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Evaluation of a Mobile Augmented Reality Game Application as an Outdoor Learning Tool

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ABSTRACT

There is a discussion on the potential of augmented reality (AR), mobile technologies to enhance learning. This article presents: 1) the EduPARK project's first cycle of design-based research for the development of a mobile AR game-like app that aims to promote learning in an urban park, and 2) an experience of students using it in loco. The focus is the students' perceptions regarding the usability and functionality of the app. Data collection involved focus groups, questionnaires and app usage information. Data was submitted to content analysis and descriptive statistics. Results revealed an excellent usability of the EduPARK app, with an average system usability scale of 85.6. Overall, students reported that the app was enjoyable, easy to use and promoted learning; however, improvements and more evaluation experiences are needed to better understand mobile AR game-like learning in urban parks.

KEYWORDS

Augmented Reality, Design-Based Research, Educational Game, Mobile Learning, Outdoor Learning, User's Evaluation

INTRODUCTION

Mobile devices are owned by an increasing percentage of students (Chen, Seilhamer, Bennett, & Bauer, 2015; Sozio et al., 2015), so educators can take advantage from their pervasiveness, as they can be used to promote learning anytime/anywhere. One of the arguments for mobile devices' educational use is that their affordances have been empirically established, both for learning achievement and for students' affective learning outcomes, such as attitude, motivation or engagement (Sung, Chang, & Liu, 2016). Moreover, mobile devices can also support emerging technologies, such as augmented reality (AR), and, when combined with educational games, they can also promote student engagement for deeper and authentic learning (Huizenga, Admiraal, Akkerman, & Dam, 2009).

The literature suggests there is no limit to the potential valuable educational uses of AR applications (Chang, Morreale, & Medicherla, 2010) that are aligned with situated (FitzGerald et al., 2013) and constructivist learning theories (Dunleavy & Dede, 2014). On the one hand, situated learning highlights the relevance of social interactions among people, for learning within a specific

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context. On the other hand, constructivist theory emphasizes the impact of the individuals' previous knowledge in the learning processes (idem, ibidem). For students to develop essential 21st century skills, such as problem solving, collaboration, digital and communication proficiency, more active and authentic learning methods, both inside and outside the classroom, are needed (Johnson et al., 2016). The development of those competences requires learners to take the responsibility for their learning and become engaged participants, rather than passive observers (Pombo et al., 2011).

The EduPARK project intends to combine mobile AR technology with outdoor gaming strategies, based on geocaching principles, to enhance student motivation and allow learning to move beyond traditional classrooms to natural spaces. Such outdoor settings allow students to explore nature while making connections with curricular content in a collaborative way. With that aim, one of the main outcomes of this project is a user-friendly mobile AR game app, enabling students, teachers and the public to explore and access interdisciplinary information while visiting a green park in Aveiro (Portugal), the Infante D. Pedro Park. This park serves as the "lungs of the city", presents a rich botanical diversity and historical patrimony and includes several curriculum-articulated learning opportunities (Pombo et al., 2017). The app comprises educational guides, in accordance with the Portuguese National Education Curriculum, with questions, challenges, enigmas, and problems using pathway orientation, so that students and park visitors can enjoy a pleasant walk while learning.

Urban green parks frequently attract a large number of students and teachers, as well as regular local visitors and a wide range of tourists (Ballantyne, Packer, & Hughes, 2008). Such pleasant environments have the potential to provide learning experiences about the importance of plants, habitats and their conservation, and may also influence the values, attitudes and actions of their visitors (Willison, 1997). The use of new interactive technologies in outdoor settings may provide an opportunity for students to be physically engaged in task solving (Bacca, Baldiris, Fabregat, Graf, & Kinshuk, 2014), participate in non-sedentary activities, experience biodiversity in Nature and value the protection of green spaces. This promotes an active participation of students, constructing their knowledge, as well as the development of values enhancing an authentic learning (Herrington & Parker, 2013). Several authors (Chang et al., 2010; Lee, 2012) emphasise that AR has the potential to foster learners' motivation and engagement in applying and discovering resources in the real world from a variety of perspectives. However, as the use of mobile AR technology is relatively new, there is little research in this area, particularly with the aim of promoting learning in the outdoors (FitzGerald et al., 2013). The exploration of this technology for educational purposes in the outdoors is new; hence, the novelty of the EduPARK project.

The main purpose of this paper is to present the EduPARK project's first cycle of design-based research to develop a prototype of a mobile AR game app that aims to promote learning in an urban green park. After the prototype development, 74 students (9/10 years-old and 13-14 years-old) used it *in loco* and evaluated it. The evaluation sessions aimed to collect students' perceptions regarding the app usability, their acceptance of the app and improvement suggestions, as well as some data of students' performance using the app to analyse learning promotion. The evaluation results are analysed with the aim of identifying features to improve in further versions of the app during subsequent cycles of this design-based research, until a stable, user-friendly and reliable app version is reached. Additionally, design guidelines for the development of mobile AR game app interdisciplinary outdoor learning are proposed.

The paper is structured in the following sections: (1) literature review on mobile AR and its relevance in education contexts; (2) research approach, explaining the first cycle of the design-based methodology, including a description of the app, data collection (with a questionnaire, focus groups, and the app usage data), and data analysis (descriptive statistics, computing of the System Usability Scale (SUS) score and content analysis); (3) main results presentation and discussion; and (4) conclusion, with the final remarks, design guidelines and recommendations for future work.

AUGMENTED REALITY MOBILE APPLICATIONS FOR EDUCATION

AR is a technology that allows overlying virtual objects in a real-world environment in real time, producing a new experience. According to Azuma et al. (2001, p. 34):

An AR system supplements the real world with virtual (computer-generated) objects that appear to coexist in the same space as the real world. While many researchers broaden the definition of AR beyond this vision, we define an AR system to have the following properties: combines real and virtual objects in a real environment; runs interactively, and in real time; and registers (aligns) real and virtual objects with each other.

Mobile devices are cost-effective, easy to use and the preferred way to deliver AR technology (Akçayır & Akçayır, 2017). Their increasingly proliferation makes AR technology accessible to support learning, though only in recent years have researchers been starting to define more clearly the advantages and challenges imposed by the use of AR for educational purposes (Akçayır & Akçayır, 2017; Bacca et al., 2014; Radu, 2014) and pointing out the relevance of these experiences articulated with the curriculum (Laine, 2018).

Mobile devices are frequently equipped with on-board sensors, such as a digital compass, gyroscope, accelerometer and GPS, making it possible to create location-based AR experiences that immerse students in the learning process. For example, Chiang, Yang, & Hwang (2014) used GPS, digital compass and gyroscope to guide students towards learning objects, strategically located in the outdoor environment. Additionally, the portability of smartphone and tablet devices facilitates outdoor learning activities by: (1) promoting student engagement (Dunleavy, Dede, & Mitchell, 2009; Kamarainen et al., 2013); (2) accessing, *in loco*, complementary information in different formats, such as text, sound, video (Srisuphab et al., 2014) or 3D models (Tarng & Ou, 2012); (3) allowing students to record data and observations, e.g., with annotated photographs (Chiang et al., 2014); (4) providing questions and challenges related to the outdoor setting and giving immediate formative feedback (Akçayır & Akçayır, 2017; Hwang, Wu, Chen, & Tu, 2015); and even (5) allowing the teacher to monitor the students' learning process and proposing adjustments to it (Chiang et al., 2014). These technologies can be complemented with other mobile devices that allow data collection, such as environmental probes (Kamarainen et al., 2013).

Several studies (Akçayır & Akçayır, 2017; Pérez-Sanagustín, Hernández-Leo, Santos, Kloos, & Blat, 2014; Radu, 2012) suggest that AR enhances a student's enjoyment, motivation and interest to learn. Akçayır & Akçayır (2017) highlight that this type of technology can make boring content more enjoyable and support autonomous learning with a positive effect on student motivation. Additionally, there seems to be a consensual agreement (Akçayır & Akçayır, 2017; Kamarainen et al., 2013; Radu, 2012) regarding the potential of AR to increase learning performance. As AR allows 3D visualization of phenomena or concepts, which is not possible with traditional textbooks, this technology can support student understanding of the learning content (Shelton & Hedley, 2002; Wu, Lee, Chang, & Liang, 2013). However, the multimedia material should have curricular and educational relevance (Radu, 2014).

Game-based AR experiences can also support in-field learning activities effectively, particularly in complex scenarios (Hwang et al., 2015), and make learning more enjoyable; as Freitas (2008) suggested, good games can be a great stimulator in educational environments. Games' competitive factor can make students more willing to engage in more challenging learning situations and improve the overall sense of enjoyment (Hwang et al., 2015). This technology can also promote better group collaboration (Bacca et al., 2014; Phon, Ali, & Halim, 2014). Collaborative learning allows students to actively exchange knowledge and the use of AR stimulates better collaborative behaviours (Phon et al., 2014). One of the most reported challenges associated with the educational use of AR are technical problems (Akçayır & Akçayır, 2017; Cheng & Tsai, 2013; Dunleavy et al., 2009; FitzGerald et al., 2013). Frequently mentioned technical issues are the precision errors in GPS that happen in location-based AR and cause frustration to users. An alternative to GPS, especially in indoor scenarios or where the GPS signal is not reliable, is to use tag-based technologies, such as QR codes, near-field communication or AR markers (Pérez-Sanagustín et al., 2014). Other issues have been highlighted, such as the Internet broadband coverage, the need to have charged batteries for the duration of the whole activity and screen visibility under sunny weather conditions (FitzGerald et al., 2013).

Another highly reported challenge of AR is its usability (Akçayır & Akçayır, 2017). This technology allows a high degree of user interaction; therefore, AR experiences need to be well designed to guide the students during the process. If this is not taken into consideration, students may experience difficulties and learning tasks can be excessively long.

Pedagogical challenges, such as planning experiences not driven by pedagogy, excessive focus on the technology, rather than on the learning opportunities of the outdoor environment, and focus on the technical requirements of the experience (battery charge, etc.), rather than on the learning, have also been pointed out (FitzGerald et al., 2013). Teachers' additional effort that needs to be made to plan and implement mobile AR learning experiences (Dunleavy et al., 2009) and teachers' lack of confidence in managing the required technology on their own (Kamarainen et al., 2013) are among other issues of concern.

Finnaly, social challenges need to be addressed as well, such as the inappropriate information sharing (e.g., about the users' location) or the expensive devices required for the learning experiences (FitzGerald et al., 2013).

Some mobile AR experiences for educational purposes have been made. Dunleavy et al. (2009) developed *Alien contact!*, a curriculum relevant, narrative-driven, inquiry-based AR simulation. It presents middle and high school students the scenario of aliens having landed on Earth and gives them the task of discovering why. In the process teams of students are prompted to move around a physical location to get closer to digital artefacts displayed in a virtual map – triggering video, audio, and text files – and solve interdisciplinary academic challenges. The authors reported high engagement and motivation to learn, authentic learning, development of physical space orientation skills, and distributed knowledge. The main difficulties pointed out were the GPS errors, screen visualization and audio listening in the outdoors, the high management requirements for teachers to maintain the activity flowing and strong competition between teams.

The AR butterfly ecological learning system (Tarng & Ou, 2012) allows fourth grade students to feed caterpillars and observe butterflies to learn about butterfly species, lifecycle and conservation, in a GPS triggering system in a butterfly garden, in a campus environment. The authors claim that using this system can effectively help students improve their learning.

The EcoMOBILE (Kamarainen et al., 2013) allows teams of middle school students to navigate a pond environment to collect water quality measurements with probeware and to observe AR information, GPS triggered, that supports their understanding and interpretation. The authors claim that these technologies keep the students motivated and allows them to explore the field at their own pace, freeing the teachers to act as facilitators and move around to check the progress of different groups. Among the student gains are affective and cognitive measurements; although, some educational issues were identified, particularly students' tendency to speed through the AR activity and teachers' doubts regarding their own ability to manage the technology needed.

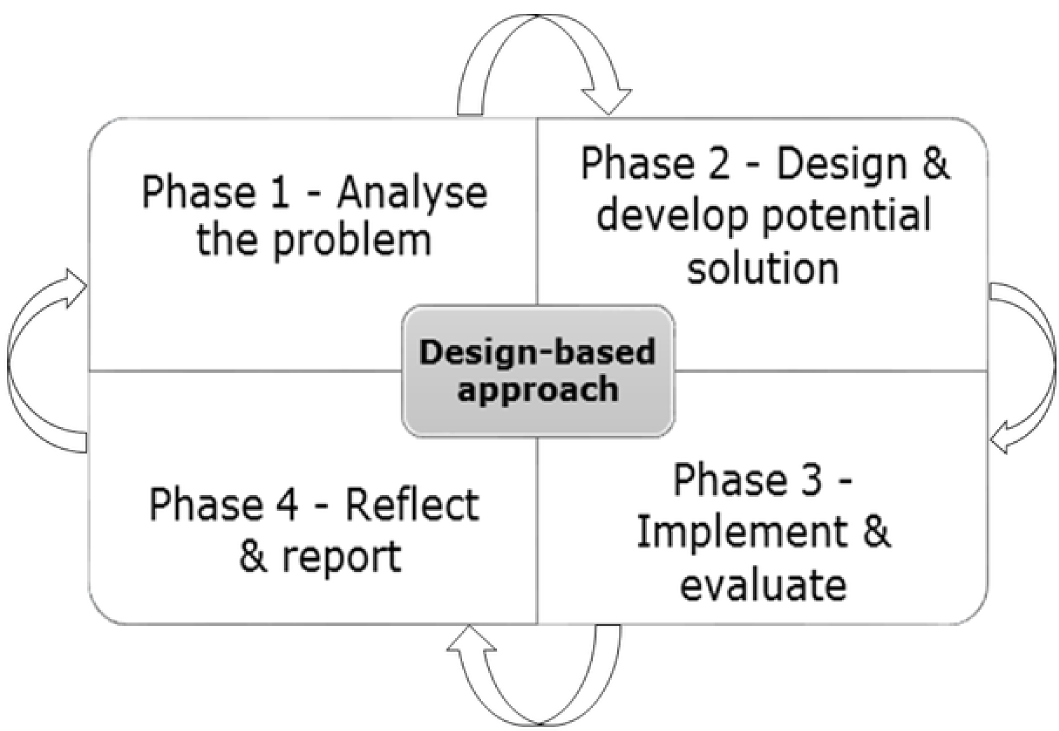
Nature AR (Alakärppä, Jaakkola, Väyrynen, & Häkkilä, 2017) is a quiz game that uses printed images and nature objects as AR markers, to provide contextual and location-specific information on those objects to pre-elementary and primary school children. The game was tested in a yard and forest setting by 11 children, who discussed in their groups the AR content and recognised the app as educational. However, they were excited with the technology and were not able to concentrate on the exploration of the physical nature items.

RESEARCH APPROACH

One of the main outcomes of the EduPARK project is a user-friendly mobile AR game app for interdisciplinary learning in an urban green park. It is being created through multiple iterations cycles for refinement and evolution of a prototype; hence, the project's methodological approach fits the design-based research, as it provides a useful framework for developing technology enhanced learning environments and improves pedagogical theory (Reevees, 2006), through, e.g., establishing design guidelines. According to Parker (2011), the strength of design-based research is its capacity to serve as a framework for combining and integrating research methods at different phases of research. The same author includes the following phases in the design-based research (Figure 1): 1 - analyse the problem and review relevant literature, as well as practitioners' experiences; 2 - design and develop potential solutions to the problem; 3 - implement and evaluate the designed solution; and 4 - reflect on the solution and on the evaluation's results and report them to the broader education community.

This paper presents the first cycle of the EduPARK project's design-based research to develop and refine a mobile AR game app that aims to promote learning in an urban green park The app prototype is evaluated through (1) the users perceptions – about its usability, acceptance and how to improve it after using the app in the Infante D. Pedro Park (Aveiro, Portugal); and (2) the users' performance using the app *in loco*. The results will be used to improve/refine the prototype in the next design-based research cycles and to propose design guidelines. Further app versions will be resubmitted to new user evaluation experiences, until a stable, user-friendly and reliable version is achieved. In this cycle, users were basic education students (9/10 years-old and 13-14 years-old) in a school visit to the selected park. Data were collected anonymously and research ethics principles were respected. The phases of the first design-based research cycle are detailed below.

Figure 1. Main phases of the design-based research approach, from Parker (2011)



Phase 1: Analyse the Problem

As stated before, the primary research focus is the design of the EduPARK mobile AR game app and its evaluation regarding usability, acceptance, how to improve it and ability to support user learning in a particular outdoor setting. Hence, the app should have educational relevance, and it was important to carefully analyse the National Curriculum (DGE, n.d.-a, n.d.-b) to identify multidisciplinary issues (e.g., integrating Biology and History) that might be explored in the selected park. The identified issues should be used to create four interdisciplinary educational guides, or quiz games, for the app. From these, three quizzes are intended for different levels of the Portuguese Education System: (1) the 1st Cycle (for 6 to 9 years-old students); (2) the 2nd (for 10 and 11 years-old students) and 3rd Cycles (for 12 to 14 years-old students) of Basic Education; (3) the Secondary (for 15 to 18 years-old students) and Higher Education; and (4) one quiz is intended for any ordinary citizen visiting the park. For the app prototype development, the project team decided to develop just two quiz-based educational guides: for the 1st and the 3rd Cycles of Basic Education. These two educational guides should be refined in further cycles and the other two guides should be created in further cycles of the app development.

The "Infante D. Pedro" Park, located in the urban area of the city of Aveiro (Portugal), was the selected outdoor setting for the development of the EduPARK app. Created in 1862, this park is currently a large green area, with a lake with reasonable dimensions, and integrates harmoniously biological and historical points of interest. Additionally, the park's origins had implications on its fauna and flora biodiversity, which includes about 70 native and exotic species of trees and bushes (Pinho & Lopes, 2007), diverse birds and invertebrate species and even fish and turtles. The park has an important educational potential, not only for academic education in several subject areas (from basic to higher education), but also for the general public and tourists. From an analysis of the park's patrimony, several teaching and learning opportunities have emerged and were explored in the educational guides. Additionally, the park spaces, which have physical barriers around most of their perimeters, are well defined safe environments for children to have mobile AR gaming experiences. This is an example of a truly authentic context for situated learning, where the location is essential for the learning (Laine, 2018). The inspiration for the EduPARK mascot (see screens b and c in Figure 2) was the park's informal name: "Monkey's park". That name's origin is linked to a female monkey that lived in a cage in the park, for several decades. The mascot is being used in the app to guide the players and give them immediate formative feedback after answering; e.g., when an incorrect answer is given, the mascot explains the right answer.

From the above analysis, a few main guidelines emerged for the EduPARK app: (1) it should promote learning contextualized in the park, e.g., related with the botanical species or with the historical monuments in the park; (2) it should promote interdisciplinary learning, e.g., using flowers to teach about symmetry axis; (3) it should be used in groups of users, so the app's educational challenges can promote collaborative discussion of ideas; (4) it should be successfully used either in formal (school visits to the park), non-formal (e.g., in environmental education sessions of app use promoted by the local City Council) or informal learning contexts (e.g., a family visiting the park explores it through one of its games/educational guides); (5) it should be user-friendly, so users, even children in the 1st cycle of education, can use it without support of the EduPARK team.

As the park does not have free internet coverage and not all Portuguese mobile device owners have a strong internet coverage service, the team decided to develop the app for offline use. The only requirement for having a mobile device with a fully functional EduPARK app, in an offline mode, should be to download the app and its educational guides before going to the park to use it. Moreover, as the project planned to promote school visits and other activities in the park for app test and exploration, the project acquired a set of smartphones to lend to the project's activity participants.

Phase 2: Design and Develop a Potential Solution

This phase was devoted to the design of the first educational guides as well as the EduPARK app. A multidisciplinary team created the first prototype and the guides: two biologists, three Science

Education researchers, three technology researchers and one practitioner. The aim was to integrate multidisciplinary content, educational issues and the technological features of the app. The guides for the 1st and 3rd Cycles were designed as a game combining geocaching principles (the search for and location of three physical caches in the Park), collaborative strategies combined with a friendly competition approach.

The mobile application, for Android devices, was developed using Unity 5, a popular cross-platform game engine (Unity Technologies, 2017). As for the AR marker detection we used the Vuforia SDK for Unity, since Vuforia is currently the most widely adopted platform for AR technology (PTC, 2016).

The EduPARK app prototype allows users to play a quiz. The prototype's basic structure and functionalities are described below and summarized from Figure 2 to Figure 7.

Initially, the players are welcomed with a short explanation of the app: it includes collaborative game quizzes with challenges of searching for caches in the park (screens a and b in Figure 2). Treasure hunts and quizzes seem to be a popular AR game type reported in the literature (Laine, 2018). In this prototype, players are also prompted to name their team and select an educational guide: 1st or 3rd Cycle (screen c in Figure 2). Overall, the game prompts the groups of students to go to specific park locations and find an AR marker or a cache with a marker inside. Examples are shown in Figure 3. Each marker consists of a square image with the mascot and a flowered frame for each location point. The option of using camera detected markers for AR rendering is frequent in the literature (Laine, 2018).

An initial mandatory tutorial explains to the players how to use the camera tool to recognize an AR marker. Players will find a different marker in each location of interest, e.g., a specific botanical species with information about its uses in medicine. Each marker unlocks the access to information relevant to answering a series of questions related to that specific location. The game is organized in the following loop (Figure 4): (1) the app gives players instructions to find a specific marker (screen e); (2) the players point the camera tool at the marker and allow it to recognize the prompted marker (screen f); (3) the app presents a set of multiple-choice questions, with associated content - text, audio or image (screens g and h) – that players need to answer; and (4) the app gives feedback to answers and awards points, for each correct answer (screen i).

The app also provides additional information to the players on the main screen (see screen e). Besides the instructions to locate the next marker, the top of that screen displays relevant information about the team's current progress: the number of answered questions, accumulated points, visited locations, and reached caches (Figure 5). This information is updated throughout the game and thus offers the players a sense of their progress.

The app integrates several tools (Figure 6): (1) backpack (screen j), a place to store and visualize photographs taken during the game; (2) camera (screen k), a tool to recognise the AR markers and to

Figure 2. EduPARK app's initial set of screens

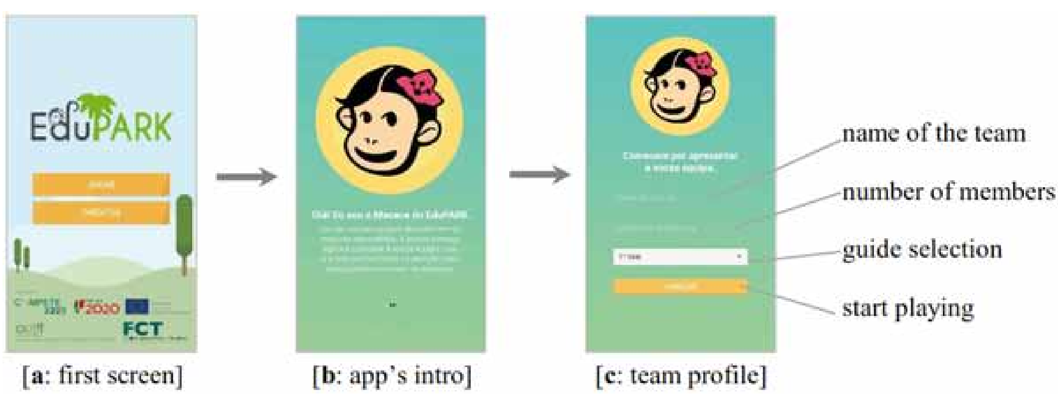


Figure 3. Example of an AR marker (left) and a cache (right)

Figure 4. EduPARK game loop

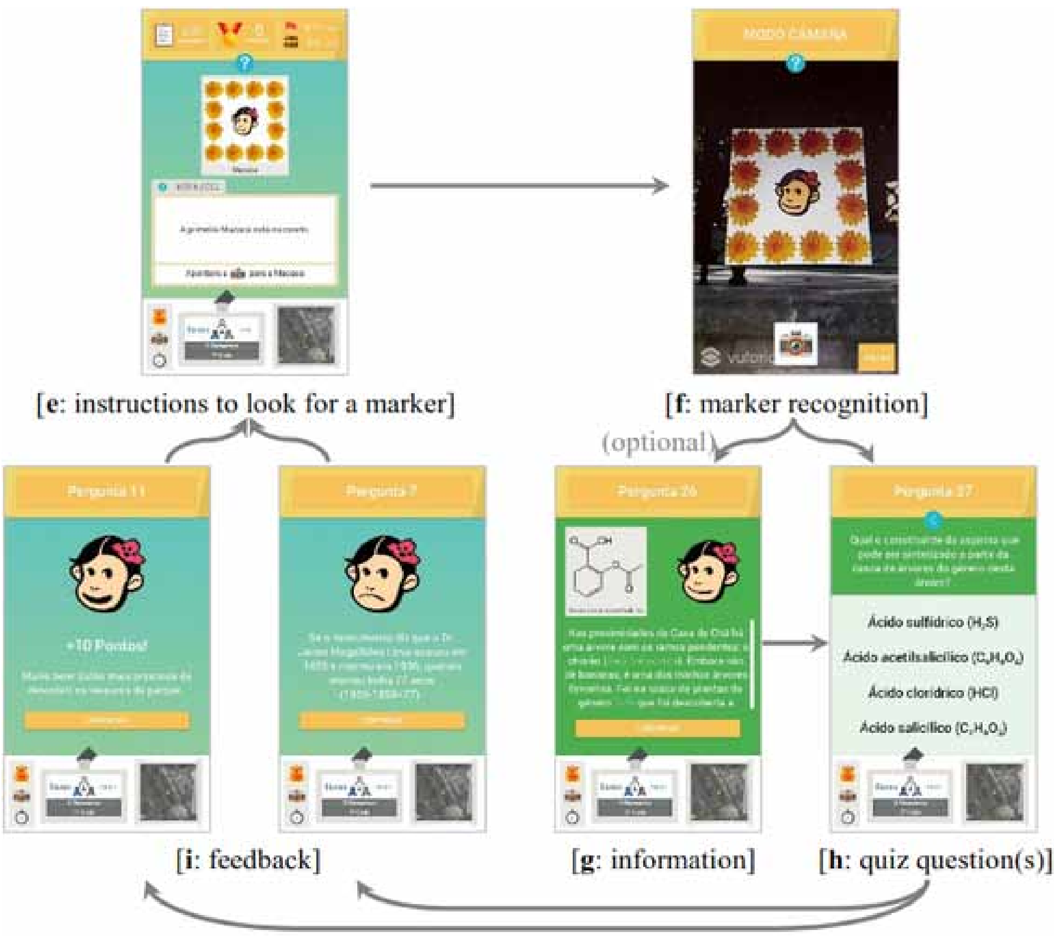
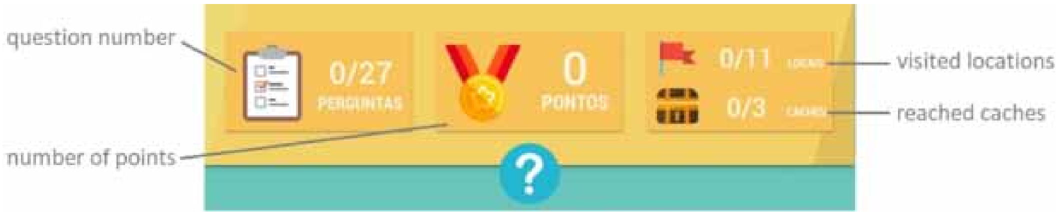


Figure 5. EduPARK app's feedback on progression along the game



take photographs; (3) compass (screen m), a tool that supports orientation in the park based on the display of the direction of magnetic north ; and (4) park map (screen n) that also supports orientation in the park, as it shows the players' location (a yellow dot) as well as the next game location (flag icon) or cache (treasure icon). The map tool uses the device's GPS data; however, as reported by some authors (Akçayır & Akçayır, 2017; Cheng & Tsai, 2013), GPS accuracy does not allow for an efficient navigation through the park using only this tool and, thus, written instructions for reaching the next location are provided.

At any time, the players can access help screens by pressing the blue help button (see screens o and p in Figure 7) and navigate through all the other help screens, with the two blue lateral navigation arrows.

Finally, the last screen of the game shows the overall performance of the team: the total number of points, the number of correct and wrong answers, as well as the time taken to complete the game.

Figure 6. EduPARK app's tools

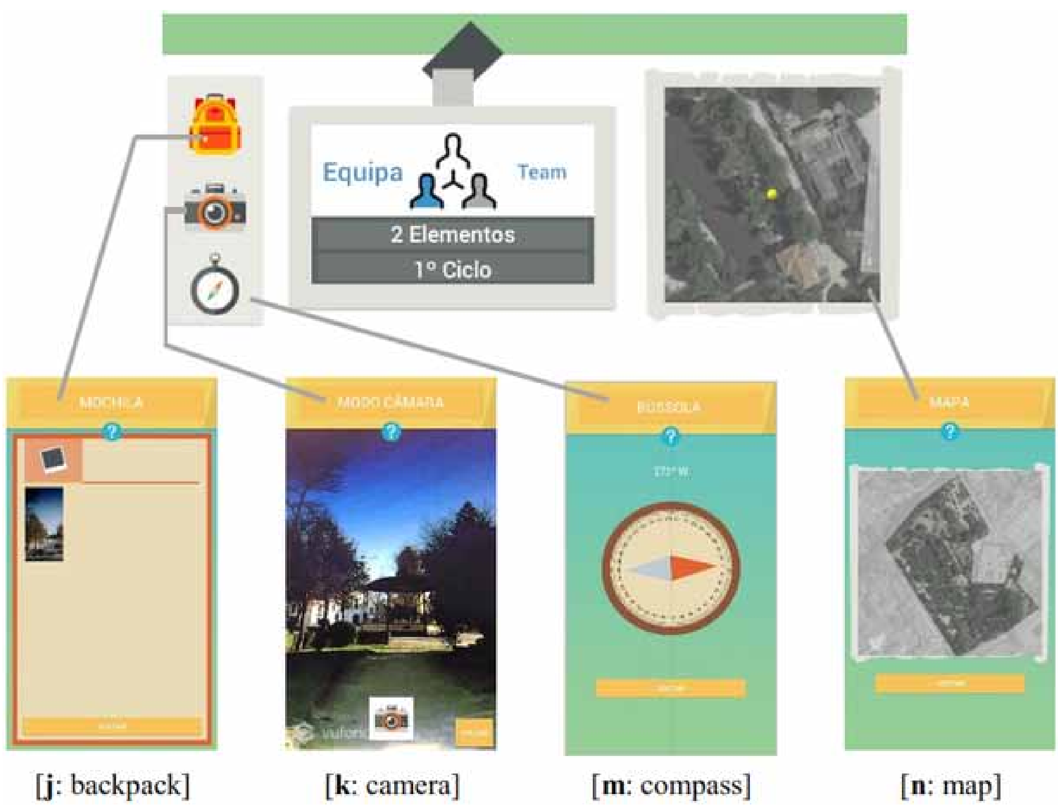


Figure 7. Examples of EduPARK app's help screens

[**o**: main menu's help] [**p**: compass' help]

If several teams are playing simultaneously (as, e.g., an entire classroom), and each team uses a smartphone, this information can be used to define the winner team as the one with the higher number of points. Time is used as a tie-breaker factor. Figure 8 shows an example of game screen.

Phase 3: Implement and Evaluate

The developed EduPARK app prototype was tested during the Open Week of Science and Technology of the University of Aveiro, and its main goal was to evaluate the app prototype's (1) usability, accordingly to a Portuguese version of Brooke's System Usability Scale (SUS); (2) acceptance, in terms of students' self-report of their enjoyment with the app, its ease of use, and learning promotion; and 3) ability to support learning in the outdoors, as hinted by the players' performance (app usage data) when using it.

During the Open Week the University organizes diverse outreach activities for the community. The EduPARK team proposed to run three sessions of activities in the selected park for Basic Education (BE) students (see Table 1). The app was used by three groups: two of the 1st Cycle of BE, each with 26 students with an average age of 9 and one with 22 students with an average of almost 13 years. They were accompanied by their teachers and came from two schools neighbouring the selected park. This formal education context of technology evaluation the outdoor setting, instead of in classroom environment, is not frequent in the literature (Laine, 2018).

At the beginning of each session, the students were briefed regarding the aim of the session, evaluating the EduPARK app, and how the app functioned. They were grouped by their teachers in teams of three or four students. Each team was assigned to an adult monitor, for safety reasons. Teams of students used one of the project's smartphones, which had the EduPARK app with the educational

Figure 8. An example of the EduPARK app last game screen

Table 1. Characterization of the classes involved in the experience

Group	Cycle of Education	N. of Students	Average Age	% of Female
G1	1st	26	9.0	69.2
G2	1st	26	9.0	50.0
G3	3rd	22	12.9	31.8

guides. Having just one smartphone per team promoted collaborative work, as students were prompted to decide together where to go and what to do and the devices rotated amongst students in a group.

The students used the app and educational guide suited for their school level during 30 minutes to 1 hour, approximately. At the end of each session students were asked to fill in a questionnaire with closed questions: multi-choice, item selection and 1 to 5 Likert scale. All students but two returned the questionnaire; so, the total number of analysed questionnaires was 72. The questionnaire comprised two parts. The first one was about the students' profile to collect basic demographic data (such as age and gender, used to produce Table 1, presented above), as well as information about the students' profile as mobile devices users. The second part of the questionnaire was about the perceived usability of the app and it was based on the "European Portuguese Validation of the System Usability Scale (SUS)" by Martins, Rosa, Queirós, Silva and Rocha (2015), which was a work that translated and validated the original instrument (Brooke, 1996) for the Portuguese language. The SUS is a robust, effective and inexpensive tool that has been widely used for assessing the usability of a system, such as websites or mobile phones (Bangor, Kortum, & Miller, 2009). Sauro (2011) reviewed 500 studies and found out that a SUS score of 68 could be considered average. Furthermore, Bangor et al. (2009) empirically defined a qualitative classification values based on the SUS values. The information collected with the second part of the questionnaire was used to compute SUS scores, between 0 and 100, according to Brooke (1996). Bangor et al. (2009)'s qualitative classification was used to interpret the results.

To complement the questionnaire, and for convenience, two facilitators conducted simultaneously two focus groups per class. The focus groups were recorded *in loco* and their duration varied from about 8 to 21 minutes, with an average of 15 minutes. Two focus groups had 11 students (3rd cycle) and four had 13 students (1st cycle). Focus groups have long been recognized as useful tools for pilot tests in educational research, as they allow participants to explain their experience in depth (Williams & Katz, 2001). The focus group comprised two parts: the first part was about the app and the second part was about the activity of using this app in the park to learn. This paper will focus only on the first part of the focus group. Questions prompted students to express: (1) their opinion concerning enjoyment and ease of the app use, and (2) improvement suggestions regarding the app interface and navigation, among other aspects. Although it was not asked directly, the app's ability to promote learning emerged in focus group data. As recommended in the literature (Williams & Katz, 2001), the facilitators paid attention to the number of questions and used language suited to participants' young age. The recorded focus groups were transcribed and were submitted to content analysis (Williams & Katz, 2001). In this process, the categories emerged from the empirical data to make an inventory of relevant topics regarding students' perceptions of the app.

To determine the app's ability to support learning, the students' performance using it *in loco* was analysed, so game results (scores, number of correct and wrong answers, and time) were also collected directly by the app, in an anonymous way. Data from the app and other data (not SUS related) from the questionnaires were analysed through descriptive statistics.

Those three sets of collected data were triangulated in order to provide a comprehensive knowledge of the students' perceptions regarding the app. This analysis will be presented in the next section. The overall lessons learned will be used to improve the development of the future app version and guides, in further cycles of this design-based research and to propose design guidelines.

Phase 4: Reflect and Report

The final phase aims to identify and discuss positive and negative aspects, as well as enhancement suggestions emerging from the empirical data. The data triangulation will be presented and discussed in the following section.

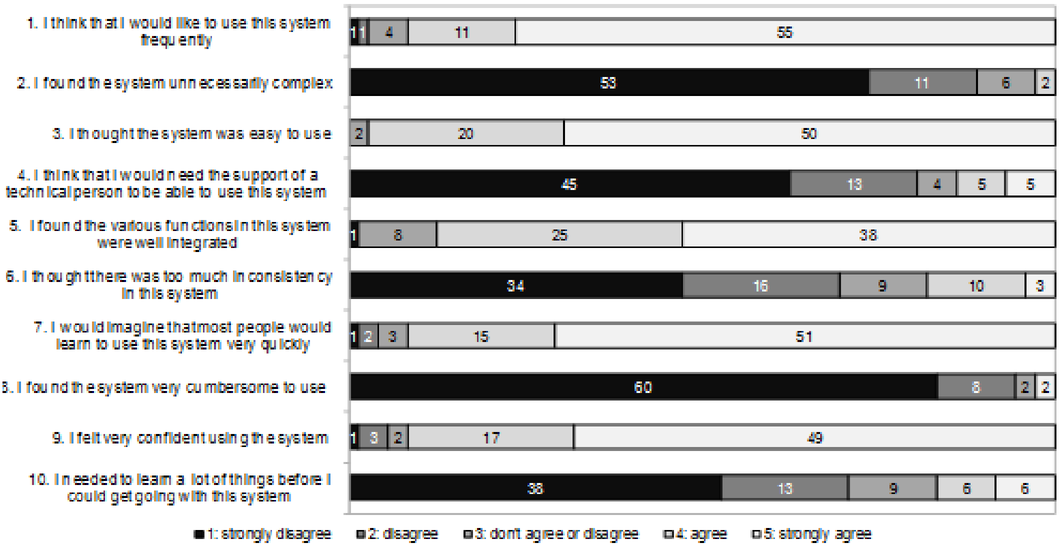
RESULTS AND DISCUSSION

The collected data allowed profiling the users' regarding their mobile device proficiency. From the total number of questionnaires (72), 68% of students claimed to own a personal mobile phone, half of those are smartphones, and use it for about 35 minutes per day. These results indicate mobile devices are indeed familiar to this cohort of young students and support the literature, regarding the proliferation of these technologies (Johnson et al., 2013; Johnson, Adams, & Cummins, 2012; Johnson, Adams, & Haywood, 2011; Johnson, Becker, Estrada, & Freeman, 2014), especially in what concerns the young population.

Additionally, students indicated that they use mobile phones mainly for gaming (41 students), watching videos (39 students), and listening to music (36 students), but not for learning purposes. These results seem to be similar to the findings of Sozio et al's. (2015) study, reporting that Portuguese students use mobiles for visiting social networking sites, watching video clips, and instant messaging, but, again, not for learning purposes.

Figure 9 shows students' overall perception of the EDUPARK app's usability. Most students strongly agreed (option 5 of the scale) with the positive statements (odd-numbered items) of the SUS scale and strongly disagreed with the negative ones (even-numbered items), indicating an overall positive perception regarding the prototype's usability.

Figure 9. Questionnaire data: Part 2 - usability of the EduPARK app



To confirm that perception, the SUS score was computed for each student and, then, an average value was computed for the 72 questionnaires. Values ranged from 55 to 100, with an average of 85.6, which is considerably higher than Sauro's (2011) average value of 68. Moreover, according to Bangor et al.'s (2009) classification, the EduPARK app's usability is considered excellent.

Regarding students' acceptance of the app, overall, they reported feeling enjoyment after using it, as revealed in following quotation: "I liked it [the EduPARK app] because I got to know things about the park that I did not know" (G2 student). This may be linked to the fact that students found the app simple and easy to use: "It was very clear what we had to do and the options we had to select were very visible; it was easy to use!" (G3 student). It is possible that the excellent usability of the app, thus being user friendly, contributes for these positive perceptions. These results are in line with the literature that claims that student engagement and motivation to learn can be promoted by the use of games (Freitas, 2008), supported by mobile (Kamarainen et al., 2013) and AR technologies (Akçayır & Akçayır, 2017; Dunleavy et al., 2009; Pérez-Sanagustín et al., 2014; Radu, 2014).

Additionally, students considered the app a resource that promotes learning in outdoor environments, as shown by the following quotation: "I think that what is fun is the fact that the app use involves nature and walking in the park." (G3 student). This activity moves learning to contexts outside the classroom, which is appreciated by students: "I liked the activity because we were outside and not closed in a classroom". Moreover, occurring in a green area, it may promote the establishment of relationships between some school concepts and real-life situations, as a G3 student pointed out: "… the topics we learnt so far [in the school] fit in the questions [of the app]." Hence, the educational guides in the app fit properly the national curriculum, as advised by Radu (2014) and (Laine, 2018).

Another aspect valued by the students was the collaboration among team members, and supports the EduPARK project option of giving one mobile device per team. This is in line with Bacca et al. (2014) and Phon et al. (2014), who claimed that digital games based on AR technology can promote group collaboration. Group collaboration may enhance interaction among students regarding information and challenges (Marques, Loureiro, & Marques, 2015).

Students seem to value the app's immediate feedback, as shown by the following statement: "The feedback was good for us to learn better." (G2 student). This feature is also pointed out as pertinent by the literature, as it provides timely and relevant information that can guide students in their learning tasks (Hwang et al., 2015) and may increase their motivation to learn (Akçayır & Akçayır, 2017). The information provided through the immediate feedback supports autonomous learning. In the absence of such feedback, this cohort of students would probably focus on ending the game faster to reach the first place and getting the best score, ignoring new learning information provided by the app.

The results also pointed out that this app may support students' motivation for learning: "I liked [this app] because we learn while we are having fun." (G3 student). Huizenga et al. (2009) indicate that seven factors trigger intrinsic motivation for learning in the use of digital games: challenges, curiosity, competition, cooperation, recognition, control and fantasy. Some of those factors were found in the results, as illustrated by the following statements: "For ranking the time was also considered, which promoted more competition" (G2 student) – for competition; "The monkey could speak" (G3 student) and "… has clothes" (G2 student) – for fantasy; "More people in the team would be better … maybe four" (G2 student) – for cooperation; "I liked if more caches were like the last one, which was really difficult to find" (G1 student) – for challenges.

To stimulate discussion about how to improve the prototype, students were asked if the app had many inconsistencies and most of them disagreed (16) or strongly disagreed (34) (see Figure 9, statement 6). Nevertheless, they were able to point out some negative aspects of the app. For example, a G1 student claimed: "It wasn't easy to understand how to explore the map". In fact, as the map tool was programmed to reveal the players' location in the park in real time using GPS signal; however, this feature was problematic due to weak GPS signal in the park and to GPS precision errors. From the literature (Akçayır & Akçayır, 2017; Cheng & Tsai, 2013), GPS precision errors in location-based AR technology are common. An alternative, in particular where GPS signal is not reliable, is the use of AR markers (Pérez-Sanagustín et al., 2014), which was the EduPARK team option. In the literature, Akçayır & Akçayır (2017) advocated the use of such markers to guide the students learning.

Finally, students were asked to actually propose suggestions for app improvement, as stated: (1) "… It would be better if the app had videos with people speaking, instead of having text to read." (G3 student), which is in line with Srisuphab et al. (2014), who mentioned that information in AR mobile apps should be presented in different formats, such as text, sound, and video; (2) "The monkey mascot should move, as in an animation." (G3 student); as stated by Kamarainen et al. (2013), this kind of animation seems to promote students' engagement; (3) "I think the app should be available in Google Play." (G3 student), indicating that this educational resource might be so relevant that everyone should have access to it. The mentioned suggestions will be considered in future cycles of the EduPARK design-based research.

To analyse the app learning support in the selected park, and also to enable improvements, the app automatically logged in an anonymous way the game results of each team.

Table 2 and 3 show students' performance using the app through the final game results of the teams from Groups 1 and 2 (1st cycle of Basic Education) and from Group 3 (3rd cycle of Basic Education), respectively.

All teams completed the game fairly easily, with an average of 23 correct answers out of 27, for Groups 1 and 2, and 30 correct answers out of 34, for Group 3. These results indicate students had a good performance with the app and point out that the app supports learning tool, as intended and recognized by the students that used the app, but further studies need to be carried out to empirically study this feature in depth. In both cases, Groups 1 and 2, some questions were answered incorrectly by about half of the teams. In future versions of the guides, those questions will be revised and, eventually, linked to additional multimedia content, such as videos or 3D visualizations.

Although, students from Groups 1 and 2 had fewer questions to answer (27), when compared to students from Group 3 (34), they took more time to complete the game, with an average of 51 minutes versus 34 minutes. These results may be explained by the fact that students from lower grades need more time to read and comprehend textual content. Further versions of the app guides should rely less on text to present information and use more visual, audio and interactive contents, especially for students from that age range.

In the following section final considerations will be pointed out, as well as future work.

Table 2. Game results of Groups 1 and 2 (1st cycle of basic education)

Group	Team	Time	Score	Correct Answers	Wrong Answers
G1	1	00:51:22	250	25	2
	2	00:49:38	210	21	6
	3	00:44:28	250	25	2
	4	00:50:05	210	21	6
	5	00:48:37	220	22	5
	6	00:59:03	260	26	1
	7	00:54:21	180	18	9
G2	1	01:09:34	190	19	8
	2	00:54:52	250	25	2
	3	00:39:33	250	25	2
	4	00:48:28	240	24	3
	5	00:50:34	240	24	3
	6	00:39:59	250	25	2
	7	00:57:18	210	21	6
	8	01:06:14	230	23	4

Table 3. Game results of Group 3 (3rd cycle of basic education)

Group	Team	Time	Score	Correct Answers	Wrong Answers
G3	1	00:35:48	290	29	5
	2	00:33:45	280	28	6
	3	00:33:16	320	32	2
	4	00:37:17	330	33	1
	5	00:34:39	320	32	2
	6	00:34:32	270	27	7
	7	00:32:55	310	31	3

CONCLUSION

This work allowed the authors to reflect on the results of an evaluation of the first prototype of the EduPARK mobile AR game app with students using it for learning in an urban green park. The methodological option revealed to be adequate for the purpose of developing and improving an innovative learning product, as the students' perspectives allowed to identify a set of issues to revise in further app versions and are crucial in this process. However, the authors are considering, in future work, the triangulation of other stakeholders, such as teachers and monitors (people who accompanied the groups in the activities), as well as external consultants.

The main results of our work are the positive perception of this cohort of students regarding the EduPARK app usability, more specifically, it can be classified as an excellent usability, according to

Bangor et al. (2009), with an average SUS of 85.6. Moreover, students' acceptance of this app was clear, as they reported feeling enjoyment with its use, found it easy to use and recognized it as an outdoor learning resource that is curriculum articulated, promotes collaboration, provides immediate feedback and enhances their motivation for learning.

The positive perception of the EduPARK app comes from a cohort of students that reported being familiar with mobile phone technologies. Lower usability results would probably be found if students were not familiar with mobile technologies, and, in that case, more scaffolding regarding the use of these devices would be needed. Nevertheless, mobiles technologies' pervasiveness in modern societies (Sozio et al., 2015) makes this scaffolding unnecessary. Moreover, this group of students seems to be accustomed to use mobile phones for leisure purposes, such as gaming, but not for learning. Therefore, and considering this work results, linking learning with pleasant activities seems carry motivational advantages. Apps like the one presented in this paper may promote mentalities change regarding the use of mobile devices to learn, the use of games to learn and the use of a combination of both to learn. In what concerns improving the app prototype in further design-based cycles of this research approach, students reported inconsistencies regarding three main aspects: (1) lack of clearness regarding the purpose of the map; (2) the GPS weak signal and precision errors; and (3) difficulties in the use of some AR markers. All those aspects are related with geo-orientation. Such technical problems, in particular with GPS for location-based AR applications, are widely reported in other studies (Akçayır & Akçayır, 2017; Cheng & Tsai, 2013). Geo-orientation must be submitted to careful consideration in outdoor learning activities, so it will not hinder the progression in the game and, consequently, create frustration in players.

This work results sustain the proposal of a set of empirically validated design guidelines for mobile AR games aiming outdoor learning, thus contributing to the specialised literature. These games should be sustained by simple and easy to use technologies. Our results – high SUS score, reported enjoyment and acknowledgement of the app as easy to use – revealed it is important to carefully consider this issue, so weak usability does not demotivate users from playing the game. The AR usability challenge has been pointed before in the literature (Akçayır & Akçayır, 2017). The games should be educationally relevant. As recommended by the literature (Laine, 2018; Radu, 2014) and pointed by the participants students, it is important the app helps them learn or recall content they are studying in their regular classrooms. Also, games should include features that literature points out as effectively sustaining learning. For instance, the immediate formative feedback is a crucial aspect for learning purposes (Akçayır & Akçayır, 2017), and should be included in this kind of educational resource. Moreover, despite mobile devices being perceived as individual tools, collaborative learning tasks are possible and recommended (Bacca et al., 2014; Dunleavy et al., 2009; Kamarainen et al., 2013; Phon et al., 2014). In this work, the fact that students played in teams allowed them to discuss ideas, collaborate and negotiate to overcome the proposed challenges. Another recommendation emergent from this work is to involve app end users in its evaluation, as they provide valuable information for further refinement.

In summary, the participant students collected perceptions revealed that the EduPARK app prototype is an innovative learning tool that (1) is easy to explore by young students, (2) integrates interdisciplinary and curriculum articulated educational materials – the guides or quiz games, (3) is interactive and enjoyable, (4) includes geocaching-based learning in outdoor environments, and (5) promotes contextualized learning in an urban green park, the Infante D. Pedro Park. This last quality of the app takes advantage of a specific physical context as a facilitator of learning, as recommended by Laine (2018). Moreover, another of the app's unique features, considering the analysed literature, is its flexibility to integrate several educational guides for different school levels. In the future, new educational guides will be developed, for different levels, from basic to higher education, and for lifelong learning as well. This is new in the mobile AR games literature, as most reported cases in Education have been created for young children (idem, ibiden).

It is important to highlight that this was a preliminary experience in the first stage of the EduPARK project. However, it allowed collecting rich data, not only from the students' perceptions, but also from the authors' reflection, and future work will take into account both aspects. Future work will involve overcoming some challenges, such as the usability of the EduPARK app in a wide typology of mobile devices, as the described activities were supported by the project's smartphones. Another challenge is related with the adaptation of data collection tools to the different types of users of the app, as younger users might feel some difficulties in their interpretation.

As final remarks, the reported work is relevant not only for educators, who may take advantage of the developed resources to promote learning, but also to app designers, as this paper presents valuable contributions for those who are in charge of creating this kind of educational resources. There are also useful contributions for researchers interested in studying the use of games to promote learning in outdoor settings.

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