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Exploring Historical Monuments and Learning History through an Augmented Reality Enhanced Serious Game

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Abstract: Theoretical subjects, such as history, usually do not attract the interest of students and as a result educational games and serious games that use augmented reality (AR) are increasingly used as a means of supporting education. It is believed that these games can make the lesson more engaging and contribute to improving student performance. However, relevant research is limited. The present research presents the AR-enhanced serious game "Exploring Ancient Greece" that aims at supporting 10- to 14-year-old students in learning the history of Ancient Greece. It consists of three levels that include: a presentation of archaeological sites with AR that gives students the chance to explore places of historical interest; a trivia game that includes an AR presentation of a monument or piece of art somewhere in the physical surroundings of the students; and an escape room where the player is trapped in an archaeological site and tries to solve riddles to find the exit. To evaluate the game, an empirical study was conducted involving students between the ages of 10 and 14 who answered knowledge questions before and after playing the game, completed a questionnaire including questions based on the System Usability Scale (SUS), as well as questions for evaluating their experience, and answered oral questions. Based on the results of this study, students improved their knowledge of history, evaluated the game positively and stated that they prefer the use of serious games and AR in education.

Keywords: serious game; augmented reality (AR); escape room; history

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Citation: Bekas, A.; Xinogalos, S. Exploring Historical Monuments and Learning History through an Augmented Reality Enhanced Serious Game. *Appl. Sci.* **2024**, *14*, 6556. https://doi.org/10.3390/app14156556

Academic Editor: Michela Mortara

Received: 18 June 2024
Revised: 12 July 2024
Accepted: 22 July 2024
Published: 26 July 2024

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1. Introduction

In recent years, the production of serious games has been rapidly increasing, and these games are being applied in various fields such as health, politics, advertising, telecommunications, education, etc. [1]. In education, as Marilla D. Svinicki [2] has noted, conventional teaching methods such as school textbooks and lectures do not provide motivation for students. Nowadays, students are more attracted to innovative learning methods, especially when they have enjoyable experiences through them [3]. Additionally, Brian M. Winn [4] demonstrated that games give learners an active role, rather than being mere spectators. Thus, learning can be enhanced when combined with the use of serious games and augmented reality (AR), offering students collaborative activities in an interactive environment, motivating them and leading them to their ultimate goal, which is knowledge, in a fun and enjoyable way [3].

In education, serious games began to establish themselves in the early 1990s, and over time, their benefits have been recognized, making them increasingly accepted within the educational community. The term "serious game" refers to a game designed primarily for the purpose of developing the player's knowledge rather than merely for entertainment. Additionally, this type of game develops a variety of additional skills, such as creativity, strategic abilities, analytical thinking, insight, and memory skills [1].

It is a fact that maintaining interest in a serious game is quite a significant challenge. Thus, these applications utilize technologies capable of enhancing the audiovisual experience and captivating the user. One of these technologies is augmented reality (AR) [5].

Although AR is not a newly emerging technology [6], it plays a leading role in these types of applications. By processing the digital representation of reality [6], it manages to adapt the game to the real world, confronting students with situations that in real life would be impossible due to various factors such as cost, safety, time, etc. [1]. Furthermore, these kinds of games usually take place outdoors, using mobile devices, promoting physical activity and contact with nature, while fostering cooperation and teamwork [5].

Research has shown that history is one of the least popular subjects in school. The average student struggles to memorize historical events, resulting in the overwhelming majority of their historical knowledge coming from sources outside the educational system [7]. In serious games within the context of history courses, emphasis is placed on developing users' ability not only to memorize but also to understand historical events. Thus, students are given the opportunity to travel through time to experience and interpret the past themselves. They have the chance to virtually visit archaeological sites, landmarks, and museums where physical presence is limited [5], allowing them to engage with ancient Greek culture and keep Greece's cultural heritage alive.

Sporadically, studies have been conducted that demonstrate the use of serious games in history courses, as a complement to traditional teaching methods, yields promising results in terms of student performance and the interest they show in the subject. However, these studies are limited [7]. Additionally, the design and implementation of the game must be properly structured to achieve the desired outcomes. It is important that the necessary guidelines are followed and that the educational goals are clear and explicit.

The present research focuses on the study of serious games for learning history using AR. As conventional teaching methods tend to weaken students' motivation and interest, the creation of effective serious games is a significant tool for enhancing learning. The aim of this research is the design, development, and evaluation of a serious game that will provide an educational experience aimed at enhancing the understanding of history in a fun and enjoyable way. Additionally, the goal is to offer an innovative educational tool that can be used by teachers and students, contributing to more efficient learning, as well as the pilot evaluation of the game in terms of short-term learning outcomes and students' perceived usability of the game and player experience.

The rest of the paper is structured as follows. In Section 2, serious games for learning history that use AR are briefly presented and comparatively analyzed. In Section 3, the AR enhanced serious game "Exploring Ancient Greece" is presented. In the following section, the research questions of the study, information regarding the participants, as well as the research methodology are presented, while in Section 6, the results of the study are analyzed. In Section 6, the limitations of the study are presented, and in Section 7, the final conclusions are drawn.

2. Related Work

This section presents serious games for learning history using AR. To find the bibliographic studies, the search engine Google Scholar was used with the query: "serious game" AND "augmented reality" AND ("history" OR "archaeological" OR "historical") AND ("education" OR "learning"). Thirteen studies that met the search criteria based on the terms we set in the query were selected and analyzed. Table 1 lists the studies with their characteristics and the results as obtained from them (in chronological order).

Table 1. Research on serious games for learning history using AR.

Study	Name	Type of Game	Theme	Participants	Methodology	Conclusions
Ferdinand et al. (2005) [8]	Middle Rhine Eduventure	- Location based - AR and VR game - Puzzle game	Marksburg Castle and the Thirty Years' War (1618–1648)	Students	Interview with questions about their experience	The data were being analyzed at the time of publication
Shih, et al. (2015) [9]	Adventure of Hukou Treasures	- Roleplay game - Presentation	Cultural heritage of Hukou Old Street in Taiwan	-	-	Enhances players' knowledge
Sylaiou, et al. (2015) [10]	-	- AR game - Trivia game	Archaeological exhibits of Fishbourne Roman Palace in England	29 students from the University of Sussex	- Qualitative and quantitative analysis - Evaluation questions in interview format - Likert scale evaluation questionnaire	The participants found the game easy to use and considered the use of AR in serious games quite useful.
Galatis et al. (2016) [11]	KnossosAR	AR game	Ancient Minoan city of Knossos	16 students aged 17–19 years	- Treasure hunt - Likert scale questionnaire for assessing the quality of the experience - Assessment interview	- The participants found the game easy to use, entertaining, and it helped them acquire new knowledge - The use of AR was chosen as the first preference
Ekonomou and Vosinakis, (2018) [12]	Oracle of Delphi app	- Location-based - Treasure hunt - Trivia game	Archaeological site of Delphi	13 Primary school students (5th and 6th grade)	- Game evaluation questionnaire	- Positive response from the students - Easy to use (85%) - Useful for acquiring knowledge (92%) - Most (77%) aimed to win the game rather than explore the archaeological site

Table 1. *Cont.*

Study	Name	Type of Game	Theme	Participants	Methodology	Conclusions
Low et al. (2019) [13]	SejarAR	AR game	History of Malaysia	25 High school students	- Usability evaluation with SUS questionnaire - Comparison of SejarAR with the educational game Memory Booster SPM	- Usability 74.2% on the SUS scale - SejarAR was preferred by 92% over the Memory Booster SPM.
Koutromanos et al. (2020) [14]	Clavis Aurea	- Location-based - Treasure Hunt	Local history of Naxos	Students aged 9–12 years	-	Most participants found the game easy to use and useful
Tzima et al. (2020) [5]	MillSecret	- AR game - Escape room	History and cultural heritage of watermills	16 participants aged 13–31 years	- Interview (20 min) - Discussion (15 min) with the participants at the end of the game	- The game was enjoyable and easy to use - The escape room sparked players' interest in local history.
Trista and Rusli, (2020) [15]	HistoriAR	- AR game - Narration	History of Indonesia	-	Questionnaire on usefulness and ease of use based on the Technology Acceptance Model	- Usefulness: 89.5% - Ease of use: 86.63%
Remolar et al. (2021) [16]	Ancient Rome Experience	- AR and VR game - Narration - Presentation	Life in ancient Rome	- 50 first-year middle school students	- Game experience assessment questionnaire - Knowledge test comparing a group of students who played the game with a group of students who did not play the game	- The students who played the game rated it almost universally 5/5 in terms of experience - In the knowledge test, in the group that played the game, 50% of the students had almost 100% success, while in the group that did not play, only 12% achieved 80% success, with the rest scoring lower

Table 1. *Cont.*

Study	Name	Type of Game	Theme	Participants	Methodology	Conclusions
Ventoulis and Xinogalos, (2022) [17]	AR The Gods of Olympus	- AR game - Narration - Memory game - Trivia game	Greek mythology	31 students from 3rd and 4th grade of elementary school	- Pre and post-game knowledge questionnaire - Game evaluation questionnaire	- Among the 31 participants, there was a performance increase of 7–9% - The students (94%) evaluated the game positively, 94% would like similar games in their lessons, and 77% found the game easy to use
Kleftodimos et al. (2023) [18]	- Once upon a time in Dispilio - Crime in the Lake Settlement	- Location-based - Trivia game (Once upon a time in Dispilio) - Storytelling (Crime in the Lake Settlement)	Cultural heritage of the prehistoric settlement in Dispilio, Kastoria, Greece	71 college students and 58 middle and high school students	Likert scale game evaluation questionnaire assessing: Challenge; External activity; Ease of use; Educational usefulness; Interaction and collaboration; Intention to use; Satisfaction	- The most positive results were recorded in the categories "challenge" and "intention to use," while everyone was receptive to using games in other subjects - Most (60%) enjoyed "Crime in the Lake Settlement" - Most (76%) learned more from "Once upon a Time in Dispilio"
Capecchi et al. (2024) [19]	-	- Location-based - Narration - Treasure hunt	History and cultural heritage of the Renaissance village of Caldana in Italy	79 students aged 12–16 years	Questionnaire on usability, motivation, and intention to use AR in the lesson	Out of the 79 participants, more than 79% found it useful, 76% found it motivating, and 80% were willing to use AR

According to the research, it was found that the majority of serious games using AR technology for learning history mainly focus on cultural heritage and the history of a specific place of historical interest, with the aim of enhancing the visitor experience. In several cases, the applications analyzed simply use gamification elements and are not actually serious games. Furthermore, when a game is designed and developed to be used only in a specific location and cannot be detached from it, it becomes unusable for a large portion of students who do not have the opportunity to visit that particular site. In the research by Ekonomou and Vosinakis [12], the serious game "Oracle of Delphi app" was developed and evaluated, aiming to transform the visit to the archaeological site of Delphi into an entertaining experience. It is a treasure hunt within a scenario where students are divided into teams and attempt to solve various puzzles. The research involved 13 elementary school students, who were asked to evaluate their experience at the end of the game. The results of the research showed that all of the students were positive about using AR games for educational purposes, 85% of the students found the game easy to use, and 92% believed it contributed to gaining knowledge. However, it is noteworthy that 77% of the students focused more on winning the game rather than gaining knowledge from it, which raises a discussion point regarding the design of serious games.

Based on the examination of the above studies, conclusions were drawn regarding the category/type of games, the field of research, the participants, the methodology, and their results.

2.1. Category/Type of Game

Most of the games belong to the category of "location-based" games and are designed to make the experience more enjoyable during a tour of a historical site [5,8,11,12,14,18,19]. Their purpose is to give visitors an active role, allowing them to interact with and explore the site rather than just being passive observers. AR is used for storytelling with three-dimensional graphics, presenting exhibits, or as part of clue-finding and treasure hunt games. Additionally, the knowledge participants gain through the game focuses on the specific place rather than on general historical knowledge. Finally, the fact that some of the games [11,15,16] include only AR narration and knowledge quizzes classifies them more as gamified educational applications rather than serious games.

2.2. Field of Research

The main areas of focus in the research include evaluating participants' experiences at the end of the game, its ease of use, and their intention to use it again [10–12,14–16,18,19]. Additionally, some studies, such as "AR The Gods of Olympus," assessed the knowledge that the participants gained from the game [16–18].

2.3. Participants

In most studies, the participants are elementary school students [12,14,17], secondary education students [11,13,16,18,19], and to a lesser extent, university students [10,18]. These participants had been exposed to serious games in the past but generally lacked experience with AR. The number of participants in each study ranges between 13 and 129 individuals.

2.4. Evaluation Method

In almost all of the studies, the evaluation method involved questionnaires in which participants answered questions regarding their experience with the game, its ease of use, and whether they prefer serious games to be integrated into education. Specifically, five studies [11,12,15,18,19] assessed the game using Likert scale questionnaires with questions about player satisfaction, game difficulty, and whether they believed the content helped broaden their knowledge. Additionally, two studies [16,17] evaluated the educational effectiveness of the game using questionnaires containing knowledge-based questions. Finally, another evaluation method was discussion with the participants [5,14] to record their experiences, which was used in conjunction with a questionnaire.

2.5. Conclusions

Based on the results of the research, we can infer that AR games are preferred as an educational process. Specifically, user response is largely positive [12,17], the games are easy to use [10,11,14], and they make learning more engaging [18,19]. However, only two studies [16,17], which focused on the knowledge gained by students, demonstrated that AR games can also contribute to this aspect.

All of the studies have shown that serious AR-based games are a useful addition to history learning that have the potential to engage students. However, regardless of their preference, the extent to which their knowledge is ultimately enriched should also be evaluated. The purpose of this research is to create a serious game that contributes to the investigation of whether the use of AR enhances students' level of understanding in history lessons.

3. The Design and Implementation of the AR Enhanced Game "Exploring Ancient Greece"

The serious game "Exploring Ancient Greece" is an educational Android application aimed at supplementing the teaching of history and making it more enjoyable. Through AR, students will have the opportunity to visit archaeological sites throughout Greece and, in doing so, learn about the life and culture of the ancient Greeks. It is designed for Primary school students from the 4th grade and up, who, based on their school curriculum, have been taught the history of Ancient Greece.

The game is divided into three levels (Figure 1). In the first level, the student explores archaeological sites from various places in Greece through AR, receiving useful information with the help of audiovisual material. The second level is a trivia game, consisting of text and AR graphics, with multiple-choice questions, where the knowledge gained from the first level is tested. The third part consists of an escape room in which the player is trapped in an archaeological site and tries to solve riddles to find the exit. Escape rooms are games that can be used for various purposes and, in addition to knowledge, require numerous additional skills such as collaboration, observation, and multitasking [5]. In education, escape rooms are widely used in subjects such as chemistry, physics, and history because they have been proven to enhance students' motivation and interest in learning, develop critical thinking and analytical skills, and contribute to their social relationships [5].



Figure 1. The start menu of the game consisting of (starting from the top): the title of the game "Exploring Ancient Greece"; the buttons for the three levels, namely "Learning through traveling", "Escape Room", and "Quiz game", and the "Exit button".

3.1. Game Design Based on the Four-Dimensional Framework

To analyze and design any serious game successfully, it is essential to define the design framework. The design framework constitutes a structured methodology that assists the designer in developing an effective educational game that achieves the set educational goals. The analysis and design of the game were determined based on the "Four-dimensional framework" [20], which consists of four elements briefly presented in the following subsections.

3.1.1. General Context

This dimension defines the scenario and the ways in which students and instructors interact with the features of the game. Our game aims to support the educational process within the context of the history subject from the third grade of primary school onwards in Greece. Through the game, educators and students can choose to use individual modules during the relevant chapter, adapting the content to the needs of the students. Alternatively, they can use the game comprehensively after completing the material to reinforce the knowledge of the topics that have been taught. The game is played on Android smartphones and tablets without the need for an Internet connection.

3.1.2. Representation

The effective visualization of the game is necessary for achieving immersion. Special emphasis was given to the representation of the game, as it is a critical element aimed at capturing the player's interest and providing motivation. AR technology was used so that the player experiences a more intense gaming experience. Additionally, a first-person game enriched with visual and sound effects was created, where the player assumes a first-person role for a more immediate interaction with the environment.

3.1.3. Learner

Important characteristics of the learners, such as age, gender, and preferences, have to be taken into account when designing a serious game. In our case, the game is intended for students in the third grade of primary school and above, meaning children aged 8 and older. Based on the curriculum of the school textbooks in the history subject, the modules addressed by the game are taught in the third and fourth grades of primary school. Additionally, the use of the game does not require specific prior knowledge because its structure is designed to provide an enjoyable educational experience. Furthermore, there are no gender restrictions for its use.

3.1.4. Pedagogical Issues

Development of educational games based on learning problems and a collaborative approach, promoting gradual progress and sociality with an informative process and support, are important features that should be taken into account when designing a game.

In our case, the content of the game was created according to the school textbook curriculum. Significant modules were selected, and sources from scientific and educational references were researched and evaluated to ensure the accuracy and validity of the information.

In the first level, video presentations related to these modules are showcased, offering an alternative way of learning that combines visual experience with a narrative aspect. At the end of each thematic module presentation, there is a three-dimensional representation of an archaeological site directly related to the presented topic.

Finally, the scenario of the first-person game is designed according to the history of the archaeological site where it takes place, while the trivia game includes questions from the thematic modules presented in the previous levels, informing the user of the correct and incorrect answers.

3.2. Game and Learning Mechanics

As already mentioned, the game consists of three distinct levels. In the following subsections, the content, as well as the main game and learning mechanics, for each of the three levels are briefly presented.

3.2.1. "Learning through Traveling"

In the "Learning through Traveling" level, some of the main themes of Ancient Greek history are analyzed (Table 2). Each unit presents an archaeological site related to the topic using AR, and through video and narration, important information is provided about the subject in general and the site specifically.

Table 2. Units of level "Learning through Traveling".

Unit	Content	Archeological Site
Minoan civilization	The history of the Minoan civilization (3000 to 1600 BC) and Minoan burial practices	Tholos tomb of Kamilari, Crete
Mycenaean civilization	Life during the Mycenaean period, the structure of Mycenaean cities, and funerary architecture	- Ancient city of Mycenae - Tholos tomb, Mycenae
Corinthian civilization	The history of ancient Corinth (700 BC to 100 AD) and the ancient city	Peirene Fountain, Corinth
Religion	The religious beliefs, worship practices of the ancient Greeks, and the architecture of ancient Greek temples	- Temple of Poseidon, Sounio - Temple of Apollo, Naxos
Sport	The relationship of the ancient Greeks with sports and the biggest sporting event of the time, the Olympic Games	- Stadium of ancient Messene - The Krypte, the entrance to the stadium of Olympia
Theater	The history of the theater and Odeon in ancient Greece. The types of theater and the architecture of the buildings.	Odeon of Herodes Atticus, acropolis of Athens
Divination	The relationship of the ancient Greeks with divination and its influence on their daily lives	Tholos of Athena Pronaia, archaeological site of Delphi

By tapping on the "Learning through Traveling" option, a second menu appears with the themes from which the user can select the one that interests them. Once the user selects a module, a video narration begins, covering the topic in general as well as the specific site that will be presented. After the video ends, the relevant archaeological site appears in AR, allowing the user to rotate the device to explore or use touch to rotate the displayed object. In Figure 2, screenshots from the "Theater" section are presented. The image on the right depicts a video presentation with information about the theater in ancient Greece. The image on the left illustrates the presentation of the Odeon of Herodes Atticus with AR. The Odeon of Herodes Atticus is presented in front of the physical environment of the user holding the mobile device. In this specific case, in the background the user can see the sky.



Figure 2. Screenshots of the "Learning through Traveling" level. The image on the left consists of the title "Odeon of Herodes Atticus" and the buttons "Next" (top) and "Exit" (bottom). The image on the right shows the parts of the ancient Greek theater. Starting from the left and clockwise "Αντηρίδες" = Buttresses,

"αναλημματικός τοίχος" = retaining wall, "διαζώματα" = tiers, "προεδρία" = front row seats, "κοίλον" = auditorium, "εδώλια" = seats, "κερκίδες" = sections, "σκάλες" = stairs, "πάροδος" = side entrance, "παρασκήνια" = backstage, "προσκήνιο" = proscenium, "σκηνή" = stage, "ορχήστρα" = orchestra, "Θέμελη" = Thymele, "Εύριπος" = Euripos.

3.2.2. Escape Room

The "Escape Room" is a first-person game in which the player is a student who, during a school trip to the archaeological site of Corinth, gets trapped in the Peirene Fountain. To find the exit, the player must solve a series of puzzles and riddles. According to the storyline, the gods Hermes and Apollo and the goddess Hera, whose temples are located at the archaeological site of Corinth, have lost some of their belongings. Hermes lost his scepter, Apollo lost his lyre, and Hera lost a feather from her peacock. The nymph Peirene narrates and guides the player to find the clues given by the gods, using various tools such as a magnifying glass and a pickaxe to find the lost items, and ultimately gain permission to exit. In Figure 3, an excerpt is presented in which the Nymph Peirene explains the game's storyline to the player and provides instructions for their mission.



Figure 3. Screenshot of the "Escape Room" level presenting the player with the storyline, as follows: *Welcome to the Peirene Fountain. This spring has been flowing for thousands of years. Here in Corinth, you can find the temples of the gods Apollo and Hermes, and the goddess Hera. The gods often come down to Corinth for a feast, but today something happened, and they need your help. Hermes has lost his scepter, the Caduceus, Apollo has lost his harp, and Hera has lost a feather from her peacock. If you help them find these items, I promise to fill the fountain so you can leave. Use your magnifying glass and search around the statues for clues that might help you. Also, look for other tools that you might need. Good luck.*

Initially, the player must search around the statues for clues. Each statue has an object, such as a vase containing a hidden message that can only be read with the magnifying glass. The message provides the player with information about where to search for the item. For example, at Hermes' statue, there is a scroll that reads, "I lit a fire in the torch, the scepter flew away…" indicating that the item is near the torch with the fire (Figure 4). After each item is found, an appropriate message appears. However, some items are hidden in places that require the player to use another tool found during the game, such as a pickaxe to cut through the bushes. This level of the game does not use AR.



Figure 4. The scepter of Hermes.

3.2.3. Quiz Game

The "Quiz Game" is a classic trivia game enhanced with AR. Each question is accompanied by an AR graphic related to the question, which is positioned in the real world around the player. To find and view the graphic, the player must rotate their device, thereby engaging with the AR elements in their physical environment. The placement of each graphic is designed to be intuitive and contextually relevant, enhancing the immersive experience. The questions pertain to information mentioned in the previous levels, and for each question, there are three possible answers, with one being correct (Figure 5). For every correct answer, the player earns 10 points, while for every incorrect answer, the player loses 10 points. The objective of the game is to collect as many points as possible. Based on the final score, appropriate messages are displayed.



Figure 5. A question in the "Quiz Game" level depicting the god associated with the correct answer to the question in front of the physical surrounding of the player. In red we see the question "The temple in Naxos known as "Portara" was devoted to god:", and below three buttons representing the available choices: "Zeus", "Apollo", and "Hermes".

3.3. Game Implementation

For the implementation of the game, the game engine Unity (version 2022.3.0f1.0.13515), Blender (version 3.6.5), Adobe Premiere Pro (version 9.0.0), Adobe Photoshop (version 13.0), and Adobe Audition (version 8.0.0.192) were used. More specifically, the Unity game engine was

chosen because it facilitates easy and rapid game development, implements the majority of the necessary technologies, and is supported by ample learning materials and examples available online. Additionally, it works in conjunction with the C# programming language, one of the most popular programming languages globally, and the games implemented can be exported for various operating systems such as Windows, Android, and iOS. Blender was used for creating and editing the graphics. Adobe Premiere Pro was employed for video creation, Adobe Photoshop for image editing, and Adobe Audition for audio editing. Lastly, for testing the game on mobile devices during development, the free Unity Remote 5 (version 5.1) app from the Google Play Store was used, allowing instant game execution on the device without installation.

Graphics in an educational game for young children are crucial as they must capture their attention and present a pleasant image. Therefore, the archaeological site graphics in the "Learning through Traveling" level and the historical objects in the "Quiz Game" level were selected from the website Sketchfab free of charge. Additional graphics for the "Escape Room" level were chosen from the Unity Asset Store. Images for video presentations were sourced from copyright-free material found on Google Images. Background music and sound effects, such as menu music, reward and error sounds, and nature sounds, were selected from Pixabay.

For the representation of 3D graphics of archaeological sites and objects with AR, the XR Origin tool provided by Unity was utilized. This tool is essential for developing applications that require immersive technologies such as Virtual Reality (VR) and Augmented Reality (AR). The XR Origin tool enables developers to specify various elements crucial for AR experiences, including the graphic elements to be displayed, the default camera of the mobile device, and the interaction with the camera's movement through various parameters. This interaction is managed by adjusting parameters such as the position, rotation, and scale of the 3D objects in response to the user's movements and the device's orientation. Additionally, XR Origin supports advanced features like plane detection and environmental understanding, which are vital for accurately placing virtual objects in a real-world context. By leveraging these capabilities, the tool ensures a seamless and interactive user experience, making it a powerful component in the development of educational games that incorporate AR elements.

4. Materials and Methods

In order to evaluate the AR enhanced serious game "Exploring Ancient Greece", a pilot evaluation was carried out. In the following subsection, the research questions of the pilot evaluation, information regarding the participants, as well as the research methodology applied, are briefly presented.

4.1. Research Questions

The purpose of this research is to apply an AR enhanced serious game in learning history in order to investigate: to what extent does AR contribute to knowledge acquisition; whether learning history becomes more attractive when combined with AR-enhanced serious games; and how do students evaluate their experience playing the game "Exploring Ancient Greece". Therefore, the research questions to be answered are:

RQ1: Did students' knowledge of history improve after using the game?

RQ2: Can the use of serious games and AR help make the process of learning history more engaging?

RQ3: How do students evaluate their experience with the game "Exploring Ancient Greece"?

4.2. Participants

A total of 13 students participated in the research, including 7 girls and 6 boys, aged between 10 and 14 years, from 4th grade of Primary School (comprising of six grades) to 2nd grade of Junior High School (comprising of three grades) according to the Greek educational system. The selection of this specific age group was made because, based on the curriculum of Greek schools, students in the 4th grade of Primary School and the 1st grade of Junior High School are taught Ancient Greek history.

4.3. Research Methodology

This research was based on students completing questionnaires before and after engaging with the game. Each student participated with parental consent, having been informed in advance about all the stages of the process, while they were explicitly informed that they had the option to withdraw at any time without any consequences. Before the formal evaluation session, participants were given a brief tutorial to introduce the basic mechanics and features of the game. However, the participants were not given additional practice sessions to explore and use the application more extensively. Future research could consider incorporating practice sessions to allow participants to become more comfortable and proficient with the game, potentially leading to more detailed feedback. Throughout the research, the researcher supervised and recorded significant events, student reactions, and observations in the form of notes. The process was conducted over two different days, with participants divided into two groups of six and seven students in order to more effectively monitor their interaction with the game and record their reactions, as well as note any difficulties faced during game-playing. The first group consisted of six students from Primary school, including four boys and two girls. The second group consisted of seven students from Junior High School, including five girls and two boys. The criteria for choosing participants were based on their age and educational level to assess the game's effectiveness across different age groups and educational stages. While efforts were made to include both boys and girls in each group, achieving a perfect gender balance was not possible due to the available pool of participants. While most participants engaged in pairs, one student had the opportunity to experience the game individually. Regardless of the pairing, both students in each pair actively participated and engaged with the game. The game design ensures that the educational content and experience remain consistent, whether a participant interacts with the device individually or alongside a partner. This approach ensures that all students benefit equally from the learning experience, irrespective of the mode of play. The game was installed on three Android mobile devices and the students participated simultaneously.

In the first stage, 10 multiple-choice questions from the game level "Quiz Game" were used in printed form and students were asked to individually answer them based on their pre-existing knowledge from school courses. Students were not given any feedback on the correct answers and their performance on the pre-test in order to be able to investigate whether a potential difference in the post-test could be attributed to playing the game. Then, in pairs, the students completed the game level "Learning through Traveling", which consists of video narrations and presentations of archaeological sites using AR, lasting about 35 min. Next, they proceeded to the "Escape Room" level, where student teams had to collaboratively complete tasks without a time limit. Following this, the "Quiz Game" level was revisited, where each student individually answered 10 multiple-choice knowledge questions, with their performance recorded by the observer.

The final stage of the process involved the anonymous completion of a questionnaire using paper and pencil. The questionnaire aimed at evaluating the students' experience and the usefulness of the game, consisting of two parts. The first part was a SUS (System Usability Scale) [21] questionnaire on a five-point Likert scale, which included 10 questions. The questionnaire was translated into Greek to ensure that the students could easily comprehend the questions. The second part was a questionnaire with eight questions on a five-point Likert scale and one open-ended question, useful for feedback. The questionnaires were placed in an envelope by the participants themselves and the envelope was handed in to the observer.

5. Results

In this section, the results of the study carried out are presented. Specifically, in Section 5.1, the results on students' performance as recorded in the pre-test and post-test are presented and comparatively analyzed. In Sections 5.2 and 5.3, the results on the

usability of the game as recorded in the SUS questionnaire, as well as the results on game experience, respectively, are presented and briefly analyzed.

5.1. Student Performance Results (Pre-Test vs. Post-Test Results)

The students answered the questions in the pre-test correctly with an average score of 5.8 out of 10. In the "Quiz Game," which followed after a 40 min presentation of the thematic units and engagement with the escape room for an average time of 10 min, the average score that the students achieved was 6.6 out of 10. These scores indicate an increase of 8.4%, but due to the small sample size (n = 13), an analysis is needed to determine if the difference is statistically significant. For the statistical analysis, a paired samples t-test was used to compare the pre-test and post-test scores of the same group of students. This test was chosen because it is appropriate for assessing whether there is a significant mean difference between two sets of paired data.

The analysis was conducted using Microsoft Excel, which provided a t-value corresponding to a p-value of 0.0025 (p-value < 0.05), indicating that the difference is statistically significant with a confidence interval of 0.36 to 1.33. Figure 6 shows the students' correct answers before and after the game, and Figure 7 presents the average scores accordingly.

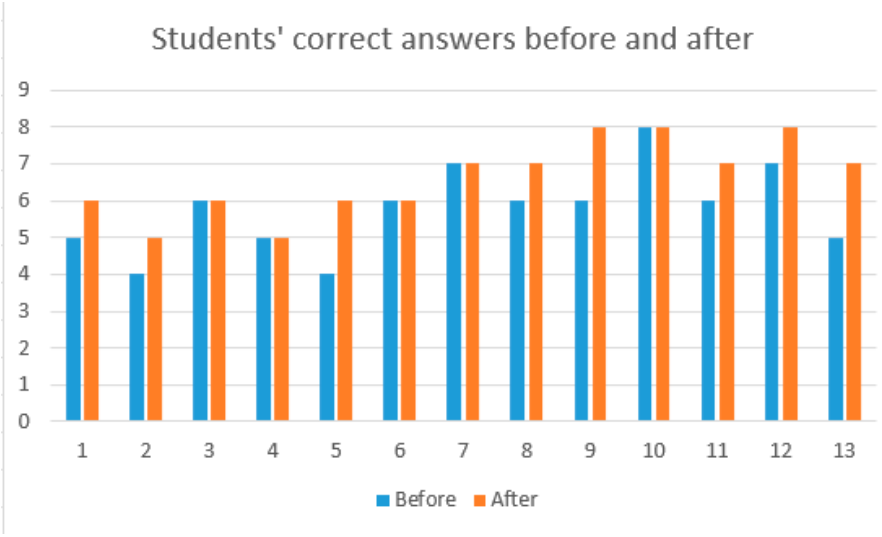

Figure 6. Students' correct answers on the pre and post test.

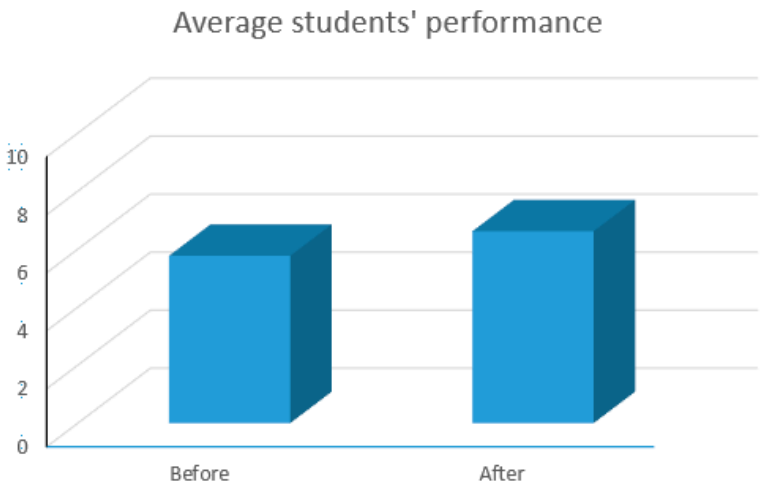

Figure 7. Average students' performance on the pre and post test.

5.2. System Usability Scale Results

The System Usability Scale (SUS) developed by Brooke [21] is a simply yet powerful and highly utilized scale for assessing the usability of a new product or service [22]. SUS can be used for measuring the usability of any interface [22], while its "*reliability using coefficient alpha ranged from 0.83 to 0.97, averaging around 0.91*" in a number of studies analyzed in [23] (p. 582). It consists of 10 closed-type questions, or best statements, based on a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree) and a formula for calculating the overall SUS score. The 10 questions are the following:

Q1. I like to use this game frequently.
Q2. I find this game to be more complicated than it should be.
Q3. I think the game is simple and easy to use.
Q4. I need technical support to use this game.
Q5. I find the game functions smoothly and the functions are well-integrated.
Q6. I think there are a lot of irregularities in the game.
Q7. I think most people can learn this game quickly.
Q8. I find this game to be time-consuming.
Q9. I feel confident while using this game.
Q10. I think there are a lot of things to learn before I can start using this game.

During the evaluation, all students appeared to understand the questions well, and there was no indication that any participant had difficulty understanding them. No additional explanations were required, suggesting that the translated questionnaire was clear to the students. Analyzing students' responses in the SUS questionnaire (Table 3) reveals that most of them found the game enjoyable and rated their experience positively. Specifically, the usability score according to the SUS scale was 79.4%, which is considered to be good [22].

Table 3. Student (S1–S13) responses in the SUS questionnaire.

Question	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13
Q1	5	4	4	5	4	4	3	5	4	3	5	4	4
Q2	2	3	1	4	3	3	1	3	2	1	2	2	1
Q3	4	3	5	3	2	3	5	2	4	5	4	4	5
Q4	2	2	2	2	2	1	1	1	2	1	2	2	1
Q5	4	5	5	4	4	5	5	5	5	4	4	5	5
Q6	2	1	1	2	1	1	2	1	1	1	2	1	1
Q7	4	5	4	4	4	5	5	4	5	5	5	4	4
Q8	3	3	2	3	4	2	2	3	2	1	2	3	2
Q9	4	4	4	5	3	4	3	4	3	3	3	3	5
Q10	1	2	2	1	1	1	2	1	1	2	1	2	1

Additionally, the vast majority of students (11 out of 13) agreed or strongly agreed that they intend to play the game again (Q1), and more than half of the students (8 out of 13) agreed or strongly agreed that the game is simple and easy to use (Q3). Just one student considered the game to be too time-consuming (Q8).

5.3. Game Experience Results

In the game experience questionnaire (Table 4), 83% of the participants responded that they found the game enjoyable, and 84% said it helped them to acquire new knowledge on history. All of the students responded positively to questions about whether they prefer serious games and the use of AR in education, as well as whether they enjoyed the tour of archaeological sites through AR.

While there were no specific questions directly asking what participants did not like or what they would improve, the SUS questionnaire and the feedback questionnaire were designed to provide comprehensive insights into the usability of the game and user satisfaction. Low scores or negative responses on these scales can highlight areas

of dissatisfaction or potential improvement. Therefore, the SUS and game experience questionnaires indirectly captured participants' dislikes and suggestions for enhancement through their overall evaluation of the application's usability and effectiveness.

Table 4. Results on game experience.

Question	Not at All	Slightly	Moderately	Very Much	Extremely	Mean
The game was enjoyable/fun	-	-	2	7	4	4.15
The game was beautifully designed	-	-	2	7	4	4.15
The game helped me gain knowledge about the history of Ancient Greece	-	-	2	6	5	4.23
I would like to use games of this type in education	-	-	-	-	13	5
I would like to use AR in education	-	-	-	-	13	5
I enjoyed the tour of archaeological sites using AR	-	-	1	-	13	5
I enjoyed the escape room	-	-	1	4	8	4.53
I liked the use of AR in the quiz game	-	-	-	2	11	4.84

Finally, based on responses to the open-type question "What I liked most about the game was. . .", it is concluded that students were most interested in the tour of archaeological sites using AR. Specifically, seven out of the thirteen students answered that they liked most the "Learning through Traveling" level, four students liked the "Escape Room" level, one student liked the "Quiz Game", and one student answered that they generally liked AR. The students' preference for the first part of the game is likely due to the fact that none of the students had previously encountered AR either in general or specifically as a means of exploring places of historical interest in a digital space. This technology, integrated into a game, offers a novel experience for them, unlike the other stages, whose game types, although enhanced with AR, are more familiar to young children.

5.4. Observation

During the study, the researcher discreetly observed students' reactions and impressions for each stage of the game and recorded this information in real-time using paper and pencil.

The part that captured the students' attention the most was the "Learning through Traveling" level, and more specifically the tour using AR, as none of the students had previously encountered this technology. Despite their lack of prior experience, almost all students were able to understand how to use the AR graphics and how to rotate the device to navigate the space from the very first archaeological site. A characteristic gesture of most students was waving their hand in front of the camera while looking through the screen to see how the graphics would react. Although Junior High School students stayed focused both on the video presentations and the AR tour of the archaeological sites, some of the Primary School students appeared to become tired with the video presentations as time passed.

In the "Escape Room" level, most students were able to play with considerable ease, as they were already familiar with first-person video games. Nine out of the thirteen students managed to solve the puzzles, some of them quite quickly, while four needed a bit of assistance. In the end, all of them used the game without difficulty and seemed satisfied with it, and this is a strong indication that their responses in the questionnaires were not biased by social desirability.

6. Limitations

The purpose of this research was to study the literature related to serious games for learning history using AR, to design and develop a serious game for teaching ancient history to students from the 4th grade and up, and to evaluate students' experience playing

the game as well as to determine whether their knowledge improved. However, there are several important limitations and constraints that must be considered when interpreting the results.

Firstly, one limitation of this study is that it primarily assesses short-term knowledge gains without investigating the long-term retention of historical knowledge and skills. While the immediate increase in test scores suggests that the game effectively enhances short-term learning, this study does not provide insights into how well students retain this knowledge over an extended period. This limitation is significant because long-term retention is crucial for a comprehensive understanding of the effectiveness of educational tools. Future studies should include follow-up assessments to evaluate the durability of the knowledge and skills gained through the game. By conducting follow-up evaluations weeks or months after the initial game session, researchers can gain valuable insights into the lasting impact of AR-based learning.

In addition, the small sample size of 13 students may not be sufficient or representative, which could affect the generalization of the results and the drawing of conclusions for a broader population. Second, the creation of graphics and audiovisual material poses a significant challenge, as using only free resources may lead to limited creative and aesthetic possibilities. This can impact the quality and attractiveness of the game, as well as the participants' experience.

Finally, the implementation time is a significant limitation, as the development of a 3D game with AR requires a substantial amount of time for design, development, and testing. The limited time available may impact the quality of the game and the evaluation of the research results.

7. Conclusions

The article presented the serious game "Exploring Ancient Greece" that aims to contribute to the learning of history by Primary and Junior High School students by utilizing AR technology. The participants in the study were Primary and Junior High School students who had previously been taught the history of Ancient Greece in school.

Based on the research results collected from the pre/post questionnaires completed by the students before and after engaging with the game, there was an 8.4% improvement in performance (RQ1). However, due to the small sample size, further research with a larger population sample is needed to confirm these results and ensure they are acceptable. From the students' responses in the game evaluation questionnaires, it is concluded that all students believe that the use of serious games and AR in education attracts their interest, making them enjoy the lessons more (RQ2). The students' experience playing the game was evaluated using the SUS questionnaire, asking questions on their game-playing experience and asking verbal questions during the game. It was found that the "Learning through Traveling" level, which included a tour of archaeological sites using AR, was their favorite. Additionally, the vast majority of students responded that they would play the game again; more than half the students found it easy to use; and just one student considered the game to be too time-consuming (RQ3).

Finally, from the results of the above research and the studies examined, we can argue that the use of serious games with AR in education have the potential to improve both student performance and make the lesson more engaging. Moreover, this study has showcased ways of utilizing AR in serious games for history, creating a digital reality on top of the physical world that seems to give students the chance to explore places of historical interest at no cost. However, it is necessary to replicate the study with a larger number of participants in order to confirm the positive results both in terms of player experience and the learning effectiveness of the game.

Author Contributions: Conceptualization, A.B. and S.X.; methodology, A.B. and S.X.; software, A.B.; validation, A.B. and S.X.; investigation, A.B. and S.X.; data curation, A.B. and S.X.; writing—original draft preparation, A.B.; writing—review and editing, S.X.; visualization, A.B.; supervision, S.X. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Ethical review and approval were waived for this study, due to non-person-related data acquisition. However, each student participated with parental consent, having been informed in advance about all the stages of the process, while they were explicitly informed that they had the option to withdraw at any time without any consequences.

Informed Consent Statement: Informed consent was obtained from the parents of the subjects involved in the study.

Data Availability Statement: The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

Acknowledgments: The game "Exploring Ancient Greece" was implemented by the first author in the context of his thesis under the supervision of the second author.

Conflicts of Interest: The authors declare no conflicts of interest.

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