22*, 91–102. [\[CrossRef\]](#)
72. Kersten, T.P.; Büyüksalih, G.; Tschirschwitz, F.; Kan, T.; Deggim, S.; Kaya, Y.; Baskaraca, A.P. The selimiye mosque of Edirne, Turkey—An immersive and interactive virtual reality experience using HTC VIVE. *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.* **2017**, *XLII-5/W1*, 403–409. [\[CrossRef\]](#)
73. Machidon, O.M.; Postelnicu, C.C.; Girbacia, F.S. 3D Reconstruction as a Service—Applications in Virtual Cultural Heritage. In *Lecture Notes in Computer Science*; Springer International Publishing: Cham, Switzerland, 2016; pp. 261–268. [\[CrossRef\]](#)
74. Canzoneri, A.; Pavoni, G.; Callieri, M.; Dellepiane, M.; Pingi, P.; Giorgi, M.D.; Scopigno, R. A Virtual Experience Across the Buried History. In *Lecture Notes in Computer Science*; Springer International Publishing: Cham, Switzerland, 2016; pp. 158–171. [\[CrossRef\]](#)
75. Gabellone, F. Integrated Technologies for Museum Communication and Interactive Apps in the PON DiCet Project. In *Lecture Notes in Computer Science*; Springer International Publishing: Cham, Switzerland, 2015; pp. 3–16. [\[CrossRef\]](#)
76. Kersten, T.; Drenkhan, D.; Deggim, S. Virtual Reality Application of the Fortress Al Zubarah in Qatar Including Performance Analysis of Real-Time Visualisation. *KN—J. Cartogr. Geogr. Inf.* **2021**, *71*, 241–251. [\[CrossRef\]](#)
77. Paolis, L.T.D.; Faggiano, F.; Gatto, C.; Barba, M.C.; Luca, V.D. Immersive virtual reality for the fruition of ancient contexts: The case of the archaeological and Naturalistic Park of Santa Maria d’Agnano in Ostuni. *Digit. Appl. Archaeol. Cult. Herit.* **2022**, *27*, e00243. [\[CrossRef\]](#)
78. Castagnetti, C.; Giannini, M.; Rivola, R. Image-based virtual tours and 3D modeling of past and current ages for the enhancement of archaeological parks: The visualversilia 3D project. *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.* **2017**, *XLII-5/W1*, 639–645. [\[CrossRef\]](#)
79. Longo, F.; Nicoletti, L.; Padovano, A.; Vetrano, M. An intelligent serious game for a multi-device cultural heritage experience. *Int. J. Simul. Process Model.* **2017**, *12*, 498. [\[CrossRef\]](#)
80. Madsen, J.B.; Madsen, C.B. Handheld Visual Representation of a Castle Chapel Ruin. *J. Comput. Cult. Herit.* **2015**, *9*, 1–18. [\[CrossRef\]](#)
81. Okanovic, V.; Ivkovic-Kihic, I.; Boskovic, D.; Mijatovic, B.; Prazina, I.; Skaljo, E.; Rizvic, S. Interaction in eXtended Reality Applications for Cultural Heritage. *Appl. Sci.* **2022**, *12*, 1241. [\[CrossRef\]](#)
82. Chen, B.; Lan, S. Research on Museum Educational Display Based on Image Recognition Tracking. *Wirel. Commun. Mob. Comput.* **2022**, *2022*, 7314887. [\[CrossRef\]](#)
83. Bekele, M.K.; Pierdicca, R.; Frontoni, E.; Malinverni, E.S.; Gain, J. A Survey of Augmented, Virtual, and Mixed Reality for Cultural Heritage. *J. Comput. Cult. Herit.* **2018**, *11*, 1–36. [\[CrossRef\]](#)
84. Shah, N.F.M.N.; Ghazali, M. A Systematic Review on Digital Technology for Enhancing User Experience in Museums. In *Communications in Computer and Information Science*; Springer: Singapore, 2018; pp. 35–46. [\[CrossRef\]](#)
85. Mancini, A.; Clini, P.; Bozzi, C.A.; Malinverni, E.S.; Pierdicca, R.; Nespeca, R. Remote Touch Interaction with High Quality Models Using an Autostereoscopic 3D Display. In *Lecture Notes in Computer Science*; Springer International Publishing: Cham, Switzerland, 2017; pp. 478–489. [\[CrossRef\]](#)
86. Popovici, D.M.; Iordache, D.; Comes, R.; Neamțu, C.G.D.; Băutu, E. Interactive Exploration of Virtual Heritage by Means of Natural Gestures. *Appl. Sci.* **2022**, *12*, 4452. [\[CrossRef\]](#)
87. Połap, D. Human–machine interaction in intelligent technologies using the augmented reality. *Inf. Technol. Control* **2018**, *47*, 691–703. [\[CrossRef\]](#)
88. Ravikumar, R.; Rajan, A.V.; Abdulla, A.; Ahamed, J. A proposal for introducing Virtual Reality Assistant at Dubai Women’s College. In Proceedings of the ITT 2017—Information Technology Trends: Exploring Current Trends in Information Technology, Conference Proceedings, Al Ain, United Arab Emirates, 25–26 October 2017; pp. 19–24.
89. Tankeleviciene, L.; Damasevicius, R. Towards a Conceptual Model of Learning Context in E-learning. In Proceedings of the 2009 Ninth IEEE International Conference on Advanced Learning Technologies, Riga, Latvia, 15–17 July 2009; IEEE: Piscataway, NJ, USA, 2009. [\[CrossRef\]](#)
90. Janonis, A.; Kiudys, E.; Girdžiūna, M.; Blažauskas, T.; Paulauskas, L.; Andrejevas, A. *Escape the Lab: Chemical Experiments in Virtual Reality*; Vol. 1283 CCIS, Communications in Computer and Information Science; Springer International Publishing: Cham, Switzerland, 2020; pp. 273–282.
91. Boletsis, C.; Cedergren, J.E. VR Locomotion in the New Era of Virtual Reality: An Empirical Comparison of Prevalent Techniques. *Adv. Hum.-Comput. Interact.* **2019**, *2019*, 7420781. [\[CrossRef\]](#)
92. Kay, R. Evaluating learning, design, and engagement in web-based learning tools (WBLTs): The WBLT Evaluation Scale. *Comput. Hum. Behav.* **2011**, *27*, 1849–1856. [\[CrossRef\]](#)

93. Allcoat, D.; von Mühlennen, A. Learning in virtual reality: Effects on performance, emotion and engagement. *Res. Learn. Technol.* **2018**, *26*, 2140. [CrossRef]
94. Veneruso, S.V.; Ferro, L.S.; Marrella, A.; Mecella, M.; Catarci, T. CyberVR. In Proceedings of the AVI'20: International Conference on Advanced Visual Interfaces, Salerno, Italy, 28 September–2 October 2020; ACM: New York, NY, USA, 2020. [CrossRef]
95. Allcoat, D.; Hatchard, T.; Azmat, F.; Stansfield, K.; Watson, D.; von Mühlennen, A. Education in the Digital Age: Learning Experience in Virtual and Mixed Realities. *J. Educ. Comput. Res.* **2021**, *59*, 795–816. [CrossRef]
96. Lem, W.G.; Kohyama-Koganeya, A.; Saito, T.; Oyama, H. Effect of a Virtual Reality Contact-Based Educational Intervention on the Public Stigma of Depression: Randomized Controlled Pilot Study. *JMIR Form. Res.* **2022**, *6*, e28072. [CrossRef] [PubMed]
97. Igroup Presence Questionnaire (IPQ) Overview. Available online: <http://www.igroup.org/pq/ipq/index.php> (accessed on 3 January 2023).
98. Lewis, J.R.; Sauro, J. The Factor Structure of the System Usability Scale. In *Human Centered Design*; Springer: Berlin/Heidelberg, Germany, 2009; pp. 94–103. [CrossRef]
99. Drago, W.A.; Wagner, R.J. Vark preferred learning styles and online education. *Manag. Res. News* **2004**, *27*, 1–13. [CrossRef]
100. Husmann, P.R.; O'Loughlin, V.D. Another Nail in the Coffin for Learning Styles? Disparities among Undergraduate Anatomy Students' Study Strategies, Class Performance, and Reported VARK Learning Styles. *Anat. Sci. Educ.* **2018**, *12*, 6–19. [CrossRef] [PubMed]
101. Furey, W. The Stubborn Myth of “Learning Styles”—State teacher-license prep materials peddle a debunked theory. *Educ. Next* **2020**, *20*, 8–13.
102. Newton, P.M. The Learning Styles Myth is Thriving in Higher Education. *Front. Psychol.* **2015**, *6*, 1908. [CrossRef] [PubMed]
103. Papadatou-Pastou, M.; Gritzali, M.; Barrable, A. The Learning Styles Educational Neuromyth: Lack of Agreement Between Teachers' Judgments, Self-Assessment, and Students' Intelligence. *Front. Educ.* **2018**, *3*, 105. [CrossRef]
104. Taçgın, Z. The perceived effectiveness regarding Immersive Virtual Reality learning environments changes by the prior knowledge of learners. *Educ. Inf. Technol.* **2020**, *25*, 2791–2809. [CrossRef]
105. Falah, J.; Wedyan, M.; Alfalah, S.F.M.; Abu-Tarboush, M.; Al-Jakheem, A.; Al-Faraneh, M.; Abuhammad, A.; Charissis, V. Identifying the Characteristics of Virtual Reality Gamification for Complex Educational Topics. *Multimodal Technol. Interact.* **2021**, *5*, 53. [CrossRef]
106. Valdez, M.T.; Ferreira, C.M.; Barbosa, F.P.M. Electrical engineering teaching and distance learning using a desktop virtual reality system. In Proceedings of the 2013 48th International Universities' Power Engineering Conference (UPEC), Dublin, Ireland, 2–5 September 2013; IEEE: Piscataway, NJ, USA, 2013. [CrossRef]
107. Kalyani, D.; Rajasekaran, K. Innovative Teaching and Learning. *J. Appl. Adv. Res.* **2018**, *3*, S23–S25. [CrossRef]

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