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Research Article

Design of a location-based augmented reality game for the development of key 21st century competences in primary education

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ABSTRACT

The use of augmented reality games (ARGs) in education has gained increased attention from curriculum developers, teachers, and researchers in the past decade. Research findings show that ARGs can promote meaningful learning environments that foster key competences for the 21st century. This paper presents the design process of "EcoAegean", an ARG for mobile devices, which was implemented in primary classroom environments to support the development of students' key competences in the context of sustainability. The game was created using an open augmented reality software platform and its design was based on contemporary theoretical underpinnings regarding the use of such games in educational contexts. In the first section of the paper, we describe the design procedures of the learning scenario as well as the game itself. In the last section of the paper, we offer a set of critical insights on the design and implementation of mobile augmented reality games for the purpose of supporting students' development of key 21st century competences.

Keywords: augmented reality, games, key competences, learning design, primary education, students

INTRODUCTION

One of the current challenges that educators are faced with is fostering the development of students' key competences. The acquisition of those key competences, namely the knowledge, skills, and attitudes necessary to adapt flexibly to a rapidly changing world, is crucial for all students. Teaching key competences requires students' engagement and involvement in goal-directed, active and authentic tasks as well as structures, innovative teaching methods and proper ICT tools that are open to everyone (Looney & Michel, 2014).

Key competences are typically defined as the sum of skills required by citizens for personal fulfillment, health, employability and social inclusion in the 21st century. In 2018, European Commission (2018) adopted the following eight key competences for lifelong learning:

1. Literacy competence,

2. Multilingual competence,
3. Mathematical competence and competence in science, technology, and engineering,
4. Digital competence,
5. Personal, social, and learning to learn competence,
6. Citizenship competence,
7. Entrepreneurship competence, and
8. Cultural awareness and expression competence.

These key competences are considered interrelated. Skills such as critical thinking, problem-solving, teamwork, communication, creativity, negotiation, analytical, and intercultural skills are embedded throughout all key competences. The early acquisition of these skills is the foundation for developing higher, more complex skills (European Commission, 2018).

Given the importance of 21st century competences for today's students' success and performance, various programs have been implemented to enhance the acquisition of those competences. The evolution of technology in the last decades offers a variety of affordable solutions for schools and educators. A plethora of technological tools, devices, and platforms could support the learning of key competences and create the basis for further development and advancement. In this context, mobile learning seems to be one of the most common approaches in education since mobile devices are primarily used among students, teachers and other people in general. Furthermore, mobile devices (e.g., smartphones, tablets, etc.) are very popular in modern classrooms due to their accessibility, networking capabilities and portability (Sharples et al., 2010). Empirical evidence from several studies suggests that mobile educational applications can be used to support the development of several key competences since they promote critical thinking and problem-solving in various contexts (Hayes, 2016).

Similarly, it is proven that video games in classrooms enable students to engage with the learning material, interact with other students in a meaningful way, and increase their curiosity and motivation (Koutromanos & Avraamidou, 2014). A recent study used Minecraft to investigate whether the use of educational video games promotes the acquisition of 21st century skills. Results revealed that Minecraft could help students learn to problem-solve, improve their research skills, be resourceful, multitask, and develop their social skills through teamwork (Hewett et al., 2020).

Augmented Reality and Augmented Reality Games

Augmented reality (AR) has been conceptualized in different ways in the past couple of decades. According to Carmigniani and Furht (2011), AR can be defined as a real-time or an indirect view of a physical, real-world environment that has been augmented by adding virtual information to it. More recently, Reilly and Dede (2019) define AR as the technology that allows users to superimpose digital information on the physical world by means of mobile devices. Previous studies on AR in education have significantly impacted students' education and overall performance compared to other traditional methods used in the classroom by supporting students' understanding of spatial and conceptual knowledge, improving long-term memory retention, enabling collaboration and increasing motivation (Radu, 2014). Based on the work by Squire and Jan (2007), mobile augmented reality games (MARGs) are games that are played in the real world with the support of mobile devices, which create an imaginary world in the real world. These games use data from a wireless network and/or GPS to determine the device's location in the area and augment the real environment with digital objects (e.g., images, audio, video, 3D, etc.), networking and communication abilities (Cheng & Tsai, 2013). MARG can be used in the classroom to promote inquiring and exploration learning and provide location-specific information so that students can collaborate to solve meaningful problems and construct their own solutions (Schrier, 2006). Hence, the technology aligns with social constructivist and situated learning theories in which knowledge is collaboratively co-created in real-world contexts using authentic disciplinary processes (Reilly & Dede, 2019). In their review Koutromanos et al. (2015), found that the use of AR games in mobile devices can positively influence learning, participation, and development of various competences.

Purpose of the Study

The main purpose of this paper is to present the design process of a MARG, that will be used in a real primary classroom environment to develop students' key competences in the context of sustainable development. In this research, we focus on the specific competences such as social and learning to learn competence, citizenship competence and entrepreneurship competence.

The study aims to contribute to the field by describing a way for teachers and students to be involved in the process as well as by proposing game-designs patterns that may prove beneficial for the development of students' 21st century skills. The involvement of students and teachers in the design enabled researchers to create a game that can be easily adapted and integrated into the curriculum and is based on students' interests and needs.

In the following sections, we first provide an overview of the existing knowledge base about the potential of MARG games in promoting key competences. Following that, we provide a concrete example of the design of the game "EcoAegean". A detailed description of the game's design process is presented, followed by a discussion about the potential and possibilities of MARG games in supporting the development of students' key competences in real classroom settings.

BACKGROUND AND RELATED WORK

MARG have been an active topic among educational technology researchers during the past fifteen years. The number of case studies and reviews is rapidly growing (Dunleavy & Dede, 2014; Laine, 2018; Li et al., 2017). These games have been used in various disciplines and educational settings, both formal and informal (Koutromanos & Avraamidou, 2014) . However, only a few studies have employed MARG as educational tools to develop students' key competences.

One of the first initiatives in the field was led by Schrier (2006). The researcher designed "reliving the revolution', a MARG related to the historic battle of Lexington. Participants interacted with virtual historic figures and items, which GPS triggered to appear on their personal digital assistant (PDA) depending on their position. The game offered the possibility for players to choose from four different roles. Game participants received information that was relevant to their role in the game and used this information to decide who fired the first shot at the battle. Initial testing was done by college and post-graduate school students through

(1) pre- and post-game survey instruments,

(2) videotaped and in-person observations of the participants' gameplay, and

(3) content analysis of the debate, game interactions, and participants' notes.

Results suggested that MARG can motivate the authentic practice of 21st century skills when adequately designed for pedagogical purposes.

"Outbreak @ The Institute" was a MARG developed by Rosenbaum et al. (2007) intending to investigate students' personal embodiment in the game. Students were challenged to identify the source of an infectious disease and prevent its spread among real and/or virtual characters. The game was played in PDAs across a university campus, where players took on the roles of doctors, medical technicians, and public health experts to contain a disease outbreak. The results from pre- and post-surveys, gameplay video and interviews with twenty-one high school students showed that MARG could support new kinds of authentic science inquiry experiences and promote skills essential for 21st century citizens.

Squire and Jan (2007) developed a location-based ARG called "Mad City Mystery". Through the gameplay, students were required to develop and argue scientific explanations in order to solve a mysterious death in their local region. The game was available in PDAs and provided three different player roles. Twenty-eight students from elementary/secondary/high school levels played the game. Data analysis from observations, interviews and questionnaires suggested that MARG can support students in scientific thinking (particularly argumentation), as well in problem-solving, communication and collaboration.

A few years later, Sanchez et al. (2010) utilized geotechnologies and AR to design a role-playing game that aimed to develop students' active citizenship skills. The scenario transferred players in a real situation in which they had to argue in favor or against six different green energy projects for their city. Students took on the

roles of six companies, local authorities and local inhabitants. Pocket PCs with GPS functionalities were used to display digital information in the place, where each project was planned to be implemented. Observation results showed that students were active, deeply involved in the situation and got the opportunity to develop skills and knowledge that are expected from future citizens.

"EcoMOBILE" was an AR game experience developed by Kamarainen et al. (2013) that was implemented during a field trip to a local pond environment. Middle school students played the game using smartphones to navigate the pond environment and to observe virtual media and information overlaid on the physical pond and environmental Probeware to conduct measurements. "EcoMOBILE" included pre-field trip training, a field trip to a local pond environment, and post-field trip discussions in the classroom. The results from questionnaires findings showed that MARG could provide a powerful pedagogical tool that supports student-centered learning, positively affecting higher-order skills such as critical thinking and problem-solving.

Lastly, "Kiwi MobileSim" was a serious mixed-reality business game developed by Ryua et al. (2014) with the aim to enhance collaborative learning and critical thinking skills. 25 undergraduate students were recruited and were randomly assigned to one of three groups:

1. Individual learning group with single player mode,
2. Collaborative learning group with pair-player mode, and
3. Collaborative learning group with two single player modes.

The game scenario asked players to recognize each department's position in a virtual company and identify the problems or issues the company was facing. In the game, players had to move around a specified area, in order to find specific departments that provided information for them. When players arrived at a given location, an interview video file began to play automatically. After viewing the video, players could gather extra information by asking experts. Results from the experimental tasks and content analysis, indicated that MARG could have a positive effect on students' levels of critical thinking.

THE AR GAME "ECOAEGEAN"

Design Process

The design of the game was based on explicit choices discussed among the research team and the teachers during the design process of the game, and it was implemented in three phases.

The first phase included refining the game's objectives and the expected learning results. Teachers provided their consultation on the game's central idea and how it would be linked to sustainable development education goals. Furthermore, the research team and the teachers analyzed several learning theories to determine the game's theoretical framework and the design principles it will rely on. "EcoAegean" design was based on situated learning theory and constructivist learning theory. According to Dunleavy and Dede (2014), AR aligns well with situated and constructivist learning theories as it positions the learner within a real-world physical and social context while guiding, scaffolding and facilitating participatory and metacognitive learning processes such as authentic inquiry, active observation, peer coaching, reciprocal teaching and legitimate peripheral participation with multiple modes of representation. Both learning theories have been used successfully in previous studies regarding the use of mobile or location-based AR games in education contexts (Rosenbaum et al., 2007; Squire & Klopfer, 2007).

In the second phase, the scenario and the game content were designed. Teachers discussed their interests and favorite genres in digital games with their students, collected feedback, and adapted the scenario's plot, roles, and virtual characters based on that. The game plot is based on a mystery narration genre, which has been a pretty popular plot model in several location-based games in the past (Markouzis & Fessakis, 2016). Teachers and the research team also considered general design guidelines for location-based mobile games as developed by Ardito et al. (2010) and design guidelines for developing digital and civic competences through mobile AR games as proposed by Tzortzoglou et al. (2021).

Lastly, the team of researchers and teachers selected the location for the game implementation in a way that it offers opportunities for authentic learning- and co-created the game content (videos, texts, and images). The game was developed on an open-source platform based on the design decisions and the game

Table 1. Game scenario's phases

Step I	Step II	Step III
-Introduction to game story -Students discuss in groups & form hypotheses about game's objective in classroom -Teacher acts as facilitator	-Students play game in selected physical location -Teacher acts as facilitator	-Students reflect on game's results & main findings/they test their initial hypotheses -Students summarize their findings & propose solutions -Teacher acts as facilitator

scenario. The game was initially tested by two teachers and a small number of students in order to point out any technical problems or errors in the game's programming and to gather feedback from students regarding their learning experience from participating in all three steps of the game. Feedback regarding the technical aspects of the game (i.e., interactions with virtual objects, transitions from one stage to another, GPS connectivity) was collected by inviting students to think aloud while playing the game at the selected location. A few minor technical dysfunctions were identified during this phase, which were fixed. Furthermore, teachers held informal discussions with the participating students after the game to record their learning but also gaming experience. Students found the game-story really interesting, and they also proposed alternative game pathways and additional virtual characters that, according to their opinion, would make the game more attractive to their peers. Their comments were considered, and the game plot was enriched accordingly. A formal evaluation study is planned for the future after implementing the game in class.

Development of Learning Scenario

"EcoAegean" scenario aims to develop students' key competences in the context of sustainable development. It is addressed to students aged 10-13 years old and its purpose is to help students learn how to sustainably manage and protect the marine and coastal ecosystem of Rhodes island, propose solutions for improving the quality of life and the development of their land, and finally develop ways and skills of intervention in their immediate social environment. For the needs of the scenario, a region with real environmental issues was selected as the game's location. This was the much frequented by tourists' beach of Kolympia, also familiar to students as a place for school excursions.

The scenario unfolds in three steps, as shown in **Table 1**. The first step takes place in the classroom. Students receive an email from Ada, a hotel owner whose business is located the beach of Kolympia. In her email, she describes some warning signs from tourists in the area who cancel their reservations, complaining about the beach and the water quality. Students are asked to visit the location and search for any information and clues that might shed light on the reasons for this alarming situation. While in class, students share their thoughts with their peers and make hypotheses.

The second step takes place at the game's location. Once there, students are divided into groups and given a tablet with a data connection. At the beginning of the game, each group is given the option to choose one of the game's player roles. The game scenario makes use of existing physical locations (i.e., the hotel, a tavern by the sea, a small fishing harbor), includes virtual characters-either based on real people (i.e., Ada the hotel owner, Babis the tavern manager) or totally fictional ones (i.e., a fisherman, a Mediterranean seal)- as well as virtual items (i.e., seawater samples, traces on the sand, plastic bags). Each of the above, also called agents in the game's creation platform, is augmented with different kinds of digital material (text, image, video, URL, and sound file), which appear automatically when the students enter the geographical boundaries of the agent's area. Students interact with virtual characters during the game, process data from digital sources, take photos and gather information from the physical environment, collect virtual items, and answer short quizzes into the game. Their objective is to gather as many clues as possible for their final report to Ada. There is no time restriction in playing the game nor a precise sequence between the agents. Each group is responsible for creating its path through the game's points of interest.

Students return to the classroom during the third step, and all groups work together. Each team presents its findings to their classmates, and all collaboratively create a mind map with the information they have gathered. They propose solutions to the issues discovered and they prepare a report for Ada as well as an article for the local newspaper and a letter to the local authorities. In all three steps of the scenario, educators act as facilitators, assisting if needed and ensuring students' safety while playing the game outdoors.

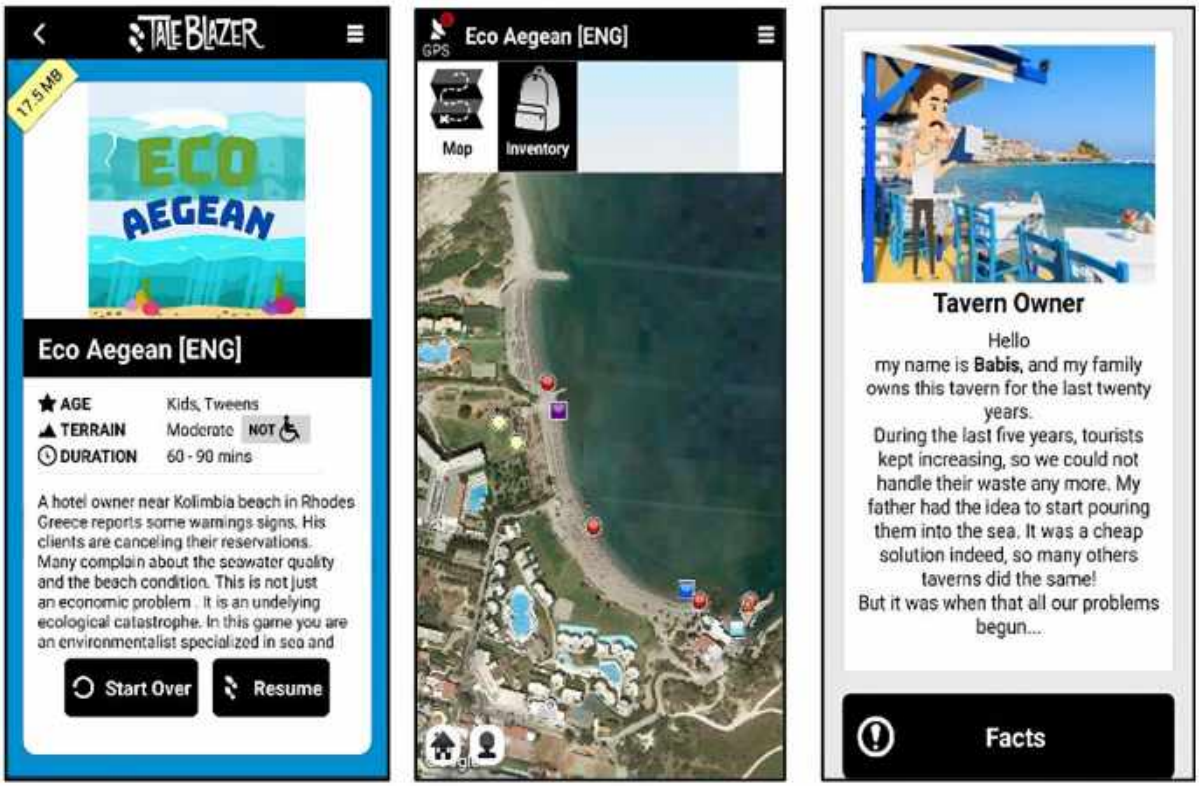

Figure 1. Screenshots from "EcoAegean" game in TaleBlazer platform (Source: In-game screenshots from Taleblazer platform)

Developing Game Through TaleBlazer Platform

"EcoAegean" was developed using TaleBlazer (www.taleblazer.org). This is an open-source, cloud-based platform for creating and playing location-based experiences. The platform was developed by the MIT Scheller teacher education program lab. It comprises a web-based editor through which one can design a game, and a free app for mobile devices (available both on Android and iOS) used for playing the game.

The web-based editor utilizes data from Google maps and allows the game designer to specify real-world locations as the game's area. In this area, the game designer is able to place the agents that represent game items or virtual characters needed for the scenario and the interaction with the player. As players move around the physical space, their devices spot their current location (typically using GPS outdoors or iBeacons indoors), allowing players to interact with virtual characters, artifacts and data within the context of real landscapes. When players choose to interact with an agent, the agent's available choices are displayed to establish a dialogue with them or communicate information about a quest. According to the players' answers, new choices or game resources can be unlocked by using the resource's hidden attribute. TaleBlazer supports the manipulation of custom attributes such as the game progress, game-ending conditions and score through an easy-to-use visual, blocks-based programming environment.

Example of the game screens are shown in **Figure 1**.

Game Design Elements for Key Competences

In the following subsections, we describe how the game's elements, tasks and actions in "EcoAegean" potentially enable and enhance the practice of key competences.

Data and information management

"EcoAegean" encourages participants to practice information management by providing information and data from different sources such as video, audio and text files. According to Squire and Jan (2007), this information support narratives, navigation and collaboration cues and help players gain more background information, clues and a richer context for play. In order to process this type of data from different sources

and to interpret the laying links between them requires data literacy skills (Schrier, 2006). "EcoAegean" also provides learners with two kinds of data: primary data, which is collected through observation of the physical environment, and secondary data, summative and background information data, provided through the game. Players have to combine the two forms of data to make this helpful data, making the game a great platform for learning opportunities regarding data and information literacy skills.

Communication and collaboration

Communication and collaboration skills are practiced through the game in two primary ways. The first design element that affords the development of these skills is playing the game in groups of users. This game design forces students to work together, elaborate and discuss ideas. Each team member may have different responsibilities, i.e., carrying the tablet and navigating from one location to another or taking notes; however, all members contribute to the team's strategy and co-decide to answer the game's quizzes. The second design element that targets communication and collaboration skills provides users with different characters' options, whom each has distinctive roles to fulfil. Each student's differentiated role in these games is presented with an alternate, incomplete view of the game (O'Shea et al., 2009). This encourages students to share information, communicate orally with their group, ask questions and debate meaning (Squire & Jan, 2007). If students do not collaborate, they will not be able to solve the problem.

In "EcoAegean", students join the game in one of two possible roles, each of them has a different path and objectives in the game. Depending on the role, different content should be gathered, and virtual characters will be met. The two roles are the following:

1. The marine biologist, who investigates the results of human activities in coastal life by visiting specific locations, taking photos, conducting virtual water analysis, and interacting with virtual animal characters.
2. The journalist, who seeks information about the socio-economic and personal reasons behind certain human behaviors by interviewing virtual characters of locals and tourists in the area.

Problem-solving and critical thinking

In "EcoAegean", the game scenario is portrayed as a mystery to be solved, a problem to which the users need to use their problem-solving skills to find an answer. This type of game scenario invites students to search, analyze and find connections between different kinds of information, draw conclusions and make decisions regarding the game. To do that effectively, learners must also critically evaluate data, question contradicting information, and relate information to other data. Hence, they practice their critical thinking skills while playing the game in order to reach their objectives.

Civic and social awareness

"EcoAegean" provides opportunities for civic and social awareness by making students aware of existing environmental problems in their region and by challenging them to come up with solutions to these problems (Koutromanos et al., 2018). The game scenario takes place in a familiar location to the students and includes virtual characters based on existing people. These elements create a realistic learning situation that connects students with their region. Lastly, the game encourages the development of active citizenship by asking students to make interventions to their social environment, i.e., by writing a newspaper article and a letter to local authorities.

CONCLUSIONS AND FUTURE WORK

In this paper we presented the design and development of a location-based AR game titled "EcoAegean", as a concrete example of the design of a MARG The game incorporated several design elements that could support the development of key competences especially data and information management, cooperation and collaboration, problem-solving and critical thinking, civic and social awareness. The design process may also serve as an example for the design of MARGs for learning in primary education. The game was initially tested by two teachers and a small number of students as a form of a pilot implementation while a formal evaluation

regarding its usability and educational value towards students' key competences development is planned for the future.

Besides the design mentioned above, some additional considerations on teachers' and students' experience and initial evaluation are important. MARG can motivate and engage environments for learning key competences (Schier, 2006). However, a game can only be a part of the learning situation. Students need to get knowledge before the start of the game, and a debriefing session is necessary after the game is over (Sanchez et al., 2010). This debriefing aims to provide opportunities for engagement in a set of reflective and meta-cognitive activities.

Furthermore, the game should be playful and personally meaningful and consider affective domains of learning especially when are designed for younger children. All names, images and virtual characters in "EcoAegean" were designed in a humorous way, so that students would experience a form of entertainment when solving challenging tasks Towards this direction, the game also allowed students to make errors and provided with opportunities to play again.

It is important to point that similarly to any curriculum material and educational activity, MARG might be experienced differently by individual uses. For example, promoting collaboration and communication through teamwork and roles may work for some users but may prove difficult for users with poor communication skills (Fotouhi-Ghazvini et al., 2009). When applying MARG, educators and game designers should also consider the users' diversified background and abilities and provide hints and feedback through the game, in order to help them better adjust to the game.

In terms of technology, TaleBlazer proved to be an easy-to-use tool, oriented towards creating low-cost location-based AR experiences and games. Its structure is in line with the typical role-based nature of educational location-based games that have been used successfully in this context. However, future enhancements could allow the use of image recognition-for image-based AR content- and game-learning analytics, which could be used to assess player progress and adapt gameplay to personal needs (Xanthopoulos & Xinogalos, 2018)

In closing, we propose that future research is directed towards exemplifying the theoretical aspects and the characteristics of design frameworks associated with MARG and characterizing rich and complex pedagogical practices that use MARG, for the purpose of developing theoretical and pedagogical frameworks for the implementation of MARG in diverse educational contexts.

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Data availability: Data generated or analyzed during this study are available from the authors on request.

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