CompARe: Design and Development of a Gamified Augmented Reality Learning Environment for Cultural Heritage Sites

CompARe Gamified AR Learning Environment

MARKOS SOUROPETSIS
Cyprus University of Technology, markos.souropetsis@cut.ac.cy

ELENI A. KYZA
Cyprus University of Technology, eleni.kyza@cut.ac.cy

Understanding cultural heritage by visiting cultural sites is vital to individuals and communities across the world. It is, therefore, important to create authentic learning situations where students can experience and meaningfully learn about cultural heritage; however, authentic learning in situ can be a challenge. Learning during educational field trips at cultural sites is often not well supported, while students' interest and motivation to learn are not always activated, which ultimately impacts the learning experience during the visit. Furthermore, students may be distracted with off-task activities and by the novelty effect of the setting during the field trip and may find it difficult to dedicate themselves to the learning activities. Augmented and virtual reality technologies, and approaches such as gamification, have created new contexts for location-based, technology-enhanced learning, which can help address some of the challenges faced during educational field trips. This paper describes the design and validation of CompARe, a gamified augmented reality learning environment (LE) created to support student learning while visiting a cultural heritage site. The CompARe LE is built around an inquiry-based scenario in which students, working in groups, take on the role of art historians and are asked to date an important wall mosaic by visiting four digital hotspots located throughout the site. CompARe was developed and validated using a design-based methodology. We present two case studies of upper elementary students using CompARe and discuss the affordances and challenges of the learning experience. We conclude with lessons learned about the effectiveness of the CompARe learning approach and discuss future steps.

CCS CONCEPTS • Applied Computing → Interactive learning environments • Human-centered computing → Mixed / augmented reality

Additional Keywords and Phrases: Cultural heritage, Learning environments, Motivation, Gamification, Learning

1 INTRODUCTION

Knowledge of the past, and appreciating cultural heritage, is necessary for young people to understand the present and move forward to the future. Exploring cultural heritage in its authentic setting, a fundamental aspect of educational field trips to such sites, can enhance students' appreciation of cultural heritage by allowing them to directly interact with the artifacts or monuments they are studying (Ott & Pozzi, 2011). This idea is supported by situated learning theories (Lave & Wenger, 1991) which emphasize the significance of the cultural and social context in which learning occurs, since the development of knowledge and cognition are interdependent with the context that produces it (Brown et al., 1989). Educational field trips at cultural heritage sites provide opportunities for authentic, experiential learning (DeWitt & Storksdieck, 2008). According to Stoddard (2018) there is a lack of published empirical research on student learning during educational field trips to historical sites, as much of the research on educational field trips comes from the field of science education (e.g., Kamarainen et al., 2013; Kyza & Georgiou, 2019) and educational trips to science museums (e.g., Yoon et al., 2012).

ACM 1556-4711/2024/11-ART
https://doi.org/10.1145/3703917

Learning technologies, and technology-supported learning, have been argued to support learning in situ. Technologies such as augmented or virtual reality (Arayaphan et al., 2022), Digital Twins, and the Metaverse (Zhang et al., 2022) are revolutionizing the field of cultural heritage. These technologies offer new ways to preserve, interpret, and engage with cultural sites, artifacts, and histories (Innocente et al., 2024). For example, the use of augmented reality (AR) technologies, namely the integration of virtual layers of data through handheld or headset devices with physical space (Klopfer & Squire, 2008), in educational settings can support collaborative and situated learning, provide higher interactivity, and increase students' engagement with learning activities (de Belen et al., 2019). In addition, the use of mobile technologies to support augmented reality experiences at cultural heritage sites has been shown to allow navigation, interaction and discovery and can, thus, provide educational support (Bekele et al., 2018), under appropriate conditions.

The goal of this study was to investigate how learning can be supported at cultural heritage sites by employing a scaffolded augmented reality learning experience. In this context, we developed CompARe, a scaffolded tool that uses QR codes to trigger augmented reality experiences, to investigate the role of such technologies in learning in situ. This paper reports on the development and empirical investigation of the CompARe gamified augmented reality learning environment (Souropetsis & Kyza, 2018), designed to support in-situ inquiry learning around a unique 6th century A.D. wall mosaic in Cyprus.

Gamification is a design strategy (Deterding et al., 2011) intended to enhance an existing learning environment using game elements so that users will experience it as game-like. Gamification, namely "the use of game design elements in non-game contexts" (Deterding et al., 2011, p.10), has been reported to have positive impact on student learning gains (Huang et al., 2020), motivation and engagement (Sailer & Homner, 2020). Its objective is to change the learner's behavior or attitude towards the learning situation (Landers, 2014). Gamification differs from serious games and game-based learning: Even though the objectives of both serious games and gamified learning environments are similar, the processes are different (Landers, 2014). Gamification integrates elements from games into conventional learning settings to enhance engagement and interest, whereas serious games are complete gaming experiences that aim to educate, in addition to entertainment. The concept of edutainment, also known as "learning through play," is widely seen as a fusion of learning and enjoyment. The trend of blending entertainment with education has grown significantly over the past few decades. The goal of edutainment game design is to educate and entertain learners by enhancing their enthusiasm and excitement through engaging, flexible, and informative educational environments. As a result, video games, and other entertainment media are used in edutainment to facilitate learning in various contexts, such as museums and cultural heritage sites (Baowidan, 2023).

The virtuality continuum (Milgram & Kishino, 1994) describes the range between real environments and virtual reality (VR) environments; augmented reality (AR) is near the one end of the continuum and augmented virtuality (AV) at the opposite end. Mixed reality (MR) extends over AR to AV in the continuum, and it encompasses a wide range of settings where real-world and digital elements are integrated into a unified visual interface (Bekele et al., 2018; Milgram & Kishino, 1994). While VR fully immerses users in a virtual environment, AR superimposes layers of digital content on physical space, and MR merges virtual and real-world objects in the same setting (Pellas et al., 2020).

This work begins with the premise that combining gamification and augmented reality technologies can support cultural heritage learning during educational field trips. Beyond the argument that learning at cultural heritage sites can be significantly enriched through digital media (Bekele et al., 2018), it is also important to report on the assessment of the impact of the implementation of new technologies at cultural heritage sites, and specifically whether digital media can support learning and how (Freeman et al., 2016 — NMC Horizon Report: 2016 Museum Edition).

This paper is organized as follows: We begin by presenting related work on the use of gamified augmented reality environments to support learning during educational field trips at cultural heritage sites. We, then, outline the design principles and development of the CompARe gamified LE. This is followed by a description of the evaluation of the LE and the presentation of the results. We conclude with the discussion and implications for future work.

2 RELATED WORK

The development of augmented reality technologies for learning has grown rapidly in recent years and has become a fascinating topic among educational technology researchers. AR technologies enable visitors to explore and engage with historical objects, sites and information in innovative and interactive ways. Cultural heritage applications based on augmented reality technologies can allow visitors to deepen their knowledge and enhance their experience during visits to cultural heritage sites, due to the integration of multimedia content with the real world. From the user's perspective, these technologies when used in these spaces have the potential to improve the quality of experience and enhance learning outcomes by stimulating senses more naturally and vividly (Innocente et al., 2023).

Recent review studies suggest that AR environments can potentially support both formal and non-formal learning, and can increase learning by creating environments where students are motivated to learn (Akçayır & Akçayır, 2017; Bacca et al., 2014; de Belen et al., 2019; Pellas et al. 2020).

The term cultural heritage includes tangible culture (such as buildings, monuments, landscapes, books, works of art and artifacts), intangible culture (such as folklore, traditions, language and knowledge) and 'natural' heritage, which includes important cultural landscapes and biodiversity. Tangible cultural assets often leverage technology's visual and spatial capabilities, enabling users to immerse themselves in detailed replicas of historical sites or artifacts (Efstathiou et al., 2018). While most research has focused on tangible cultural heritage (Liarokapis et al., 2017; Sun et al. al., 2023), some research has focused on preserving intangible culture, which safeguards traditions and practices (Innocente et al., 2024).

It has been argued that the use of AR technologies in such contexts can contribute to improved learning outcomes (Bekele et al., 2018), as compared to guided cultural site visits using technologies like audio guides (Chang et al., 2016); this can be partly attributed to the fact that the AR technologies appear to retain the attention of the visitors for a longer period (Yoon et al., 2012). Reports also indicate that in such contexts, students participated more and were more involved with peers in the presence of digital augmentation (Yoon & Wang, 2014); in addition, students' curiosity increased, just as their willingness to share their experiences and their promptness to use new technologies (Bekele et al., 2018).

In their study, Efstathiou et al. (2018) reported that a location-based augmented reality inquiry-learning environment supported 3rd grade elementary school students' learning at an archaeological site. The findings showed that a technology-enhanced scaffolded environment can contribute to the development of historical empathy and conceptual understanding to a greater extent as compared to a control group who went on a traditional field trip to the same site, without the use of AR technology.

Several studies have illustrated the benefits of appropriately designed technologies in promoting student learning and motivation during educational field trips across various contexts, such as history, science (Chen et al., 2015; Efstathiou et al., 2018), biology (Laru et al., 2012) and environmental science (Kamarainen et al., 2013; Kyza & Georgiou, 2019). These studies found evidence that students increased their learning, motivation, and engagement. However, according to Stoddard (2018) there is still a need for additional empirical research on student learning during educational field trips to historical sites.

The use of gamified technologies in cultural heritage sites can turn knowledge acquisition into a fun experience, and has the potential for immersion, activation of motivation, promotion of cognitive gains and awareness, as well as facilitation of behavior change (Liarokapis et al., 2017; Sun et al. al., 2023). Furthermore, gamification can engage young people with cultural meanings, significance, and values (Lucchi, 2023). Although in recent years there has been an increase in discussions about the use of gamified augmented reality environments in formal education to enhance learning and teaching practices (Lampropoulos et al., 2022), reports of empirical studies on their use for learning at cultural heritage sites are few (Cesaria et al., 2020; Eleftheria et al., 2013; Tan & Lim, 2017; Tsai & Chiang, 2019).

In their study, Tsai and Chiang (2019) used a gamified augmented reality tour guide and reported learning gains and positive user experiences; however, the study did not clarify which gamification elements were used and how. The sample consisted of 32 adults and there was no control group. Similar results are reported in the study by Tan and Lim (2017) where 50 adults used a gamified augmented reality environment to explore historical sites. The results showed an increase in learning gains in this one-group research design study. In their study, Eleftheria et al. (2013) presented the development of an augmented reality textbook with

embedded gamification elements that can be applied for learning art, culture, or history. Their work presents the design of the system, but no empirical evaluation was reported. Similarly, Cesaria et al. (2020) presented the design and development of a gamified augmented reality tangible user interface to support learning about cultural heritage. Although some results were reported, such as increased student motivation and engagement during an experiential workshop, no other details of the empirical evaluation were shared.

In conclusion, it seems that further research is needed to evaluate the relationship between the use of gamified augmented reality environments in cultural heritage sites for learning since published empirical research is scarce.

3 COMPARE: A GAMIFIED AUGMENTED REALITY LEARNING ENVIRONMENT

3.1 Design Rationale

The development of the learning environment (LE) was a joint effort with the Cyprus Ministry of Education, Sport and Youth. Specifically, a Ministry Inspector and museum educators from the Department of Primary Education approached the authors, explaining the challenges faced by students when visiting the specific cultural heritage site and proposed to collaborate on the development of a new, digitally enhanced educational field-trip program.

Based on our prior research work, we decided to create an augmented reality app to develop a technology-enhanced, scaffolded learning environment. This was necessary as our review of the existing apps did not yield any AR apps that could pedagogically support the learning experience in this way, nor did we find any such apps that could support the learning experience in the Greek language.

The outcome was the design and development of the CompARe app; the latter runs on Android OS tablets and includes scaffolding tools to support students' inquiry-based activity. Scaffolding is of great importance in the design of AR learning activities, as it can help students create opportunities for better learning outcomes (Kyza & Georgiou, 2019). Furthermore, according to Tsai and Huang (2014), when students participate in educational field trips, they should be supported to actively engage with the experience, since they usually passively receive knowledge without considering its temporal and spatial dimensions. As a result, the CompARe LE is scaffolded and incorporates specific pedagogical strategies to support learning activities such as identifying, interpreting, and comparing evidence to address the driving question students were provided with, in order to reach an evidence-based explanation.

3.2 Design Principles

The development of the CompARe learning environment (LE) aimed to scaffold students during educational visits to a local cultural heritage site, which is part of the Ministry curriculum for museum education. Specifically, the objectives of the gamified LE are: (a) to provide support to the students to learn through inquiry while on an educational field trip, (b) to support student learning about early Byzantine art and the history of the cultural heritage site, and (c) to increase student participation and engagement during the visit. In addition to the employment of augmented reality technology, the CompARe LE also uses gamification as a pedagogical engagement strategy, offering students a gamified experience. Among others, students earn points if they answer questions in the app correctly, and they are awarded with badges every time they complete the activities at a QR hotspot. The design of the CompARe is based on the following four dimensions:

- The context: a Byzantine church on the UNESCO World Heritage Tentative List[1], Panagia Aggeloktistis (church of Virgin Mary Built by Angels) at the village of Kiti in Cyprus. The church is a cultural heritage site dating back to the 5th century AD. The interior of the church is decorated with a famous 6th century A.D. wall mosaic of Virgin Mary (Figure 1).
- Technology: mobile devices (tablets) and internet access (Wi-Fi) to enrich students' experience during the educational field trip.

[1] https://whc.unesco.org/en/tentativelists/?action=listtentative&state=cy&order=states

- Learning theories: to support the learning experience and to scaffold students' inquiry during the visit.
- Gamification: to support students' engagement and motivation to learn.

Figure 1: (Left) The exterior of the Panagia Aggeloktisti church; (Right) The 6th century A.D. wall mosaic of Virgin Mary

Inquiry is a pedagogical strategy in which students construct knowledge through scaffolded exploration (Keselman, 2003). In inquiry-based learning students learn through processes of observation, investigation, and discovery (Pedaste et al., 2015). In-situ inquiry-based learning has the potential to support students in understanding historical concepts by actively engaging them in problem-based data collection, analysis, and interpretation while at the site (Efstathiou et al., 2018).

The CompARe LE is organized around a Byzantine art inquiry learning scenario, developed specifically for this experience, about the unique 6th century A.D. Byzantine wall mosaic of Virgin Mary, considered to be one of the most significant wall mosaics of early Christian art. The learning experience was designed around this specific location, connecting with what Dunleavy and Dede (2014) refer to as place-dependent augmented reality experience. In a place-dependent model, students observe and interact with authentic environment elements to accomplish their task (Dunleavy & Dede, 2014). This is aligned with the situated learning theory (Lave & Wenger, 1991), which posits that "all learning takes place within a specific context and the quality of the learning is a result of interactions among the people, places, objects, processes, and culture, within and relative to that given context" (Dunleavy & Dede, 2014, p.736).

Recognizing the importance of the sociocultural context of school field trips, and the role it plays in students' learning, we chose to have the students carry out the inquiry in pairs. Collaboration can provide contexts for spontaneously articulating one's understanding, which can also improve the transfer of learning to other contexts (Falk & Dierking, 2000). Furthermore, competition and collaboration become important components of a gamified experience, by creating opportunities for peer learning and increasing motivation to participate (Sintoris et al., 2010).

Learning about art leads to knowledge about the culture that produced it. In order to appreciate art, a person has to develop aesthetic judgement, which is not just an emotional stimulus but a series of cognitive processes. These processes comprise classification, namely in which era an artwork belongs, and identification, namely understanding the theme and the symbolism deriving from the artwork. If the visitor acquires elemental knowledge of the artwork, then the aesthetic judgment will be positive (Scheiter et a;., 2014). With the aim of helping students develop aesthetic judgement, the design of the learning environment incorporates the art history method of compare-and-contrast (Arends et al., 2012) that is, comparing different pieces of art to each other in order to find commonalities or differences in their era, technique or style.

The CompARe LE also includes several gamification elements that enrich the learning experience. Specifically, it includes the following:

- Personalization: students have the ability to name their team.
- Scoring system: students earn points by completing a task at each hotspot. More specifically, the students are rewarded with points, after answering a multiple-choice question. If they answer incorrectly, they are given feedback with the correct answer. Students have only one chance to answer the question.

- Badges: students receive badges by completing the task at each hotspot, regardless of whether the answer they gave is correct or incorrect. The badge is considered as a reward for completing the hotspot.
- Time limit (Countdown): students have limited time (40 minutes) to complete their inquiry; when the time limit expires, the learning environment locks and students cannot interact with it.
- Progress: students can monitor their progress during the mission, and which hotspots they have visited so far.
- Leaderboard: students can track their position in real time and see the overall standing of the teams participating in the gamified inquiry.

In addition to the gamified design, the learning environment also includes scaffolding (Quintana et al., 2004; Reiser, 2004) which seeks to guide the learners' interactions and to help them shape their thinking in productive ways. The following CompARe features were included to scaffold students during their inquiry and to enrich their learning experience:

- A problem- and role-based scenario, with a driving question, placing students in the role of an art historian seeking to specify when the mosaic was created based on the characteristics of the mosaic.
- A comparison tool, allowing the comparison of mosaics of the same and/or different eras.
- A recording tool, allowing students to record an audio of their comparisons instead of being required to type.
- A "my files" tool, allowing students to revisit their recordings.

3.3 The CompARe Development and Architecture

The development of the learning environment had to address certain situational constraints. A typical educational school visit to the specific site lasts approximately one and a half hours during regular school hours, so the whole duration of the intervention could not exceed one hour, including the pre and post activities.

The basic function of CompARe is the recognition of discrete quick response (QR) codes using the mobile device's camera. Each QR code, placed at different locations at the site (hotspots), triggers a different response on the device's display. The hotspots are triggered once the students scan one of the markers which are placed at each hotspot, using the device's camera. Hotspots contain multimedia content (text, images, video). There are four hotspots inside the church as shown in Figure 2: Stations 1 - 4 represent the position of the hotspots while the symbol "m" represents the position of the 6th century wall mosaic.

CompARe runs on the Android mobile operating system, versions 4.4.2. KitKat and above. The content, as well as the other parameters of the scenario, can be modified through an online management system. Through the online management system, the administrator can: (a) generate and match the QR codes with the hotspots, (b) add and modify the title and the content (multimedia, questions) of each hotspot, and (c) set the time limit (countdown) for the completion of the gamified activity. Finally, the administrator can monitor the score of each team and the leaderboard in real time.

3.4 User Interface Design: The experience

In this section we present the flow of the experience along with the description of the user interface.

The learning scenario, as mentioned in previous sections, concerns an inquiry on Byzantine art: more specifically the students are invited to collaborate to date the wall mosaic of Panagia Aggeloktisti, which is located on the conch of the apse inside the church. Students take on the role of art historians in an effort to reach a conclusion about the dating of the wall mosaic through the examination of the historical artifact, the synthesis of information collected from multimedia sources which are provided at each hotspot, and the comparison of religious artwork from different historical eras.

The students' first task is to name their team. Next, students read their mission (driving question), that is to date the wall mosaic. When students open the CompARe app, they also see a live feed of their environment through the tablet's camera, thus situating the activity in the real world (augmented reality experience).

The user interface includes several features that support the learning experience as shown in Figure 3:

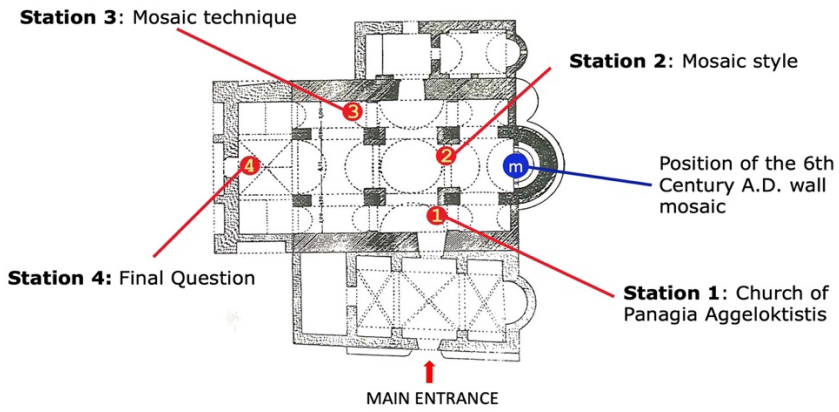

Figure 2: Spatial arrangement of the four hotspots and the wall mosaic inside the church

- Information board: contains the team's name and score, and the countdown for the end of the inquiry.
- Progress: students can monitor their progress (i.e., which hotspots they have completed) and to see the leaderboard.
- Scan: students can scan the QR image button to activate the AR experience.
- Record: students can record their voices in order to document their observations at any time of the activity.
- Files: students can listen to their recordings.
- Mission: students can revisit their mission at any time.

Students can visit hotspots 1-3 in any order they want. The only restriction is that students must visit hotspot 4 at the end of the experience, since it is where they are asked to provide their answer, that is, which, in their opinion, is the correct date of construction of the wall mosaic. The hotspots are:

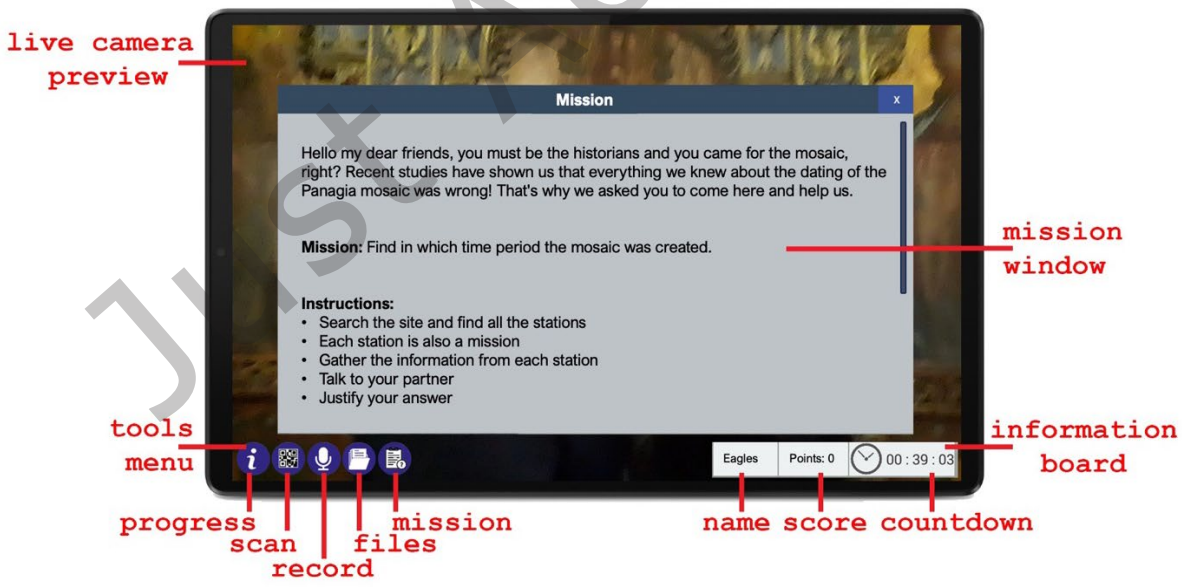

Figure 3: Mission Screen (translated from Greek)

- Station 1 - Church of Panagia Aggeloktisti
- Station 2 - Mosaic style
- Station 3 - Mosaic technique

- Station 4 - Final Hotspot

Back to the flow of the activity, students must locate the actual QR codes inside the church; then after scanning the marker, the hotspot is activated, and a new window appears on the screen of the mobile device. The window contains the title of the hotspot, the multimedia content (text, image, video and question) and a menu bar with four options, one for every content type (Figure 4). Students can choose the order of navigation and when to access the corresponding content.

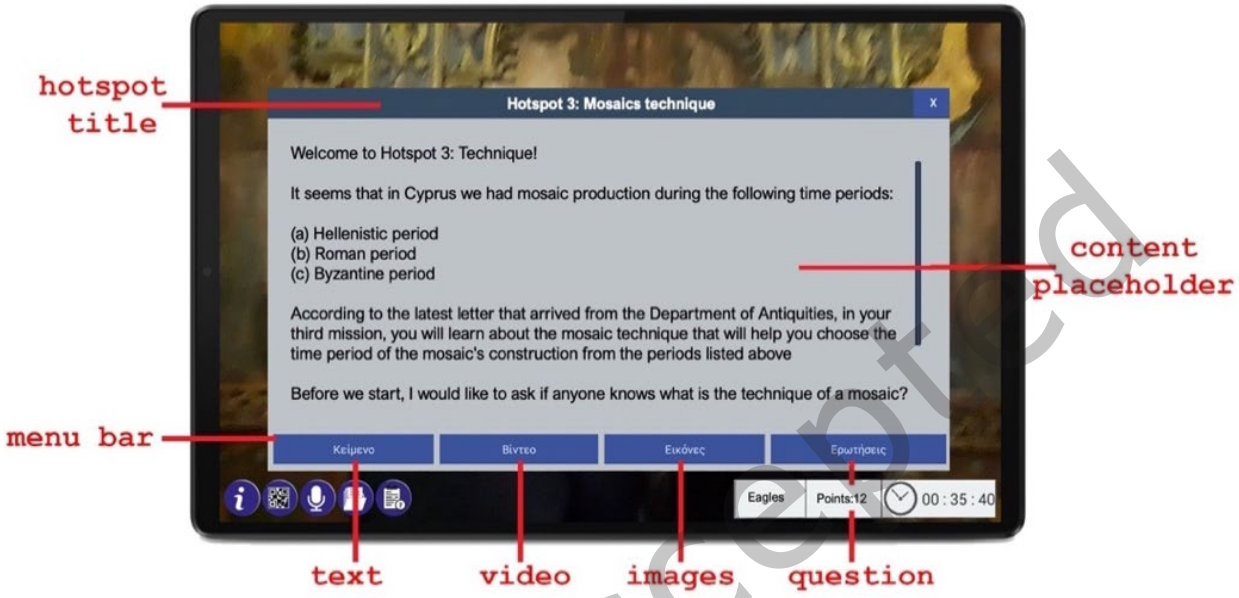

Figure 4: Active hotspot screen (translated from Greek)

The first hotspot contains general information about the church and its history. At hotspots two and three, the students digitally meet two real-world experts through video recordings: a mosaic artist, and a professor of archeology, specializing in mosaics. The experts provide information about the differences in the technique and the style of the construction of the mosaics during different time periods in Cyprus and other areas of the Byzantine Empire. Textual information provided in the app can help students identify various resources which can help them in their inquiry. The images are displayed in high resolution, offering the ability to zoom in and out the wall mosaic of Panagia Aggeloktistis and the other mosaics of the same or different era shown in the learning environment (Figure 5).

Figure 5: Compare and Contrast Images

Students are prompted to compare and contrast the available mosaics along two dimensions: (a) method of production (technique), and (b) style (symbolism). During the comparison process, students can record their

conversations using the embedded recording tool. Finally, to complete their task at each of the three hotspots, students are requested to respond to a multiple-choice question, the answer to which contributes to solving the initial inquiry. The question at each hotspot is based on the hotspot content, that is the expert video, the textual information provided, and the comparison of the mosaics. After students submit their answer, the leaderboard is automatically updated. If they answer correctly, then a reward window appears on screen, in which the earned points and the badge are listed. If students answer incorrectly, then a feedback window appears on the screen with the correct answer. Students have only one chance to answer this question. However, they are awarded badges with the completion of each station, regardless of whether their answer is correct or incorrect. The badge is considered a reward for completing the station.

The score for each question varies and it is based on the number of multiple choices given to the users in each question. For example, at the first hotspot students have three possible answers so the score is set to six points, while at the second station, where users have four possible answers, the score is set to eight points. The maximum score that a team can reach is thirty-four (34) points. At the last hotspot students are asked to provide a final answer to the question of dating the mosaic and to justify their answer based on evidence amassed during their inquiry.

4 EMPIRICAL STUDIES TO VALIDATE THE LEARNING ENVIRONMENT

In this section we summarize the results of the empirical studies and discuss lessons learned about students' experiences. The CompARe gamified learning environment (LE) was evaluated with upper elementary students. The empirical validation of the CompARe is based on two studies, following a design-based research methodology (Barab & Squire, 2004; The Design-Based Research Collective, 2003). The two studies led to the refinement of the initial design of the learning environment and identified problems that related to students' motivation and the scaffolding required to support learning. Ethical approval for the research was provided by the Cyprus National Centre of Educational Research and Evaluation (7.15.06.15.1/3).

4.1 Study 1

The goal of the first study was to empirically validate the gamified LE and the research tools that were used in the second case study. The study was conducted with the participation of 15 upper elementary students using CompARe in groups of two, and one group of three. The study focused on how students interacted with the CompARe gamified AR learning environment and the usability issues that arose.

Data were collected through a focus group interview, during which the students shared their experience with the environment. The focus group interview protocol included questions such as: 'Was there anything in the learning environment that made it difficult or stressful for you? If yes, what was it?'; 'Was there something in the learning environment that you didn't know how to use? If so, what was it?'; 'Was there anything that made it difficult for you to understand the text?', etc. Furthermore, during the implementation, the interactions of four dyads were video-recorded through a first-person video perspective using head-mounted wearable cameras (Kyza et al., 2019), to document the difficulties in the use of the environment during the intervention.

Evidence of the effectiveness and usability of the LE was captured through the first-person video recordings and through the focus group. Based on the students' feedback, the most important issue raised during the focus group was the duration of the experience, as they stated that the available time was insufficient for completing the mission, and suggested reducing the length of the videos or reducing the amount of text. They also stated that they had several unknown words. The results from the focus group and video analysis led to the refinement of the original design of the learning environment and helped identify problems that related to students' motivation and challenges during the use of the gamified environment. Furthermore, based on the students' feedback we decided that the QR markers should be larger in size and positioned in places with better lightning, so that it was easier to scan by the tablet's camera. The process also led to the revision of the research tools; for instance, the focus group protocol was redesigned as a semi-structured interview protocol to allow for more in-depth data collection.

4.2 Study 2

For the second study, a one-group, pretest–posttest experimental design (Martella et al., 2013) was employed. Before the learning experience students were asked to complete a pretest motivation questionnaire and a prior learning assessment, which are explained later in this section. Then, the researcher briefly introduced the students to the learning environment before their engagement with the inquiry. Students were asked to complete a posttest motivation questionnaire and a posttest learning assessment directly after concluding their final mission.

The research questions for this study were: (1) How did the 6th grade school students evaluate the use of the CompARe learning environment (LE) during an educational field trip at a cultural heritage site? (2) To what extent did the CompARe LE affect students' intrinsic motivation? and (3) To what extent did the CompARe LE affect students' learning gains?

Three intact 6th grade classes (59 students, 25 boys) aged 11 – 12 years old, from a medium-sized, rural village in Cyprus participated in this study, which was completed during three educational field trips to the cultural heritage site. Students worked in groups of two, and one group of three, using the CompARe gamified LE (see Figure 6). The composition of the groups was decided by their teachers. Students were given 40 minutes to finish the inquiry.

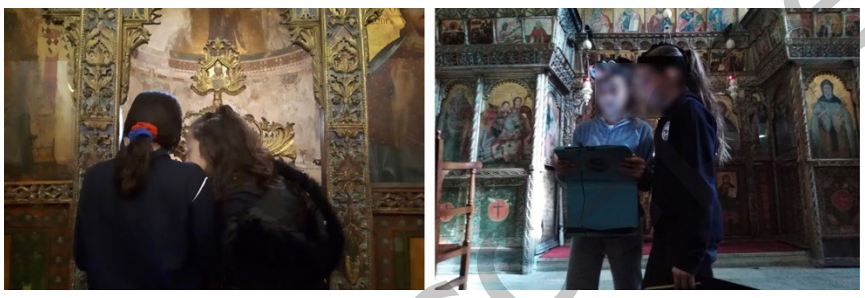

Figure 6: Students using the CompARe gamified AR learning environment

To explore the effects of the learning environment on students' intrinsic motivation a pretest–posttest design was adopted based on prior published studies. The questionnaire included 5-point Likert scale questions ranging from Disagree (1) to Agree (5). The pretest items investigated the extent to which students were motivated by school tasks, while the posttest items evaluated the extent to which the students were intrinsically motivated during the AR learning experience. Based on the questionnaire's authors (Vos & Denessen, 2011) although the pre and post-tests do not measure the same activity, both are measuring psychological constructs which have been reported to give a consistent view of student motivation. The questionnaires were adapted from the Intrinsic Motivation Inventory (IMI) (Ryan & Deci, 2000) which was adjusted for a pretest–posttest design (Vos & Denessen, 2011). The Intrinsic Motivation Inventory is a multidimensional measuring questionnaire that aims to evaluate the subjective experience of participants involved in an activity and has been used in several studies related to intrinsic motivation (Ryan & Deci, 2000). The adapted version includes three subcategories: interest, perceived competence, and effort. The interest scale refers to intrinsic motivation, perceived competence is considered to be a positive prediction of intrinsic motivation, and effort is a separate variable that is relevant to motivation (Vos & Denessen, 2011).

Data about learning were collected through a pre-post learning assessments assessing learning gains. The assessment comprised four multiple-choice items to evaluate students' factual knowledge (e.g., 'What are the specific characteristics in the technique of mosaics production during the Hellenistic period?' or 'What are the specific characteristics in the style of mosaics production during the Byzantine period?'), as well as one open-ended task to evaluate students' conceptual understanding and reasoning (e.g., *'The following pictures present two different mosaics. Were the two mosaics created during the same historical period or not? Explain your answer.')*. The highest score that students could get for factual knowledge was five marks, while the highest score for the open-ended question was two marks.

The semi-structured, in-depth interview was very important for understanding the user experience. Upon the conclusion of the learning process, 24 participants were interviewed in pairs (n=12) using semi-structured,

in-depth interview techniques. The interview protocol included questions about the students' views on the use of the CompARe learning environment (LE). The average duration of each interview was around 17 minutes. Students were asked to share their experience and answer questions about their motivation during the use of the learning environment. The interview protocol included questions such as: 'Was there any element of the learning environment that bothered you during your inquiry, driving you away from your goal? If yes, what was it? What exactly bothered you?'; 'Was there anything in the learning environment you found interesting? If yes, what was it? Why was it interesting for you?'; and 'Was there any element of the learning environment you did not know how to use? If yes, what was it?', etc.

The interviews were recorded, transcribed and analyzed to answer the questions raised about the usability of the CompARe LE. The questionnaire data were analyzed using paired samples t-test comparisons, to examine differences between the pre- and post-test learning scores, as well as differences between students' intrinsic motivation, comparing school experience with their field experience at the cultural site.

4.2.1Results

4.2.1.1 Usability

The analysis of the qualitative data provided insights about the usability of the CompARe learning environment. The analysis identified statements showing how students were able to interact with the application and which difficulties they encountered using it. Based on the participants' feedback, the majority of the students enjoyed the experience and found the navigation and interaction with the learning environment very easy.

- P6: It was interesting when we found the next clue and then we sat down to read the mission and the question we had to answer.
- P22: It was easy to handle, it didn't bother me at all.
- P40: I liked that we were scanning and finding (information).
- P25: I liked that it was fun and at the same time we were learning.

However, four pairs reported having trouble in scanning the QR images at the early stages of the learning experience.

- P1 & P2: When we scanned (the QR codes) we were losing time because it [the app] was not responding quickly.
- P5 & P6: At first, we struggled with scanning.

Most of the students liked the multimedia elements of the learning environment and found them useful, except for the text elements for which three pairs stated that they found them too long or too difficult to understand.

- P1: I liked that he talked (in the video) about the history of mosaics.
- P20 & P21: When comparing the images, the comparisons were clear.
- P7 & P8: I would change the text, make it smaller.
- P1 7 P2: The texts were too long and for us difficult to understand.

In addition to the challenges in using the learning environment, some external factors related to Wi-Fi access also affected the use of CompARe: for example, a pair stated that video and images were not loading probably because students were away from the portable Wi-Fi hotspot.

- P5 & P6: The video was interrupted due to internet problems.

Furthermore, the students' overall impression of the gamification elements (teams, score, leaderboard, countdown) was positive since all the teams made positive comments about them, except for the badges, to which most students (nine pairs) did not pay any attention:

- P1 & P2: Having the countdown made the experience more competitive - Countdown
- P20: I believe if there was no score there would not be so much interest – Score

— P22 & P23: It was cool because we were trying to find the correct answers in order to be first (on the rankings), to get more points – Leaderboard
— P36 & P37: It was great that we worked together and we liked naming our team– Teams
— P24: We didn't take them (badges) into account, we went over it quickly -Badges
— P42 & P43: We didn't pay attention to them -Badges

4.2.1.2 Intrinsic motivation

To understand students' intrinsic motivation, we analyzed the pre- and posttests in terms of interest, competence and effort (Table 1). To investigate if there was a statistically significant difference in students' responses between pre and posttests, a paired sample t-test analysis was conducted. There was a significant difference in the interest scale pretest scores (M=3.80, SD=.87) and posttest scores (M=4.56, SD=.70), $t(57)$=5.83, p=.00). The latter suggests that the students were more motivated during their AR learning experience than their regular school setting experience. In contrast, the analysis showed that students felt less competent during the AR learning experience (M=3.81, SD=1.24) than during their regular school experiences (M=4.12, SD=.70), $t(57)$=2.16, p<.05). This might be explained by the novelty of the experience and the challenges of the inquiry mission they were given.

Table 1: Pre- and posttest scores on students' intrinsic motivation (competence, interest, and effort)

Intrinsic motivation scales	Pretest (regular school experience)		Posttest (CompARe experience)		$t(57)$
	Mean	*SD*	*Mean*	*SD*	
Interest	3.80	.87	4.56	.70	5.83***
Competence	4.12	.70	3.81	1.24	2.16*
Effort	4.44	.61	4.26	.79	1.70

Note: *p < .05. **p < .01. ***p < .001

4.2.1.3 Learning gains

To understand students' learning gains, we analyzed the pre and post learning assessments in terms of factual knowledge and conceptual understanding and reasoning. No statistically significant differences were identified between the pretest and posttest scores of students' factual knowledge. However, the analysis revealed a statistically significant difference between students' pre and post conceptual understanding and reasoning scores. More specifically, the posttest (M=1.10, SD=.68) exceeded the overall initial performance of the students (M=1.0, SD=.52) and this difference was statistically significant [t=-2.23, p<0.05]. This suggests that students' learning increased.

5 DISCUSSION

This paper describes the design and validation of the CompARe gamified augmented reality learning environment, aimed to support student learning while visiting a cultural heritage site. The first research question in this study focused on the evaluation of the usability of the CompARe learning environment. Based on the findings of this study, the learning scenario and the gamification elements promoted students' positive experiences during an educational field trip at the site. Students described the interaction with the technology as positive, because it engaged them in inquiry-learning while exploring the cultural heritage site.

Findings from Study 1 pointed to usability issues that could be improved. In general, students appreciated the multimedia elements of the environment, like the video and images, and found them useful, but did not prefer reading the longer text elements. Participants believed that shortening or simplifying the text elements would make the learning environment more appealing. The overall student impression of the gamification elements was positive, with the only exception being the badges which could be better designed, so that they are more engaging for the students. These insights gave us the opportunity to make corrections to the inquiry-learning scenario in preparation for Study 2.

The second research question in this study focused on the impact of the gamified AR learning environment on students' intrinsic motivation. The results of the pre- and post-tests showed a statistically significant difference in the interest scale of the Intrinsic Motivation Inventory (Ryan & Deci, 2000). This indicates that the students were more motivated during their AR learning experience than their regular school setting experience. This was also confirmed from their interviews. These findings are in line with other studies suggesting that the use of appropriately designed technologies, like mobile learning systems (Chen et al., 2015), augmented reality (Kamarainen et al., 2013), and virtual reality (Bachiller et al., 2023; Sun et al., 2023), during educational field trips can increase students' motivation and engagement (Seaborn & Fels, 2015).

The third research question in this study focused on the impact of the gamified learning environment on students' learning. The results of the analysis showed statistically significant differences between students' pre- and post-conceptual understanding and reasoning. These findings are in line with other studies suggesting that the use of technology-enhanced scaffolded environment during a field trip can contribute to better conceptual understanding (Efstathiou et al., 2018). In addition, the findings of this study demonstrate that the inclusion of gamification in cultural heritage learning environments has the potential for the activation of motivation and promotion of cognitive gains; the latter is also aligned with findings reported in other studies (Liarokapis et al., 2017; Sun et al. al., 2023).

Finaly, the CompARe gamified augmented reality learning environment, which is designed around an inquiry learning scenario, can be used with other cultural heritage sites, as it is not only exclusively linked to the specific site. The content, as well as the other parameters of the scenario, can be modified through the online management system. Through the online management system, the administrator can: (a) generate and match the QR images with the hotspots, (b) add and modify the title and the content (multimedia content, questions) of each hotspot, and (c) set the time limit (countdown) for the completion of the gamified activity. Therefore, a different inquiry learning scenario, with more or fewer hotspots, can easily be applied to a new site.

6 LIMITATIONS

While this study offers a significant contribution to understanding the use of gamified augmented reality learning environments during educational field trips and the impact of gamification on student's motivation and learning gains, it is important to note certain limitations that may influence the generalizability and application of the results. First, the sample of this study was relatively small. Additionally, the absence of a control group might be seen as a limitation of this study and of the generalizability of its findings; in addition, the effect size of the intervention may be harder to assess accurately. These limitations will be addressed in future work, which can examine the effect of gamification more systematically. Future studies can make comparisons between two versions of the augmented reality learning environment, a version of the learning environment without any gamification elements (teams, score, leaderboard, stopwatch, badges) and a gamified version of the learning environment to enable more robust comparisons and establish clearer causality between the intervention and observed outcomes. By including a control group, future research can enhance the validity, reliability, and generalizability of the results, providing a stronger foundation for drawing meaningful conclusions about the intervention's effectiveness.

7 CONCLUSIONS

This study reported on the development and empirical investigation of the CompARe gamified learning environment, exploring, specifically, the effect of gamification on students' motivation and learning gains using a one-group pre-post design. The findings of the study can serve as evidence that the use of scaffolded, gamified augmented reality learning environments during educational field trips in authentic settings can enhance students' motivation and learning, thus leading to the appreciation and understanding of cultural heritage. The CompARe app and learning environment can also be seen as a prototype example of an AR learning ecosystem that can digitally enrich students' cultural experiences during educational field trips.

ACKNOWLEDGMENTS

The authors would like to thank Kyriakos Charidimou, Ira Papageorgiou and Marina Protopapa from the Cyprus Ministry of Education, Sport and Youth for their contribution to the development of the learning environment and their support of this work. We would also like to thank the elementary school students for their participation in this study. This work was partially supported by the Youth Board of Cyprus, "Students in Action" Project (14.05.001.2//68/2019).

REFERENCES

[1] Akçayır, M., & Akçayır, G. (2017). Advantages and challenges associated with augmented reality for education: A systematic review of the literature. *Educational Research Review, 20*, 1-11.

[2] Arayaphan, W., Intawong, K., & Puritat, K. (2022). Digitalization of ancient fabric using virtual reality technology at the Wieng Yong House Museum: The FabricVR project. *Digital Applications in Archaeology and Cultural Heritage, 26*, e00233.

[3] Arends, M., Weingartner, M., Froschauer, J., Goldfarb, D., & Merkl, D. (2012, July). Learning about Art History by exploratory search, contextual view and social tags. In *2012 IEEE 12th International Conference on Advanced Learning Technologies* (pp. 395-399). IEEE.

[4] Bacca, J., Baldiris, S., Fabregat, R., Graf, S., & Kinshuk. (2014). Augmented Reality Trends in Education: A Systematic Review of Research and Applications. *Journal of Educational Technology & Society, 17*(4), 133-149.

[5] Bachiller, C., Monzo, J. M., & Rey, B. (2023). Augmented and virtual reality to enhance the didactical experience of technological heritage museums. *Applied Sciences, 13*(6), 3539.

[6] Barab, S., & Squire, K. (2004). Design-Based Research: Putting a Stake in the Ground. *Journal of the Learning Sciences, 13*(1), 1-14.

[7] Baowidan, S.A. (2023). A Survey on Application of Game Design Element in Edutainment. In Fang, X. (eds) *HCI in Games. HCII 2023. Lecture Notes in Computer Science*, vol 14046. Springer, Cham.

[8] Bekele, M. K., Pierdicca, R., Frontoni, E., Malinverni, E. S., & Gain, J. (2018). A survey of augmented, virtual, and mixed reality for cultural heritage. *Journal on Computing and Cultural Heritage, 11*(2), 1-36.

[9] Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher, 18*(1), 32-42.

[10] Cesaria, F., Cucinelli, A. M., De Prezzo, G., & Spada, I. (2020). *Gamification in cultural heritage: a tangible user interface game for learning about local heritage.* Digital cultural heritage, 411-422.

[11] Chang, K. E., Chang, C. T., Hou, H. T., Sung, Y. T., Chao, H. L., & Lee, C. M. (2014). Development and behavioral pattern analysis of a mobile guide system with augmented reality for painting appreciation instruction in an art museum. *Computers & Education, 71*, 185-197.

[12] Chen, C. H., Liu, G. Z., & Hwang, G. J. (2016). Interaction between gaming and multistage guiding strategies on students' field trip mobile learning performance and motivation. *British Journal of Educational Technology, 47*(6), 1032-1050.

[13] de Belen, R. A. J., Nguyen, H., Filonik, D., Del Favero, D., & Bednarz, T. (2019). A systematic review of the current state of collaborative mixed reality technologies: 2013–2018. *AIMS Electronics and Electrical Engineering, 3*(2), 181-223.

[14] Deterding, S., Dixon, D., Khaled, R., & Nacke, L. (2011, September). From game design elements to gamefulness: defining" gamification". In *Proceedings of the 15th international academic MindTrek conference: Envisioning future media environments* (pp. 9-15).

[15] DeWitt, J., & Storksdieck, M. (2008). A short review of school field trips: Key findings from the past and implications for the future. *Visitor studies, 11*(2), 181-197.

[16] Dunleavy, M., & Dede, C. (2014). Augmented reality teaching and learning. In *Handbook of research on educational communications and technology* (pp. 735-745). Springer, New York, NY

[17] Efstathiou, I., Kyza, E. A., & Georgiou, Y. (2018). An inquiry-based augmented reality mobile learning approach to fostering primary school students' historical reasoning in non-formal settings. *Interactive Learning Environments, 26*(1), 22-41.

[18] Eleftheria, C. A., Charikleia, P., Iason, C. G., Athanasios, T., & Dimitrios, T (2013). *An innovative augmented reality educational platform using Gamification to enhance lifelong learning and cultural education.* Paper presented at the IISA 2013.

[19] Falk, J. H., & Dierking, L. D. (2000). L*earning from museums: Visitors experiences and their making of meaning*, Altamira Press, Walnut Creek, CA.

[20] Freeman, A., Becker, S. A., Cummins, M., McKelroy, E., Giesinger, C., & Yuhnke, B. (2016). *NMC horizon report: 2016 museum edition.* The New Media Consortium.

[21] Huang, R., Ritzhaupt, A. D., Sommer, M., Zhu, J., Stephen, A., Valle, N., ... & Li, J. (2020). The impact of gamification in educational settings on student learning outcomes: a meta-analysis. *Educational Technology Research and Development, 68*(4), 1875-1901.

[22] Innocente, C., Ulrich, L., Moos, S., & Vezzetti, E. (2023). A framework study on the use of immersive XR technologies in the cultural heritage domain. *Journal of Cultural Heritage, 62*, 268-283.

[23] Innocente, C., Nonis, F., Lo Faro, A., Ruggieri, R., Ulrich, L., & Vezzetti, E. (2024). A Metaverse Platform for Preserving and Promoting Intangible Cultural Heritage. *Applied Sciences, 14*(8), 3426.

[24] Kamarainen, A. M., Metcalf, S., Grotzer, T., Browne, A., Mazzuca, D., Tutwiler, M. S., & Dede, C. (2013). EcoMOBILE: Integrating augmented reality and probeware with environmental education field trips. *Computers & Education, 68*, 545–556.

[25] Keselman, A. (2003). Supporting inquiry learning by promoting normative understanding of multivariable causality. *Journal of Research in Science Teaching, 40*(9), 898-921.

[26] Klopfer, E., & Squire, K. (2008). Environmental Detectives—the development of an augmented reality platform for environmental simulations. *Educational technology research and development, 56*, 203-228.

[27] Kyza, E. A., & Georgiou, Y. (2019). Scaffolding augmented reality inquiry learning: The design and investigation of the TraceReaders location-based, augmented reality platform. *Interactive Learning Environments, 27*(2), 211-225.

[28] Kyza, E. A., Georgiou, Y., Souropetsis, M., & Agesilaou, A. (2019). Collecting ecologically valid data in location-aware augmented reality settings: A comparison of three data collection techniques. I*nternational Journal of Mobile and Blended Learning, 11*(2), 78-95.

[29] Lampropoulos, G., Keramopoulos, E., Diamantaras, K., & Evangelidis, G. (2022). Augmented Reality and Gamification in Education: A Systematic Literature Review of Research, Applications, and Empirical Studies. *Applied Sciences, 12*(13), 6809.

[30] Landers, R. N. (2014). Developing a theory of gamified learning: Linking serious games and gamification of learning. *Simulation & gaming, 45*(6), 752-768.

[31] Laru, J., Järvelä, S., & Clariana, R. B. (2012). Supporting collaborative inquiry during a biology field trip with mobile peer-to-peer tools for learning: a case study with K-12 learners. *Interactive Learning Environments, 20*(2), 103-117.

[32] Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation.* Cambridge university press.

[33] Lee, H., Stern, M. J., & Powell, R. B. (2020). Do pre-visit preparation and post-visit activities improve student outcomes on field trips? *Environmental Education Research, 26*(7), 989-1007.

[34] Liarokapis, F., Petridis, P., Andrews, D., & de Freitas, S. (2017). Multimodal serious games technologies for cultural heritage. In M. Ioannides, N. Magnenat-Thalmann, & G. Papagiannakis (Eds.), *Mixed reality and gamification for cultural heritage* (pp. 371–392). Springer.

[35] Lucchi, E. (2023). Digital twins for the automation of the heritage construction sector. *Automation in Construction, 156*, 105073.

[36] Martella, R. C., Nelson, J. R., Morgan, R. L., & Marchand-Martella, N. E. (2013). U*nderstanding and Interpreting Educational Research.* Guilford Press.

[37] Milgram, P., & Kishino, F. (1994). A taxonomy of mixed reality visual displays. *IEICE Transactions on Information and Systems, 77*(12), 1321-1329.

[38] Ott, M., & Pozzi, F. (2011). Towards a new era for Cultural Heritage Education: Discussing the role of ICT. *Computers in Human Behavior, 27*(4), 1365-1371.

[39] Pedaste, M., Mäeots, M., Siiman, L. A., de Jong, T., van Riesen, S. A. N., Kamp, E. T., Manoli, C. C., Zacharia, Z. C., & Tsourlidaki, E. (2015). Phases of inquiry-based learning: Definitions and the inquiry cycle. *Educational Research Review, 14*, 47-61.

[40] Pellas, N., Kazanidis, I., & Palaigeorgiou, G. (2020). A systematic literature review of mixed reality environments in K-12 education. *Education and Information Technologies, 25*(4).

[41] Quintana, C., Reiser, B. J., Davis, E. A., Krajcik, J., Fretz, E., Duncan, R. G., ... & Soloway, E. (2004). A scaffolding design framework for software to support science inquiry. *The Journal of the Learning Sciences, 13*(3), 337-386.

[42] Reiser, B. J. (2004). Scaffolding complex learning: The mechanisms of structuring and problematizing student work. *The Journal of the Learning Sciences, 13*(3), 273-304.

[43] Ryan, R. M., & Deci, E. L. (2000). Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. *American Psychologist, 55*(1), 68.

[44] Sailer, M., & Homner, L. (2020). The gamification of learning: A meta-analysis. *Educational Psychology Review, 32*, 77–112.

[45] Scheiter, K., Schleinschok, K., & Bodemer, D. (2014). How to Learn About Art in a Museum Setting Using Multitouch Technology: Providing Affordances for Collaboration and Comparison. In: Liu, C. C. et al. (Eds.) *Proceedings of the 22nd International Conference on Computers in Education.* (pp 25-27). Japan: ICCE 2014 Organizing Committee.

[46] Seaborn, K., & Fels, D. I. (2015). Gamification in theory and action: A survey. *International Journal of human-computer studies, 74*, 14-31.

[47] Sintoris, C., Stoica, A., Papadimitriou, I., Yiannoutsou, N., Komis, V., & Avouris, N. (2010). MuseumScrabble: Design of a mobile game for children's interaction with a digitally augmented cultural space. *International Journal of Mobile Human Computer Interaction, 2*(2), 53–71.

[48] Souropetsis, M., & Kyza, E. A. (2018). *CompARe: Gamified Mixed Reality Learning Environment.* [Mobile App]. Cyprus University of Technology.

[49] Stoddard, J. D. (2018). Learning history beyond school: Museums, public sites, and informal education. In S. A. Metzger, S. & L. M. Harris (Eds.), *The Wiley international handbook of history teaching and learning*, (631-656). New York: Wiley-Blackwell.

[50] Sun, T., Jin, T., Huang, Y., Li, M., Wang, Y., Jia, Z., & Fu, X. (2023). Restoring Dunhuang Murals: Crafting Cultural Heritage Preservation Knowledge into Immersive Virtual Reality Experience Design. International Journal of Human–Computer Interaction, 1-22.

[51] Tan, K. L., & Lim, C. K. (2017). Digital heritage gamification: an augmented-virtual walkthrough to learn and explore tangible cultural heritage. *Journal of Telecommunication, Electronic and Computer Engineering (JTEC), 9*(2-12), 125-129.

[52] The Design-Based Research Collective (2003). Design-Based Research: An Emerging Paradigm for Educational Inquiry. *Educational Researcher, 32*(1), 5-8.

[53] Tsai, T. H., & Chiang, Y. W. (2019, December). Research study on applying SLAM-Based Augmented Reality technology for gamification history guided tour. *In Proceedings 2019 IEEE International Conference on Architecture, Construction, Environment and Hydraulics (ICACEH)* (pp. 116-119). IEEE.

[54] Tsai, C. H., & Huang, J. Y. (2014, August). A mobile augmented reality based scaffolding platform for outdoor fieldtrip learning. In *Proceedings 2014 IIAI 3rd International Conference on Advanced Applied Informatics* (pp. 307-312). IEEE.

[55] Vos, N., Van Der Meijden, H., & Denessen, E. (2011). Effects of constructing versus playing an educational game on student motivation and deep learning strategy use. *Computers & Education, 56*(1), 127-137.

[56] Yoon, S. A., Elinich, K., Wang, J., Steinmeier, C., & Van Schooneveld, J. G. (2012). Learning impacts of a digital augmentation in a science museum. *Visitor Studies, 15*(2), 157-170.

[57] Yoon, S. A., & Wang, J. (2014). Making the invisible visible in science museums through augmented reality devices. *TechTrends, 58*(1), 49-55.

[58] Zhang, X., Yang, D., Yow, C. H., Huang, L., Wu, X., Huang, X., Guo, J., Zhou, S., & Cai, Y. (2022). Metaverse for cultural heritages. *Electronics, 11*(22), 3730