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# A Systematic Review on Augmented Reality Applications in Informal Learning Environments

Dimitrios Markouzis, Learning Technology and Educational Engineering Laboratory [LTEE Lab], Greece*
https://orcid.org/0000-0001-7340-8937

Aikaterini Baziakou, Learning Technology and Educational Engineering Laboratory [LTEE Lab], Greece

Georgios Fesakis, Learning Technology and Educational Engineering Laboratory [LTEE Lab], Greece
https://orcid.org/0000-0002-1721-6655

Angelique Dimitracopoulou, Learning Technology and Educational Engineering Laboratory [LTEE Lab], Greece
https://orcid.org/0000-0002-4686-1530

## ABSTRACT

In recent years more and more people use their mobile phones daily for work or entertainment. The increasing use of mobile devices has led researchers to seek new ways of learning with their support, beyond the confines of formal education. The increasing computing power of mobile devices has contributed to the emergence of new, rapidly evolving technologies, with augmented reality (AR) applications being at the forefront of these developments. This article provides a literature review of AR applications for mobile devices related to informal education. It analyses their structural elements to examine if they exploit powerful features such as collaboration and content modification, as well as storytelling potentials. The findings show that most of these applications use those learning affordances only to a very limited extent, as they are mainly designed for individual usage, do not allow user-originated contribution to the digital material, and do not incorporate elements of any storytelling model.

## KEYWORDS

Greece, Learning Technology and Educational Engineering Laboratory, University of the Aegean

## INTRODUCTION

During the last decade, there have been significant advancements in the types of activities developed and proposed for formal and informal learning environments. Contemporary technological developments constitute crucial contributing elements to these advancements, allowing us to break away from the temporary, one-dimensional connections of technologies with the natural environment (technology → natural environment and natural environment → technology), and achieve a level that

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provides important new possibilities: (a) continuous connection between the technological and natural world, (b) natural and smooth-flow connection of people - objects - digital world, (c) recognition of the people - digital system interaction, not only through the users' hands but their whole bodies (Dimitracopoulou, 2018).

The widespread availability of portable, interconnected devices with multimedia capabilities and the development of social networking software (Chatti et al., 2007) greatly influence the field of science and information. Older systems, capable of providing specific information at specific access points, are being replaced by new, dynamic systems that allow limitless navigation and real-time exchange of information (van der Vlist et al., 2013). Additionally, the evolution of technology and, more specifically, Augmented Reality (AR) technology that allows the seamless integration of virtual content with the real world (Azuma et al., 2011), contributes greatly to this upward change. The importance of AR does not lie in the technology itself but in the added value it offers to the learning environment (Dunleavy et al., 2009). Its use is recognized as a lever for increasing the implementation of complex systems in informal learning environments, which support dynamically unfolding tours/browsing of real museums, parks, historical landmarks, etc., enriching the user experience. This study aims to investigate the extent to which the available technological capabilities are utilised in the design of AR applications for informal learning environments.

## BACKGROUND

Learning is the process by which a person cultivates their skills, knowledge, understanding, values, perspectives, feelings, and critical thinking abilities (Livingstone, 2001), and it is distinguished into formal, non-formal, and informal learning.

The present research examines learning in informal learning environments, i.e., learning that is not organized and systematic but is, instead, flexible, unstructured, and spontaneous, has an individualized rhythm, and takes place throughout a person's life and through everyday experiences (Hein, 2002). According to Livingstone (2001), informal learning is any activity aimed at the acquisition of knowledge and understanding that arises without the presence of a required curriculum. It can occur in any context, above and beyond that of educational institutions, in cultural institutions such as museums and historical sites, as well as in other points of interest such as parks, lakes, etc. Informal learning environments produce new profiles of learners with broad and sophisticated cognitive skills (Greenfield, 2009). The basic terms of informal learning (e.g., objectives, content, means, duration) are determined by the individuals and groups who choose to participate in it (Livingstone, 2001). The use of technology and, more specifically, the use of AR helps to enhance informal learning.

AR is one of the fastest-growing technologies used in recent years in mobile phones and tablets. Many researchers have attempted to define the term AR (Azuma, 1997; Milgram et al., 1994; Wu et al., 2013). However, Klopfer (2008) argues that it is difficult to precisely define AR, as its definition may limit its exact meaning. Nevertheless, any technology that combines digital information with the real world can be considered AR technology. AR applications that are available today can be divided into two major categories: a) location-based, and b) marker-based. Bower et al. (2014) argue that AR can be used in informal learning environments because it is consistent with the pedagogical theories of Situated Learning, Game-based Learning, and Inquiry-based Learning. Adding digital information to real objects and locations can help users better understand scientific phenomena, relate them to real-life situations, grasp dynamic systems, learn about a place's history, or culture, and become more environmentally conscious. Furthermore, AR can be used to provide personalized information and feedback to the user according to their choices, or it can be combined with digital interactive storytelling technologies to provide a more immersive experience.

Storytelling as a tool has played a very important role in the evolution of cultures, constituting both a form of communication as well as a basic means for the transfer of knowledge and perceptions across generations. Storytelling is the interactive art of using words and actions to represent the

elements and images of a story in a way that stimulates the listener's imagination (National Storytelling Network, n.d.). From its original inception until today, storytelling has been a widely used educational strategy as it has been found to effectively capture the learners' interest and help them consolidate the information received. People can more easily memorize and retrieve the information they have received through storytelling since the way the learning subject, as well as any kind of information, is coded and presented significantly affects the learners' ability to memorize and retrieve it in the future (Mathews, 1977). Recent technological advancements have also transformed the field of storytelling. Digital storytelling is an art form that uses music, image, video, and storytelling to create stories about people's lives, work, and experiences that are then shared over the Internet (Serafim & Fessakis, 2017). Digital storytelling is also defined by Lathem (2005) as the combination of traditional oral storytelling with 21st-century multimedia and telecommunication tools. Although digital storytelling is not a new idea and its benefits are well-known, the fact that it is not often used in educational applications constitutes a matter of great concern.

Collaboration also plays a key role in the learning process. According to Dillenbourg (1996) the benefits of collaborative learning are numerous. These categories of activities allow students to become more actively involved in the learning process, cultivate critical thinking and reflection, come up with different solutions and strategies for a problem, strengthen their democratic perception of student relationships etc. The technological developments offer new opportunities to create collaborative learning environments. Lukosch et al. (2015) studied AR applications that enhance collaboration, arguing that many of them had a positive effect on solving complex problems. Zheng et al. (2019) reviewed studies related to technological collaborative learning environments for informal education and found that only 7% of the cases concerned AR applications while the online learning platforms were the most preferred tools at a percentage of 36%. This indicates that the integration of collaborative activities into AR applications for mobile devices continues to be at an early stage.

## RELATED WORK

Over the past decade, several research reviews investigated the use of AR applications. Some of them tried to point out a global view on AR in education (Baca et al, 2014; Akcayir & Akcayir, 2017), while others focused on formal education settings (Nouri et al., 2018). The published review studies have identified the main affordances, advantages, and disadvantages related to AR technology, presenting the learning benefits, the users' motivations, as well as the emotions elicited when using such applications. It is fruitful to focus for this article on reviews on mobile AR systems that have included in their analysis, studies regarding outdoor or informal learning contexts (Table 1).

Stymne (2020) has conducted a systematic review on outdoor learning with mobile technology, on a total of 87 articles published between 2004 and 2017. Those articles were identified after applying search criteria in scientific databases such as ERIC and Scopus, as well as in related conference proceedings. This review concluded that biology was the most common subject for mobile activities (followed by history), primary education was the most common educational level, and AR was the most common technology used for augmenting the learning environment, while taking photos and taking notes were the most common methods for data collection in outdoor learning activities.

Petrovich et al. (2018) conducted a research review on the use of AR applications in informal learning environments. A total of 18 articles published between 2010 and 2017, identified via ERIC and ScienceDirect data bases, were analysed. The results showed higher learning outcomes, motivation for learning, interest in the museum content of applications, as well as improved experience with the use of AR systems. Additionally, the researchers identified many similarities between formal and informal learning environments in relation to the increase in learning performance when using such applications. The interaction and socialization between the participants are described as the main positive elements of informal education. Another finding stemming from this study concerns the age

**Table 1. Review studies on topics related to AR and Informal Learning**

| Study | Analysis Dimension | Studies reviewed | Summary of main findings |
|---|---|---|---|
| Stymne, 2020 | "Outdoor learning with mobile technology" *Review Years:* 2004-2019 | 87 | *Edu Subjects:* Biology, followed by History, Maths etc.<br>*Edu Levels:* Primary education etc.<br>*Technologies:* AR the most common for augmenting the outdoor learning environment<br>*Methods of data collection for inquiry learning activities*: photos and then taking notes and audio |
| Petrovich et all. 2018 | "AR experiences in informal education" *Review Years:* 2010-2017 | 18 | *Edu Levels:* Lyceum, univ students and adults<br>*AR effects:* better learning effects, motivation, interest on museum content etc.<br>*Benefits:* Interaction and socialization among participants around tablet or mobile devices |
| Golff et al.,2018 | "AR in STEM in informal learning environments" *Review Years:* 2003-2017 | 17 | *AR effects:* Improve learning and conceptual understanding, more interest and greater engagement, and enhances collaboration among students around devices |
| Ibanez et all, 2018 | "AR in STEM" *Review Years*: 2010-2017 | 28 | *AR effects:* Impact on learning, 'positive' sentiments etc.<br>*Applications' design categories:* inquiry- exploration, simulation, games |
| Dunley & Dede, 2014 | "AR in formal & informal settings" *Review Years:* 2004-2014 | 19 | *AR effects:* the information augmenting the natural space, facilitates authentic and participatory learning<br>*Limitations:* the cognitive overload of learners |

group of the participants included in the specific surveys; more specifically, 62% of the studies were carried out on high school students, 19% on adults, and 14% on university students.

Ibáñez and Delgado-Kloos (2018) conducted a literature review on the use of AR technology to support the learning of science, technology, engineering, and mathematics (STEM). 28 studies published from 2010 to 2017 in the ACM Digital Library, ERIC, IEEE Xplore, ISI Web of Science, ScienceDirect, Scopus, and Springer databases were analysed. Through examining the general features and specific design principles of AR applications for STEM learning, the researchers demonstrated three application categories: exploration, simulation, and game-based applications. Additionally, this study found that most of the reviewed studies evaluated the effect of AR on enhancing learning outcomes, followed by those that explored emotions.

At around the same time, Goff et al. (2018) focused on the use of AR technology for STEM learning in informal learning environments. By conducting bibliographic searches on the ScienceDirect, Google Scholar, Web of Sciences, and ERIC databases, and setting specific inclusion criteria, they came up with a total of 17 studies. The results of the examined studies showed an increase in learning outcomes, conceptual understanding, greater interest in the subject as well as AR, and greater user engagement. An important conclusion, according to the researchers, is that the use of AR in an informal learning environment simplifies the process of acquiring knowledge and enhances collaboration between users even beyond the application's framework.

Dunleavy and Dede's (2014) literature review focuses on AR applications for mobile devices in formal and informal learning environments. Most of the studies examined in this review report the provision of additional information in a natural space as the most important benefit of AR, facilitating participatory and authentic learning, while the most important limitation appears to be the cognitive

overload of students. The majority of findings on AR application design principles support their distinction into four broad categories based on location, narrative, roles, and experience mechanics.

The abovementioned studies provide a multifaceted picture that is critical to understand the advantages, limitations and trends of AR technology in formal and informal learning environments.

Most of these review studies, however, do not consider important factors and affordances of mobile AR applications, examining whether it is predicated on an appropriate design, promoting collaboration between users, whether it allows users to contribute to the AR content, as well as whether it includes script related features exploiting narration dynamics.

## RESEARCH QUESTIONS

Within this context and aiming at providing more powerful learning environments, three key research questions are addressed by the present review study:

**RQ1:** Do informal learning AR applications for mobile devices promote collaboration and how it is achieved?
**RQ2:** Do these AR applications allow the users to contribute (create or change) with new digital content that is accessible to other users?
**RQ3:** Do AR applications provide key elements of storytelling?

In parallel, this review considered and analysed four basic characteristics of the reviewed studies such as:

**RQi:** The publication date of the study.
**RQii:** The AR application users' age group.
**RQiii:** The involved scientific subject(s) of related learning activities.
**RQiv:** The identified learning outcomes of the reviewed studies.

## METHOD

Three scientific databases were used to retrieve relevant bibliographic sources: ERIC, ScienceDirect, and Google Scholar. The advanced search function was used, adding the terms: (augmented reality) AND (mobile learning OR informal learning OR storytelling OR collaboration)- in the title and the summary of the articles. The publication period researched included the last decade, between 2012-2022, with the last bibliographical search taking place on 30 April 2022.

## RESULTS

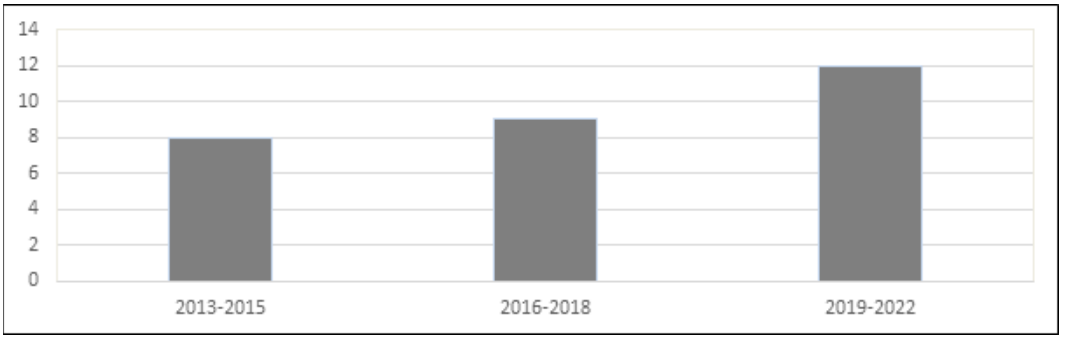
The literature review yielded a total of 42 papers, 29 of which were included in the final study. The remaining 13 papers either related to formal education case studies, did not explicitly state the operation of the AR application, or did not use a portable AR device to conduct the research. Table 2 summarizes the selected articles. More specifically column with header a) "Paper" mentions the authors, b) "Age" mentions the age group of the participants, c) "Subject" mentions the scientific subject, d) "Place" mentions the place where it took place, e) "Narration" mentions if the application includes a story and its narrative genre and f) "Outcome" mentions the outcomes.

Out of the 29 studies chosen, 41% (n = 12) were originally published after 2019, while 72.4% (n = 21) were published after 2016. It is also worth mentioning that this review is published in the first half of 2022. This fact indicates an increasing trend of research interest in the use of AR in informal learning, as reflected in Figure 1.

**Table 2. Articles of literature review**

| Paper | Age | Subject | Place | Narration | Outcome |
|---|---|---|---|---|---|
| Chang (2013) | >18 | History | Park | Time Travel | Knowledge Improvement, Interest, Willingness to participate again |
| Lochrie et al. (2013) | >18 | History | City | No | Interest |
| Chang et al. (2014) | >18 | Art | Museum | No | Knowledge Improvement, Satisfaction |
| Holden (2014) | >18 | Foreign Language | City | Mystery Game | Knowledge Improvement, Interest, Willingness to participate again |
| Pendit et al. (2014) | >18 | History | Park | No | Interest, Satisfaction |
| Sommerauer & Müller (2014) | all | Maths | Museum | No | Knowledge Improvement |
| Chang et al. (2015) | >18 | History | Park | No | Knowledge Improvement, Satisfaction |
| McMahon et al. (2015) | >18 | Navigation | City | No | Knowledge Improvement |
| Harley et al. (2016) | >18 | History | City | No | Knowledge Improvement, Satisfaction |
| Hsiao et al. (2016) | 12-13 | Science | Museum | No | Knowledge Improvement |
| Hu Tsai (2016) | | History | Camp | Mystery Game | Prototype |
| Markouzis & Fessakis (2016) | >18 | History | City | Mystery Game with Quests | Knowledge Improvement, Interest, Willingness to participate again |
| Coelho & Costa (2017) | | History | Museum | Mystery Game with Quests | Prototype |
| Juan et al. (2017) | >18 | History | Museum | No | Satisfaction |
| Grevtsova, I. (2017) | > 18 | History | City | No | Knowledge Improvement, Interest |
| Costa et al. (2018) | 8-11 | Astronomy | Camp | No | Knowledge Improvement, Interest |
| Sommerauer & Müller (2018) | 15-18 | Maths | Museum | No | Knowledge Improvement |
| Chien (2019) | >18 | Foreign Language | Park | No | Knowledge Improvement, Satisfaction |
| Kyza & Georgiou (2019) | 7-12 | History | Park | No | Knowledge Improvement, Interest |
| Poitras et al. (2019) | >18 | History | Camp | Time Travel | Knowledge Improvement, Satisfaction |
| Innocent & Leorke (2020) | >18 | History | City | Mystery Game | Knowledge Improvement, Interest |
| Lehto et al. (2020 | all | History | City | Mystery Game with Quests | Interest, Satisfaction |
| Pombo & Marques (2020) | 10-15 | Environment | Park | Mystery Game with Quests | Knowledge Improvement, Willingness to participate again |
| Vicari (2020) | 13-15 | Astronomy | Museum | Mystery Game with Quests | Knowledge Improvement, Interest |
| Kennedy et al. (2021) | >18 | History | Museum | No | Knowledge Improvement, Interest |
| Wahyuni et al. (2021) | >18 | History | City | Mystery Game with Quests | Satisfaction, Interest |
| Chen et al. (2022) | 11 | Science | Museum | No | Knowledge Improvement |
| Jiang et al. (2022) | >18 | History | Park | Mystery Game with Quests | Knowledge Improvement |
| Nevola et al. (2022) | >18 | History | City | Time Travel | Knowledge Improvement |

**Figure 1. Number of published studies per publication period**




Analysis of the yielded papers reveals that most of the studies (approximately 53%) concern applications for adults, 24% for adolescents, and 18% for children, while the remaining 5% (2 studies) do not report this information because the applications were considered a prototype. Figure 2 reflects the above findings. Due to the fact that some studies include more than one age group (as grouped by the authors) the total sum of the studies, as presented in Figure 2, is greater than 29, which is the sum of the studies included in this review.

Furthermore, in regards to the scientific subject, the review concludes that History (more specifically information about historical sites, archaeological sites, etc.) is included in more than half of the studies, at a percentage of 62% (n = 18), while the rest of the studies include, to an almost equal extent, Science (n = 2), Navigation (n = 1), Environment (n = 1), Foreign Languages (n = 2), Mathematics (n = 2), Astronomy (n = 2) and Art (n = 1) (Figure 3).

In addition, urban areas such as entire cities (35%, n = 10) are the spaces mentioned in most studies. An almost equal percentage of studies concerns museums (31%, n = 9) and outdoor areas with some historical interest (24%, n = 7) (e.g., archaeological sites). Finally, 3 studies (10%) relate to a campus (Figure 4). Based on the above data it appears that 69% (n = 20) of studies concern outdoor spaces and 31% (n = 9) concern indoor spaces.

In addition to the abovementioned factors, another element that was also examined was the AR applications' effects to learners/users obtained from these studies. These were categorized as follows: Knowledge (i.e., whether users improved their knowledge of the scientific subject mediated through the application), Satisfaction (i.e., whether users enjoyed the application and positive emotions were elicited), Interest (i.e., whether the application succeeded at retaining a high level of interest amongst the users and whether the users actively participated without their involvement seeming

**Figure 2. Age distribution of participants in the studies included in the literature review**

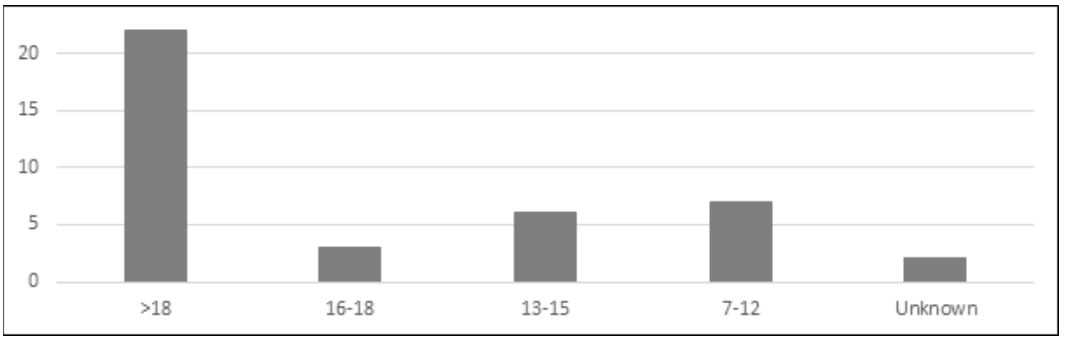


**Figure 3. Scientific subject of studies included in the literature review**

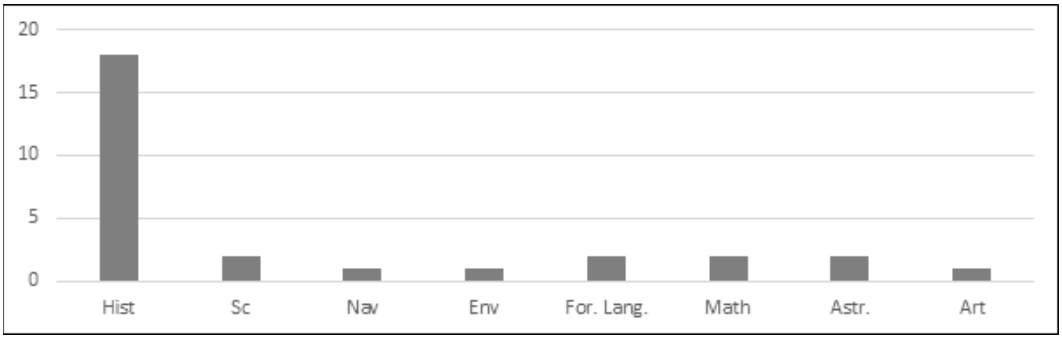
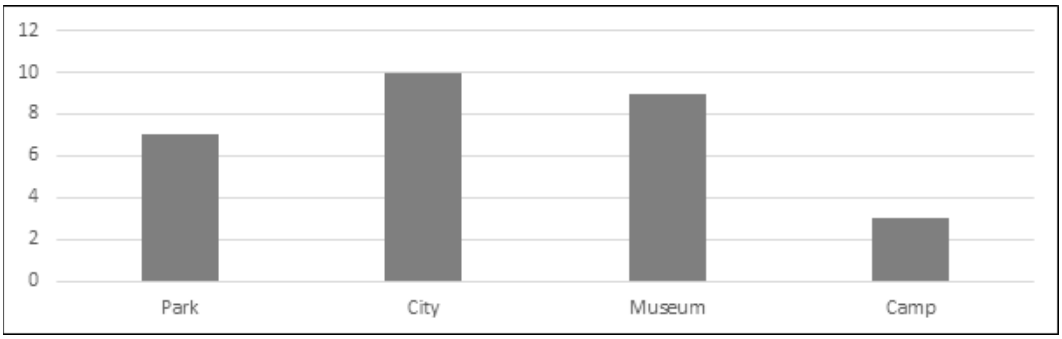
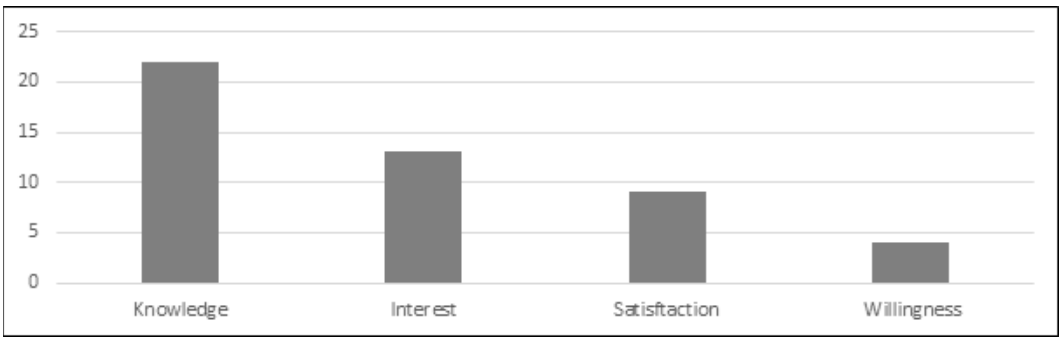



**Figure 4. Implementation space of studies included in the literature review**




boring), and finally, Willingness (i.e., whether users acquired a positive attitude towards AR and would like to use similar applications again in the future). Figure 5 shows the distribution of study results in these categories. As with the age distribution analysis, here also a study may address issues belonging to more than one category and, thus, the total number of studies appears to be greater than 29 (number of studies selected from the literature review). Figure 5 clearly portrays that almost half of the studies (46%) examine the learning outcomes of the application. It is worth noting that in all applications it is reported that users improved their knowledge of the scientific subject. The second most considered element is whether user interest was maintained at a high level (27%). In

**Figure 5. Results of studies included in the literature review**



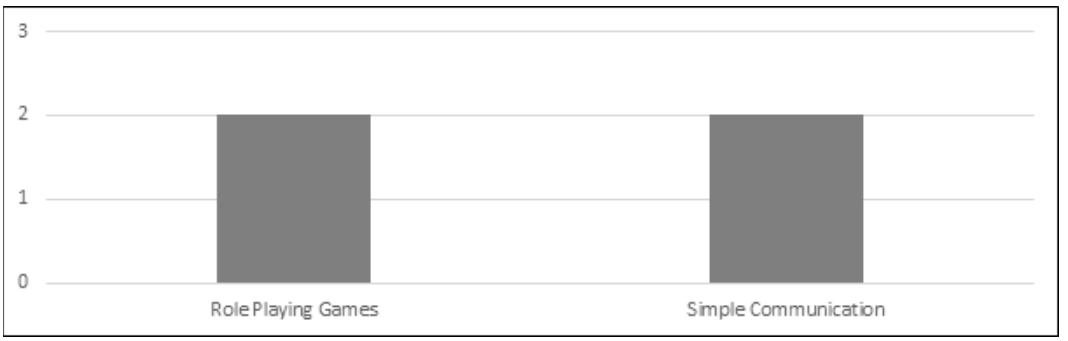
this category, too, no phenomena of indifference or boredom were observed by the users. In fact, in 2 cases the scenario alone seemed to have had a positive effect on increasing interest. The third most mentioned factor is satisfaction, considered in 19% of studies. All users stated that they were satisfied with their participation and in some cases report that feelings of joy and happiness were created during the use of the application. Finally, a smaller percentage of studies (8%) investigates the positive attitude of the participants towards AR, with results showing that, in this case too, everyone reports a positive attitude.

Moreover, the review [RQ1] showed that only 14% (n = 4) of studies were related to applications that promote or require collaboration between users, while the remaining 86% relate to individual applications (Figure 6). In fact, out of the former 4 studies, 2 refer to role-playing games where each player has their own digital role based on which the appropriate information is displayed on the device. Players with different roles had to work together to complete their missions. The remaining 2 studies promote collaboration between users by simply enabling the exchange of messages or digital material without, however, this communication being necessary for the proper use of the application. Therefore, and for the purposes of this review, the authors classify these studies under the "Simple communication" category (Figure 7). Cases where collaboration outside of the application was observed, such as when a group of users shared the same mobile device and communicated around the device, were considered as designed for individual use.

Also, regarding the content contribution [RQ2], i.e., the users' ability to create or edit digital content so that the experience of each user is affected by the "interventions" of other users, the vast majority of the applications studied (97%, n = 28) do not offer this feature. On the other

**Figure 6. Number of studies that the applications were designed to promote collaboration through AR device**


**Figure 7. Type of communication investigated in the studies included in the literature review**

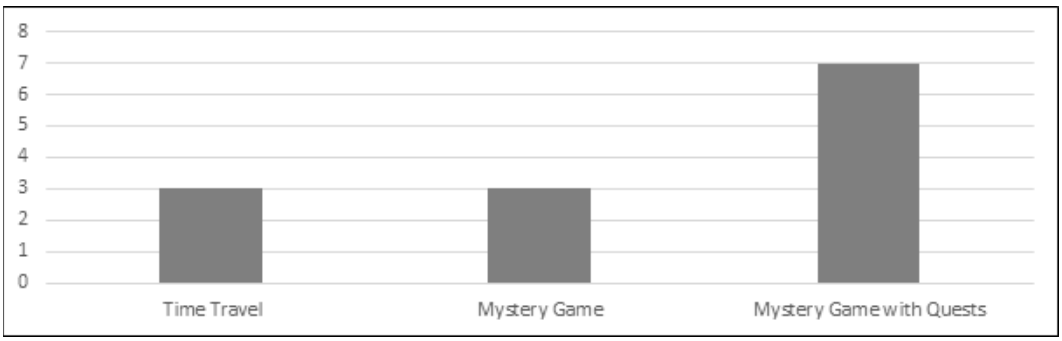


hand, only 1 study (3%) allow intervention in the content (e.g. after obtaining approval from the application administrators).

The last element investigated [RQ3] was whether the applications include storytelling based on a script, as well as to which storytelling genre the script belongs. The storytelling genres that we mentioned here-in-after emerged from the literature review of Markouzis and Fessakis (2016) on AR mobile applications using interactive storytelling. More specifically, the storytelling genres are quests, adventure games, mystery games, treasure hunts, scavenger hunts, races, real-world simulations, role-playing games, time travels, and journalistic games. The present review results showed that 55% (n = 16) of applications did not include any storytelling genre. This means that the user was simply navigating the space by receiving digital information. On the other hand, 45% (n = 13) of applications included storytelling, which in turn resulted in the user's choices and, therefore, the digital information displayed depending on both the script and their choices. Regarding the storytelling genres, 54% (n = 7) concern quests according to which the player must complete specific missions (e.g., solve puzzles) in order to complete the story. These can be either standalone missions or semantically related to each other. 23% (n = 3) concerns mystery games, where there is a single script, more complex than that of quests (e.g., it might include more digital characters with whom the user needs to interact, it might be collaborative, of a longer duration, etc.) and, finally, the remaining 3 (23%) are classified as time travels. In this last category, there is a key person who recounts the story to the user and guides them in their choices. Figures 8 and 9 represent the above findings.

**Figure 8. Number of studies included in the literature review that incorporate digital storytelling**


**Figure 9. Storytelling genre of studies incorporating digital storytelling**



## CONCLUSION

A preliminary analysis of the literature review findings indicates an active research interest in the impact of AR on informal learning environments as the number of published studies in the last three years appears to be higher than in previous years. This conclusion is further supported by the fact that the present study was published on, and hence included studies from, only the first half of 2022. Furthermore, most of the studies (53%) concern adults, fewer of them concern adolescents (24%), and only a small percentage (18%) include younger children. This observation is in contrast with Petrovich's et al. (2018) review results, which state that 63% of AR applications concerned high school students, while the remaining 37% of applications were addressed to adults. The common denominator of both reviews is that no studies involving informal AR learning applications for younger ages were found.

Additionally, the most common scientific subject incorporated in these applications is History (62%), with users asked to gather information about sites of historical significance (Chang, 2013), moving around cities to collect historical data (Markouzis & Fessakis, 2016). This finding, combined with the fact that most of the research concerns cities (35%), museums (31%) and sites of historical significance (24%), is fully consistent with the conclusions of Schwan et al. (2014), who argue that a significant part of informal learning takes place in these areas. Regarding the results of the studies examined in this review, these were distinguished into four major categories: Learning (46%), Interest (27%), Satisfaction (19%), and Positive Attitude towards AR (8%). These findings are consistent with other similar reviews (Goff et al., 2018; Ibáñez & Delgado-Kloos, 2018; Petrovich et al., 2018), which show that most researchers investigate the learning outcomes of these applications, the retention of interest during activities, and the elicitation of positive emotions such as pleasure and satisfaction. It is worth noting that in the present study no research was found to report negative conclusions in any of the four categories mentioned. Nevola et al. (2022), however, highlight the need for more research in this field and, in particular, the long-term outcomes of AR use in order to draw safer conclusions and to gain an in-depth understanding of the capabilities these technologies have to offer.

Regarding the first research question [RQ1], i.e., whether cooperation is enhanced through AR applications, the answer is 'no'. This means that most applications are were designed for individual usage. When a provision for collaboration exists, it focuses either on simple message exchange (Chang, 2013; Wahyuni et al., 2021) or on user-interaction for problem-solving through the application or in the context of a game (Holden, 2014; Innocent & Leorke, 2020). In contrast to Petrovich et al. (2018), who examined the interaction of participants around the mobile AR application, this parameter was not considered in the present study given that it does not require a specific and appropriate design for collaborative use (Pombo & Marques, 2020). The second research question [RQ2] concerned the ability of AR applications for mobile devices to allow users to create new digital material accessible to other users. In this case, too, the answer is negative, indicating that most applications do not offer that possibility. Only 1 application (3%) (Lochrie et al., 2013) provided this feature to users, enabling digital enrichment of the application. Finally, regarding the last research question [RQ3] about the existence of scripts and plots in AR applications for mobile devices, the results are more evenly distributed than in the first two questions. 55% of applications did not include a script, as opposed to 45% in which the activity was part of a story. The storytelling genre that prevailed was Adventure Game with Missions (Markouzis & Fessakis, 2016; Pombo & Marques, 2020; Wahyuni et al., 2021), followed by Time Travels (Chang, 2013; Poitras et al., 2019), while one case included a Mystery Game (Holden, 2014). In fact, in two cases (Holden, 2014; Markouzis & Fessakis, 2016) the participants reported that the script motivated them and kept their interest high, while in one case (Pendit et al., 2014) they reported that the presentation of the content coupled with storytelling was able to elicit feelings of joy and satisfaction in users. These findings are consistent with the views of Egan (1985) and Applebee (1987) that incorporating a problem into a storytelling context can positively contribute to its comprehensibility. Attempting to combine the findings of the research questions with those of the key elements of this review (publication date, age group, scientific subject,

and research results), we conclude that most of the applications that included a script (77%, n = 10) concerned the subject of History.

## SYNOPSIS

At the end of the first decade of the 21st century, researchers (e.g., Dunleavy et al., 2009) pointed out the importance of fully exploring the potential of AR in education, reflecting that we were only beginning to consider the whole range of possibilities offered by this emerging technology. Several review studies published during the next decade, and especially those related to informal learning, (Stymne, 2020; Petrovich et al., 2018; Ibáñez & Delgado-Kloos, 2018; Goff et al., 2018) continue to provide overviews of the affordances, potential, and limitations of AR applications.

The present work offers a literature review, regarding the last ten years [2012-2022], of AR learning applications for mobile devices concerning informal learning. The added value of this review is registered on its three main research questions that investigate whether the design of AR applications allows users to collaborate through AR devices, and/or to influence the digital material, as well as the existence of any script related feature. Furthermore, the reviewed studies characteristics such as the date of publication, age group, scientific subject, and the results of these studies were also examined so that, in addition to the added value of the review, comparative results with similar reviews could also be investigated (Goff et al., 2018; Ibáñez & Delgado-Kloos, 2018; Petrovich et al., 2018) showing a general agreement between findings. The study of the research questions showed that collaboration, as well as the creation of new digital material, are features that are generally absent from these applications. Besides a lack of sufficient pedagogical consideration to fully exploit the available technological developments, maybe the absence of powerful features from AR applications is because appropriate design requires specialized scientific and technical knowledge and more sophisticated technologies. As for the script, this feature is found in several applications (40%) as it constitutes a key motivator for users. The results lead the authors to the conclusion that such additional requirements and features can become a key asset for informal learning. Widely, these affordances are significant in supporting active, contextualised and meaningful 'in situ' learning, allowing us to shape, interact with, and contribute ourselves to the environments we move through, while the promotion of the social interactions, exchanges and collaboration through AR applications, via personal mobile devices, seems to offer a remedial dimension to individualism and the isolation trends of the post-COVID era. Consequently an urgent, next research challenge might be the use of appropriately designed collaborative functions, the study of the impact of AR applications on shared contributions of digital materials, and how they affect learning outcomes and user motivation in the short and long term.

Finally, regarding the limitations of this research, it is to be noted that only articles from three databases are used. That means that there is a potential that results may vary if additional databases were included in the research. However, since the considered databases are large enough, the effect of the corresponding limitation is deemed to be relatively small.

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All authors of this article declare there are no competing interest.

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## Corresponding Author:

Correspondence should be addressed to Dimitrios Markouzis, markouzis@rhodes.aegean.gr

## REFERENCES

Akcayir, M., & Akcayir, G. (2017). Advantages and Challenges Associated with Augmented Reality for Education: A Systematic Review of the Literature. *Educational Research Review*, *20*, 1–11. doi:10.1016/j.edurev.2016.11.002

Applebee, A. N. (1978). *The child's concept of story*. University of Chicago Press.

Azuma, R., Billinghurst, M., & Klinker, G. (2011). Special section on mobile augmented reality [editorial]. *Computers & Graphics*, *35*(4), vii–viii. doi:10.1016/j.cag.2011.05.002

Azuma, R. T. (1997). A survey of augmented reality. *Presence: Virtual and Augmented Reality*, *6*(4), 355–385. doi:10.1162/pres.1997.6.4.355

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

Bower, M., Howe, C., McCredie, N., Robinson, A., & Grover, D. (2014). Augmented Reality in education–cases, places and potentials. *Educational Media International*, *51*(1), 1–15. doi:10.1080/09523987.2014.889400

Chang, K. E., Chang, C. T., Hou, H. T., Sung, Y. T., Chao, H. L., & Lee, C. M. (2014). Development and behavioural pattern analysis of a mobile guide system with augmented reality for painting appreciation instruction in an art museum. *Computers & Education*, *71*, 185–197. doi:10.1016/j.compedu.2013.09.022

Chang, Y. H. (2013). Applying an AR Technique to Enhance Situated Heritage Learning in a Ubiquitous Learning Environment. *Turkish Online Journal of Educational Technology-TOJET*, *12*(3), 21–32.

Chang, Y. L., Hou, H. T., Pan, C. Y., Sung, Y. T., & Chang, K. E. (2015). Apply an augmented reality in a mobile guidance to increase sense of place for heritage places. *Journal of Educational Technology & Society*, *18*(2), 166–178.

Chatti, M. A., Jarke, M., & Frosch-Wilke, D. (2007). The future of e-learning: A shift to knowledge networking and social software. *International Journal of Knowledge and Learning*, *3*(4-5), 404–420. doi:10.1504/IJKL.2007.016702

Chen, C. H., Chan, W. P., Huang, K., & Liao, C. W. (2022). Supporting informal science learning with metacognitive scaffolding and augmented reality: Effects on science knowledge, intrinsic motivation, and cognitive load. *Research in Science & Technological Education*, 1–16. doi:10.1080/02635143.2022.2032629

Chien, C. Y. (2019). English for Ecotourism and Its Sustainability with Augmented Reality Technology. *International Education Studies*, *12*(6), 134–147. doi:10.5539/ies.v12n6p134

Coelho, A., & Costa, L. M. (2017). The integration of augmented reality and the concept of sticker album collection for informal learning in museums. In *International Conference on Immersive Learning,* (107-115). Springer, Cham. doi:10.1007/978-3-319-60633-0_9

Costa, M. C., Patricio, J. M., Carrança, J. A., & Farropo, B. (2018). Augmented reality technologies to promote STEM learning. In *13th Iberian conference on information systems and technologies (CISTI),* IEEE, (1-4). doi:10.23919/CISTI.2018.8399267

Dillenbourg P., (1996). Distributing Cognition over humans and machines. In Vosniadou S., De Corte E., Glaser B. & Mandl H. (Eds), International Perspectives on the Psychological Foundations of Technology-Based Learning Environments, pp. 165-184, Mahwah, NJ: Lawrence Erlbaum.

Dimitracopoulou, A. (2018). Trends and Dimensions of 'Environments of Educational Material' in Technology Enhanced Learning Activities: Definitions and Specifications. In C. Skoumpourdi, & M. Skoumios (Eds) *3rd Conference on Educational Material of Mathematics and Sciences*, (117-145).

Dunleavy, M., & Dede, C. (2014). Augmented reality teaching and learning. Handbook of research on educational communications and technology, (pp. 735-745). New York: Springer. http://dx.doi.org/10.1007/978-1-4614-3185-5_59

Dunleavy, M., Dede, C., & Mitchell, R. (2009). Affordances and limitations of immersive participatory augmented reality simulations for teaching and learning. *Journal of Science Education and Technology*, *18*(1), 7–22. doi:10.1007/s10956-008-9119-1

Egan, K. (1985). Teaching as Story-telling: A Non-mechanistic Approach to Planning Teaching. *Journal of Curriculum Studies*, *17*(4), 397–406. doi:10.1080/0022027850170405

Goff, E. E., Mulvey, K. L., Irvin, M. J., & Hartstone-Rose, A. (2018). Applications of augmented reality in informal science learning sites: A review. *Journal of Science Education and Technology*, *27*(5), 433–447. doi:10.1007/s10956-018-9734-4

Greenfield, P. M. (2009). Technology and informal education: What is taught, what is learned. *Science*, *323*(5910), 69–71. doi:10.1126/science.1167190 PMID:19119220

Grevtsova, I. (2017). The City as an open-air museum An educational mobile application for the historic centre of Barcelona. *Museumedu* (4), 95-108.

Harley, J. M., Poitras, E. G., Jarrell, A., Duffy, M. C., & Lajoie, S. P. (2016). Comparing virtual and location-based augmented reality mobile learning: Emotions and learning outcomes. *Educational Technology Research and Development*, *64*(3), 359–388. doi:10.1007/s11423-015-9420-7

Hein, G. E. (2002). *Learning in the Museum*. Routledge. doi:10.4324/9780203028322

Holden, C. (2014). The local games lab ABQ: Homegrown augmented reality. *TechTrends*, *58*(1), 42–48. doi:10.1007/s11528-013-0719-0

Hsiao, H. S., Chang, C. S., Lin, C. Y., & Wang, Y. Z. (2016). Weather observers: A manipulative augmented reality system for weather simulations at home, in the classroom, and at a museum. *Interactive Learning Environments*, *24*(1), 205–223. doi:10.1080/10494820.2013.834829

Hu, P. Y., & Tsai, P. F. (2016). Mobile outdoor augmented reality project for historic sites in Tainan. In *ICAMSE*, IEEE, (pp. 509–511). doi:10.1109/ICAMSE.2016.7840184

Ibáñez, M. B., & Delgado-Kloos, C. (2018). Augmented reality for STEM learning: A systematic review. *Computers & Education*, *123*, 109–123. doi:10.1016/j.compedu.2018.05.002

Innocent, T., & Leorke, D. (2020). (De) coding the City: Analyzing Urban Play through" Wayfinder" Live. *American Journal of Play*, *12*(3), 270–304.

Jiang, S., Moyle, B., Yung, R., Tao, L., & Scott, N. (2022). Augmented reality and the enhancement of memorable tourism experiences at heritage sites. *Current Issues in Tourism*, 1–16. doi:10.1080/13683500.2022.2026303

Kennedy, A. A., Thacker, I., Nye, B. D., Sinatra, G. M., Swartout, W., & Lindsey, E. (2021). Promoting interest, positive emotions, and knowledge using augmented reality in a museum setting. *International Journal of Science Education. Part B*, *11*(3), 242–258.

Klopfer, E., & Squire, K. (2008). Environmental Detectives—The development of an augmented reality platform for environmental simulations. *Educational Technology Research and Development*, *56*(2), 203–228. doi:10.1007/s11423-007-9037-6

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. doi:10.1080/10494820.2018.1458039

Lathem, S. (2005). Learning communities and digital storytelling: New media for ancient tradition. *In Society for Information Technology & Teacher Education International Conference,* AACE, (2286-2291).

Lehto, A., Luostarinen, N., & Kostia, P. (2020). Augmented reality gaming as a tool for subjectivizing visitor experience at cultural heritage locations—Case lights on! [JOCCH]. *Journal on Computing and Cultural Heritage*, *13*(4), 1–16. doi:10.1145/3415142

Livingstone, D. (2001). Adults' informal learning: definitions, findings, gaps and future research. *NALL Working Paper 21, New Approaches to Lifelong Learning (NALL),* Ontario Institute for Studies in Education, University of Toronto

Lochrie, M., Čopič Pucihar, K., Gradinar, A., & Coulton, P. (2013). Time-wARpXplorer: creating a playful experience in an urban time warp. Physical and Digital in Games and Play. MindTrek2013, DOI: 10.13140/RG.2.1.2698.9607

Lukosch, S., Billinghurst, M., Alem, L., & Kiyokawa, K. (2015). Collaboration in augmented reality. *Computer Supported Cooperative Work*, *24*(6), 515–525. doi:10.1007/s10606-015-9239-0

Markouzis, D., & Fessakis, G. (2016). Rapid prototyping of interactive storytelling and mobile augmented reality applications for learning and entertainment–The case of "k-Knights". [iJEP]. *International Journal of Engineering Pedagogy*, *6*(2), 30–38. doi:10.3991/ijep.v6i2.5560

Mathews, R. C. (1977). Semantic judgments as encoding operations: The effects of attention to particular semantic categories on the usefulness of interitem relations in recall. *Journal of Experimental Psychology. Human Learning and Memory*, *3*(2), 160–173. doi:10.1037/0278-7393.3.2.160

McMahon, D., Cihak, D. F., & Wright, R. (2015). Augmented reality as a navigation tool to employment opportunities for postsecondary education students with intellectual disabilities and autism. *Journal of Research on Technology in Education*, *47*(3), 157–172. doi:10.1080/15391523.2015.1047698

Milgram, P., Takemura, H., Utsumi, A., & Kishino, F. (1995). Augmented reality: A class of displays on the reality-virtuality continuum. In Telemanipulator and telepresence technologies,SPIE, 2351, 282-292, http://dx.doi.org/10.1117/12.197321

National Storytelling Network. (n.d.). *National Storytelling Network.* https://storynet.org/

Nevola, F., Coles, T., & Mosconi, C. (2022). Hidden Florence revealed? Critical insights from the operation of an augmented reality app in a World Heritage City. *Journal of Heritage Tourism*, *17*(4), 1–20. doi:10.1080/1743873X.2022.2036165

Nouri, J., Rahmani, R., & Hansen, P. (2018). A systematic review on learning through mobile Augmented Reality [iJIM]. *International Journal of Interactive Mobile Technologies*, *12*(3), 75–85. doi:10.3991/ijim.v12i3.8404

Pendit, U. C., Zaibon, S. B., & Bakar, J. A. (2014). Mobile augmented reality for enjoyable informal learning in cultural heritage site. *International Journal of Computers and Applications*, *92*(14), 19–26. doi:10.5120/16077-5286

Petrovich, M., Shah, M., & Foster, A. (2018). Augmented reality experiences in informal education. In TALE conference, IEEE, (815-819). doi:10.1109/TALE.2018.8615396

Poitras, E. G., Harley, J. M., & Liu, Y. S. (2019). Achievement emotions with location-based mobile augmented reality: An examination of discourse processes in simulated guided walking tours. *British Journal of Educational Technology*, *50*(6), 3345–3360. doi:10.1111/bjet.12738

Pombo, L., & Marques, M. M. (2020). The potential educational value of mobile augmented reality games: The case of EduPARK app. *Education in Science*, *10*(10), 287. doi:10.3390/educsci10100287

Schwan, S., Grajal, A., & Lewalter, D. (2014). Understanding and engagement in places of science experience: Science museums, science centers, zoos, and aquariums. *Educational Psychologist*, *49*(2), 70–85. doi:10.1080/00461520.2014.917588

Serafeim, K., & Fesakis, G. (2010). Digital story telling: Software overview, In V., Koltsakis, G., Salonikidis, and M., Dodontsis, (Eds.) *2nd Conference: Digital and internet applications for education*,1558-1569. ISBN: 978-960-99301-0-9

Sommerauer, P., & Müller, O. (2014). Augmented reality in informal learning environments: A field experiment in a mathematics exhibition. *Computers & Education*, *79*, 59–68. doi:10.1016/j.compedu.2014.07.013

Sommerauer, P., & Müller, O. (2018). Augmented reality in informal learning environments: Investigating short-term and long-term effects. Hawaii International Conference on System Sciences. doi:10.24251/HICSS.2018.176

Stymne J. (2020) Outdoor learning with mobile technology: A systematic review. *IADIS International Journal on WWW/Internet*, *18*(1), 76-106

van der Vlist, B., Niezen, G., Rapp, S., Hu, J., & Feijs, L. (2013). Configuring and controlling ubiquitous computing infrastructure with semantic connections: A tangible and an AR approach. *Personal and Ubiquitous Computing*, *17*(4), 783–799. doi:10.1007/s00779-012-0627-x

Vicari, C. (2020). Escape the Planet: Empowering Student Designers to Create a Science-Based Escape Room with Augmented Reality. *International Journal of Designs for Learning*, *11*(2), 80–95. doi:10.14434/ijdl.v11i2.24110

Wahyuni, M., Pangaribuan, C. H., Ayu, M. A., & Abidin, A. D. (2021, August). The Role of Location-based Augmented Reality in Enhancing Visit Intention of Cultural Heritage Site. In *ICIMTech-2021,* IEEE, (Vol. 1, pp. 625–630). doi:10.1109/ICIMTech53080.2021.9535005

Wu, H. K., Lee, S. W. Y., Chang, H. Y., & Liang, J. C. (2013). Current status, opportunities and challenges of augmented reality in education. *Computers & Education*, *62*, 41–49. doi:10.1016/j.compedu.2012.10.024

Yoon, S. A., Anderson, E., Park, M., Elinich, K., & Lin, J. (2018). How augmented reality, textual, and collaborative scaffolds work synergistically to improve learning in a science museum. *Research in Science & Technological Education*, *36*(3), 261–281. doi:10.1080/02635143.2017.1386645

Zheng, L., Zhang, X., & Gyasi, J. F. (2019). A literature review of features and trends of technology-supported collaborative learning in informal learning settings from 2007 to 2018. *Journal of Computers in Education*, *6*(4), 529–561. doi:10.1007/s40692-019-00148-2

*Dimitris Markouzis holds a B.Sc. in Informatics, a M.Sc in Informatics on the topic of Software from University of Ioannina and a Phd on Designing and Implementation of mobile augmented reality serious games and study their effect on the spatial ability development from University of the Aegean. At this time he is Post Doc researcher in University of the Aegean on the topic of "Design and Development of Location Depended, Augmented Reality, Entertainment and Education Mobile Applications and their Impact onto the Destination Branding Management"*

*Aikaterini Baziakou has MSc studies at the University of the Aegean with the title "Design of Interactive and Industrial Products and Systems". She is a Primary School teacher and a PhD Candidate of School of Humanity, University of the Aegean, Greece. She is also a member of the Learning Technology and Educational Engineering Laboratory [LTEE lab / ltee.aegean.gr]. Her research is in the area of technology-enhanced learning, augmented reality, and science education for elementary students.*

*Georgios Fesakis holds a B.Sc. and a M.Sc. in Informatics from University of Athens and a PhD in Informatics Didactics from University of the Aegean. He serves as professor at the University of the Aegean where he is teaching since 2004. His research interests include ICT design for learning, CS & Mathematics Didactics. He is member of ACM CSE-SIG. Detailed information at: http://ltee.aegean.gr/gfesakis.*

*Angelique Dimitracopoulou is Professor ["Design of Technology Based Learning Environments"] of School of Humanity, University of the Aegean, Greece. She is Director of the Learning Technology and Educational Engineering Laboratory [LTEE lab / ltee.aegean.gr]. Her research outputs have contributed mainly on the following dimensions: (I) Design of technology-based learning environments empowering learners in everyday learning life (modeling systems, collaborative systems and apps, mobile apps, learning analytics tools supporting self-regulation etc). (II) Design of Learning Activities & multimodal participants support. (III) Social media & digital multimodal argumentations (video) on crucial societal issues. For more information see [ltee.aegean.gr/adimitr].*