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EmoFindAR: Evaluation of a mobile multiplayer augmented reality game for primary school children

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ABSTRACT

Games are powerful generators of positive emotions in children and are intrinsically satisfying. In this context, our work evaluates the use of mobile augmented reality without markers as the technology to implement a multiplayer game scenario that can be used to improve socialization, communication skills and emotional intelligence in primary school children. The present study addresses the usability of two gameplay styles and their impact on users' communication and motivation: competitive vs collaborative play. The game integrates Mobile Augmented Reality (MAR) technology without markers to create a geolocation scenario with unlimited physical space. The results indicate that both game modes are intrinsically satisfactory for children triggering positive emotions such as enthusiasm, enjoyment and curiosity that improve the participants' mood and help increase the degree of involvement. Moreover, we observed that the collaborative game version has a greater impact on emotional affection, social interaction and interest. In addition, we observed in our study that the quality of the communication in the collaborative mode is good in terms of several factors such as sustaining mutual understanding, dialogue management, information pooling, reaching consensus, time management and reciprocal interaction. Finally, several design implications and suggestions related to game time management, scaffolding, mixed competitive-collaborative modes, dynamic 3D content and active learning, among others, are discussed. The present evaluation contributes to the identification of the most relevant aspects to be considered in the future design of MAR-based gamification strategies in education.

1. Introduction

Collaboration in the classroom has become a popular research topic since it allows students to get involved in group activities that not only increase learning, but also produce other benefits, such as the development of relationships and social skills (Garcia, Jurdi, Jaen, & Nacher, 2018). The importance of collaboration has already been demonstrated in prior research (Laal & Ghodsi, 2012), who organize the benefits of collaborative learning in four categories: social, psychological, academic and assessment. Collaborative learning also contributes to building more positive heterogeneous relationships and encouraging diversity understanding (Swing & Peterson, 1982). In addition, advocates of collaborative learning claim that the active exchange of ideas in this type of learning not only increases interest among the participants but also promotes critical thinking (Gokhale, 1995). In fact, collaboration has been

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identified as a key 21st century skill that is included in most current educational models (Garcia et al., 2018).

Gamification, one of the most frequently used pedagogical strategies, promotes the use of game elements and game design principles, to improve the commitment and motivation of the participants in an activity that is usually carried out without play (Nah, Zeng, Telaprolu, Ayyappa, & Eschenbrenner, 2014, pp. 401–409). As defined by Deterding and his team (Deterding, Dixon, Khaled, & Nacke, 2011), gamification refers to the "use of design elements characteristic of games in non-game contexts". This strategy brings several benefits in learning contexts such as: being able to create a pleasant learning environment, ensure active participation and increase performance (Garcia et al., 2018).

In the past, the most popular gaming technologies for educational purposes have been traditional video consoles and desktop or laptop computers. These platforms, however, present several disadvantages for children, for example, they require users to stay in one place, which prevents them from moving and exercising; and most of them are for single-users, which complicates the design of activities to promote social skills and cooperation (Garcia et al., 2018).

However, the affordability and common use of devices such as smartphones or tablets have recently made them alternatives to support the construction of positive social spaces for collaborative learning by means of games. In addition, if the devices are scattered over a large area, physical activity, a key factor in children's development, can be encouraged (Garcia et al., 2018).

Currently, smartphones or tablets use various technologies such as image recognition, object tracking and sensors to measure location and orientation, allowing compatibility with other emerging and innovative technologies, including Augmented Reality (AR), which in this context becomes Mobile Augmented Reality (MAR).

MAR is defined as augmented reality generated and rendered with mobile devices in mobile environments, addressing a wide range of application areas, one being video games, such as the popular Pokemon Go (Paavilainen et al., 2017; Ruiz-Ariza, Casuso, Suarez-Manzano, & Martínez-López, 2018). These games are created for the specific purposes of competition, however, a challenge that is currently being addressed is the cooperative use of this technology in education to create "multipersonal" augmented reality spaces involving several users interacting with the same virtual objects at the same time (Phon, Ali, & Halim, 2014). This approach can be very useful and interesting in multiplayer games that seek to foment socializing activities, communication and collaboration (McNaughton, Rosedale, Jesson, Hoda, & Teng, 2018).

In this context, our work evaluates the use of MAR without markers as the technology to implement a multiplayer game scenario in the context of primary school children. The present study addresses the usability of two gameplay styles and their impact on users' communication and motivation: competitive vs collaborative play. The game integrates MAR technology without markers to create a geolocation scenario with unlimited physical space. The present evaluation contributes to the identification of the most relevant aspects to be considered in the future design of MAR-based gamification strategies in education.

2. Related works

MAR applications are an emerging and promising technology that is currently revolutionizing educational processes at all levels from pre-school to university (Akçayır & Akçayır, 2017). Currently, a great number of applications exist that are focused on college students such as Anatomy 4D (Walker, McMahon, Rosenblatt, & Arner, 2017) and Sky Map (Agrawal, Kulkarni, Joshi, & Tiku, 2015), which provide students with information to support and enrich the learning process in specific fields such as anatomy, astronomy, etc. In the educational context there are also applications designed for younger students: Ibáñez and Delgado-Kloos (Ibáñez & Delgado-Kloos, 2018) analyzes several works related to STEM learning with AR, Arloon Geometry (Pinto, 2015), which allows young children to become familiar with geometric shapes and AR Flashcards (Walker et al., 2017) for early learning of letters, addition, shapes, colors, and planets. All these applications highlight MAR's educational benefits as they awaken interest, increase motivation and, most importantly, capture the students' attention, especially in primary schools, which are key elements in improving learning processes. However, none of the previous works have emotions and emotional intelligence learning as the focus of interest. Recognizing basic emotions and performing actions based on the skills defined by Mayer and others (Mayer, Caruso, & Salovey, 1999) are important processes that have to be learned and practised. We therefore find emotional intelligence to be an important area in which multi-user MAR scenarios could be implemented.

In addition to MAR's educational uses, there are also works that focus on entertainment such as: Chromville (Mota, Ruiz-Rube, Dodero, & Figueiredo, 2016), which allows users to experience how their colored drawings come to life, Peronio Pop-Up Book (ThinkMobiles, 2018), an interactive book featuring an adventurous child facing challenges, and Quiver (Mota et al., 2016), based on interactive tabs that show 3D drawings with which children can interact. These apps motivate the youngest to play but are limited by being designed for individual scenarios (single-user), preventing peer interactions and the practice of social skills.

Although there are also MAR applications that incorporate multi-user game dynamics at different educational levels (Fidan & Tuncel, 2019), in primary education there are fewer experiences (Ibáñez & Delgado-Kloos, 2018; Vladimirovna, 2016; Walker et al., 2017), despite it favoring competitive and collaborative scenarios that encourage young students to learn. One example is WallaMe (Vladimirovna, 2016), which allows users to leave hidden messages in diverse places of the world to be read by other users. However, there is no evidence that it improves children's peer interaction and socialization.

In this category, we also find gaming initiatives that are specifically designed to create competitive environments, e.g. the Nightenfell app (ThinkMobiles, 2018), a multi-player game in which augmented reality is used to interact with elements of a fantasy world full of shots, kites, spells and enigmas, where users struggle to reach the highest game levels. Unlike the most popular competitive dynamics, collaboration has received less attention as a learning strategy in MAR games. Collaboration is present in games such as Ingress (ThinkMobiles, 2018), the predecessor of the well-known Pokemon Go (ThinkMobiles, 2018), which creates problem-solving environments, an area of crucial interest that stimulates coordination, planning and interaction for children to promote communication and cooperation skills. Given this duality in terms of the possible game modalities that can be implemented, we consider that it is relevant to analyze how children perceive them.

Finally, although examples such as WallaMe, Nightenfell, Pokemon Go and Ingress, use competition or collaboration game dynamics, their impact on peer communications has not been evaluated in primary school children.

2.1. Research questions

In the context of the previous related works, three research questions are addressed in our work:

- RQ-A: Can multi-user MAR gamification activities favor the expression and identification of basic emotions in primary school children?
- RQ-B: How do children perceive the use of a multi-user MAR game in both competitive and collaborative modes?
- RQ-C: What is the impact of competitive and collaborative gamification on coordination and communication among primary school children?

To address these research questions and to gain further insight into the way children communicate when using MAR systems, the present work evaluates its use in a multi-user serious learning scenario. It not only measures the impact of MAR on how primary school children communicate and interact with each other using both collaboration and competition as alternative gamification strategies, but also proposes future lines of work in this emerging area.

3. EmoFindAR

EmoFindAR is a multiplayer MAR game that allows primary school children to recognize basic emotions and perform actions based on the skills defined by Mayer and others (Mayer et al., 1999) related to the perception, assimilation, understanding and regulation of emotions (Yadegaridehkordi, Noor, Ayub, Affal, & Hussin, 2019). Being a multiplayer environment, it is intended to facilitate communication and collaboration among participants to promote the practice of basic communication skills. EmoFindAR supports

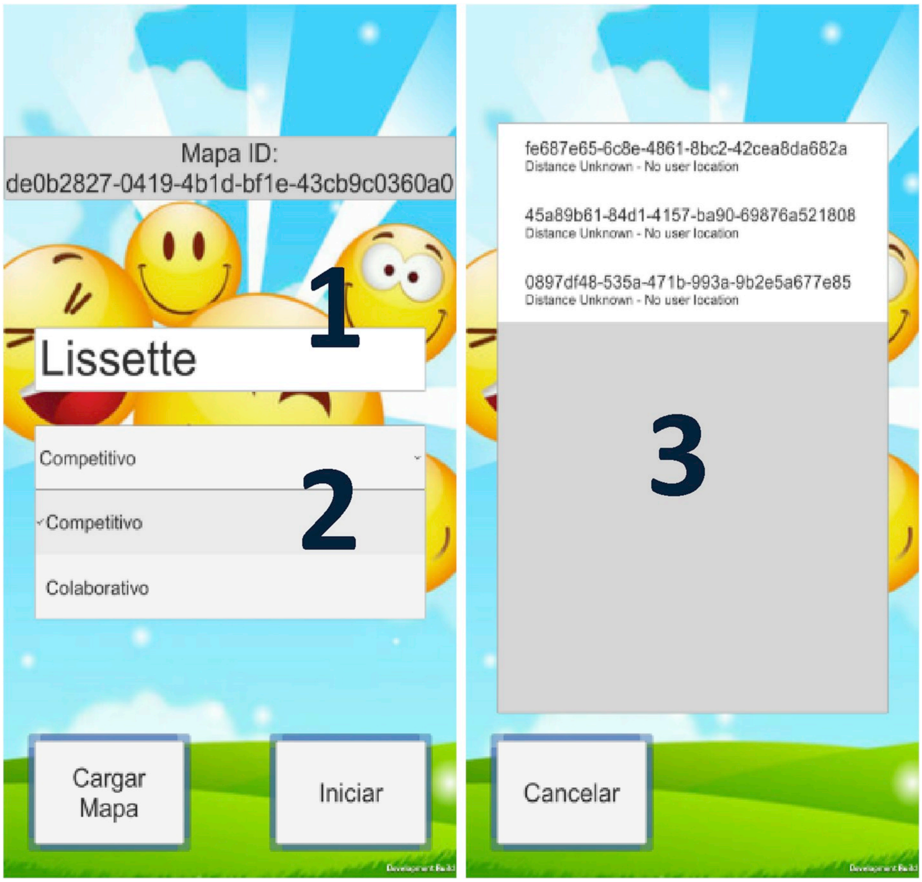

Fig. 1. Initial screen.

competitive and collaborative game modes, so that the impact of the game can be assessed in the form of communication and interaction between the participants.

In this game, the participants discover characters in the physical environment that show different emotions such as anger, sadness, joy, or others. The objective is to encourage players to identify these emotions and to act on them by launching objects that represent actions to improve the characters' emotional state. As a consequence of these interactions in the physical environment, a gamification strategy was defined that allows players to capture the existing characters if they achieve a certain emotional state, as in other games such as the well-known PokemonGo (Ruiz-Ariza et al., 2018), but making the participants identify and act on the characters' emotional states.

The mobile game has a main interface (see Fig. 1) that can register the user's data (1), game mode selected (2) and selection of the map (3) of the AR physical space.

The game's main augmented scene contains two types of 3D objects, the emotional characters to be captured and the objects to be thrown at them to change their emotional state.

The main interface (see Fig. 2) has an area that shows information on all players (1), a menu of objects that can be thrown (2), the total score obtained (3) and the characters already captured (4).

Our game defines several characters to be captured (see Fig. 3) that represent a specific type of emotion (anger, sadness or joy), instantiated in a networked multiplayer system and synchronized on all the players' devices, so that both the 3D positions and the characters' emotional state will always be updated in real-time in all the scenes.

At the start of the game the characters are randomly positioned around the physical environment (points on the 3D map), motivating the players to approach them and move around to visualize these 3D objects from different perspectives. Each character has an associated 2D interface (see Fig. 4), which shows the percentage of the desired final emotion already acquired, which varies according to the object thrown at it and how appropriate it is for the change of emotional state.

Additionally, restrictions have been introduced to the game to increase its level of difficulty. In the prototype, the characters or actors in the game continuously move within the 3D augmented space and do not remain static, so it is more difficult to locate and throw objects at them.

EmoFindAR has a collection of 21 objects to be thrown (see Fig. 5) to reach the desired final emotional state.

As soon as the player selects an object (see Fig. 6) from the menu (1), it is instantiated in the multi-player augmented space as a 3D object. The object is positioned at the center of the screen (2), follows the movement of the camera and is thrown in whatever direction the camera is pointing (3) when the player taps the object on the screen. Each object can only be thrown by the player who created it, although the others can see the object and its 3D trajectory. This increases the awareness of what the others are doing.

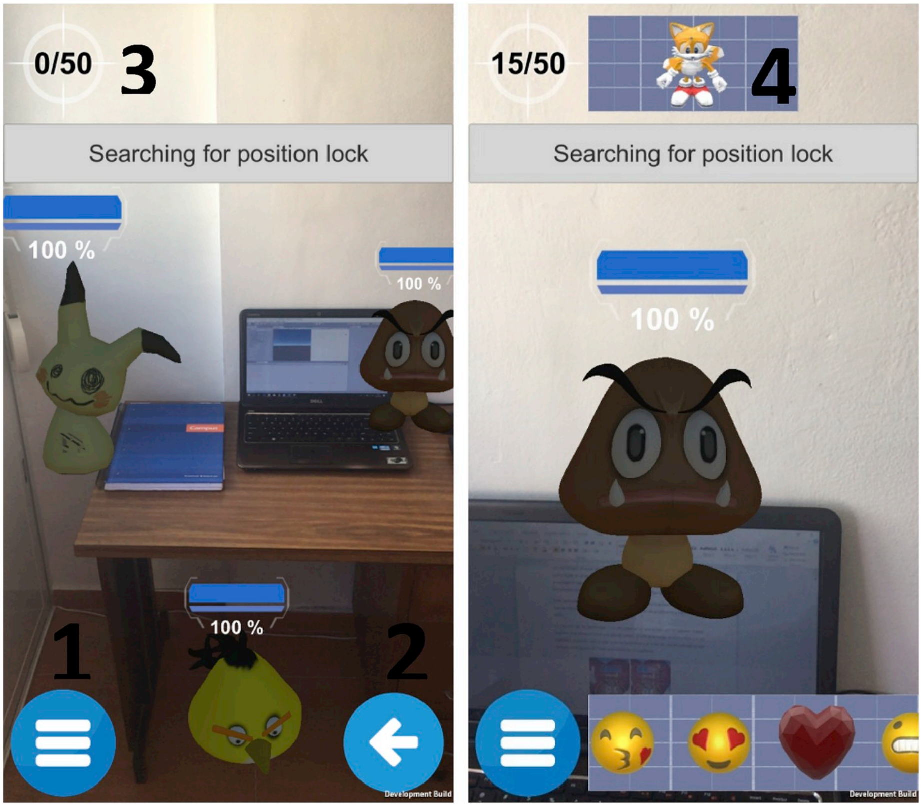

Fig. 2. Augmented space.

Fig. 3. Characters to be captured.

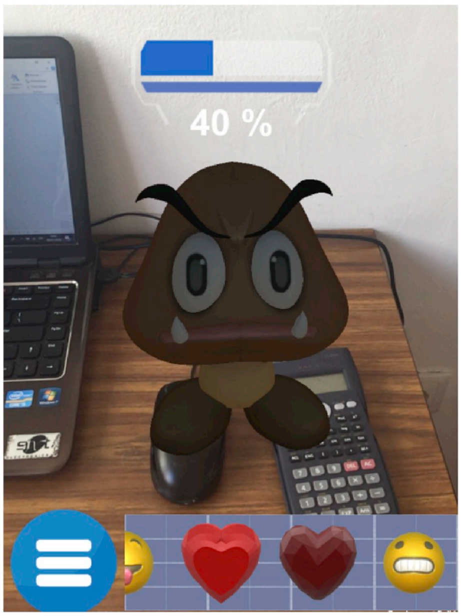

Fig. 4. Character's emotional state percentage.

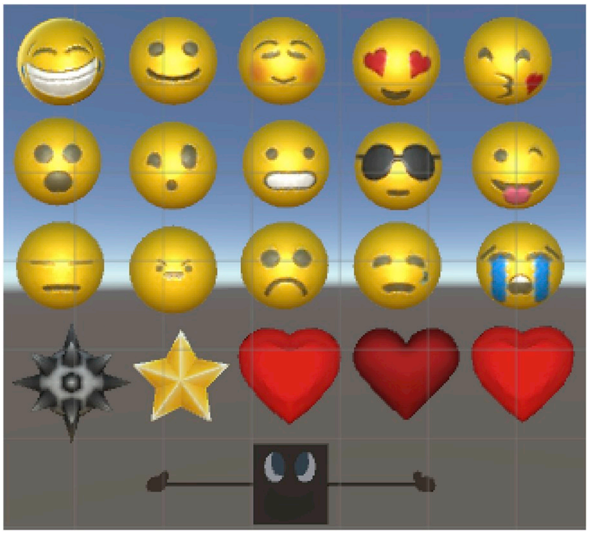

Fig. 5. Objects to be thrown.

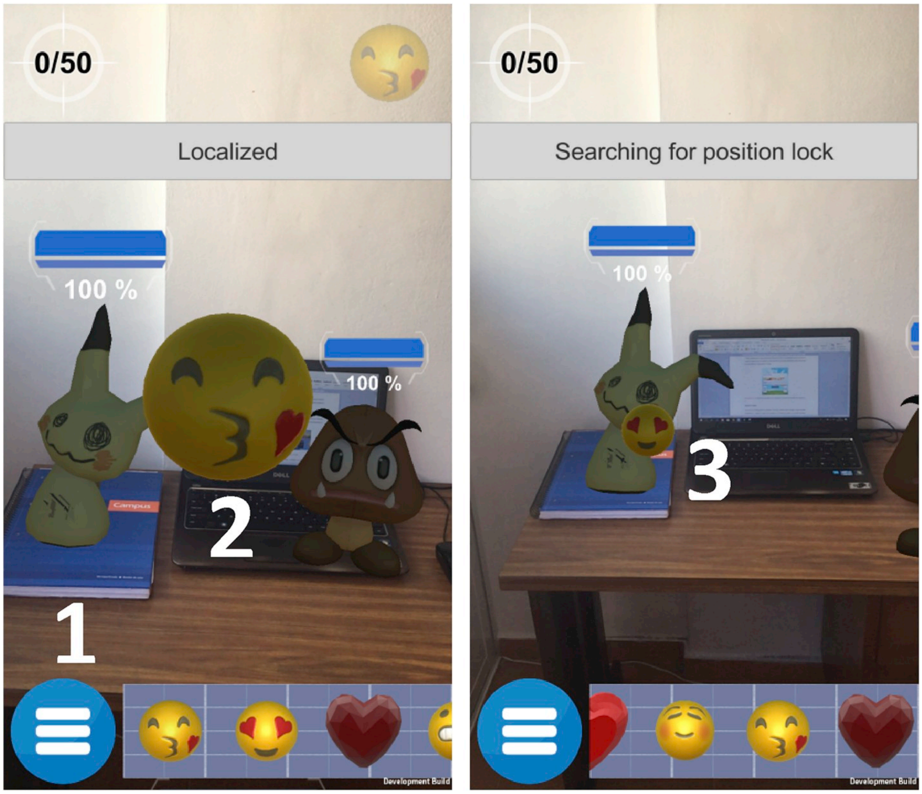

Fig. 6. Objects that can be thrown.

The objects (see Fig. 7) may only be thrown once (1) and when it hits a character it changes the level of emotion desired. The player must find the objects already thrown in the physical environment (2) and retrieve them to use them again. These objects are periodically put in new positions, making the logic of the game even more dynamic. Once recovered from the augmented 3D space, the object is only visible and accessible to the player who retrieved it.

The game ends when all the characters are captured, i.e. when they all reach their desired emotional state. At this time (see Fig. 8) the game gives the list of players (1), the characters captured by each player (2), and the winner (3). If the game is played in the competitive mode, the interface shows the participants with their points obtained (4). When it is collaborative everyone wins and only

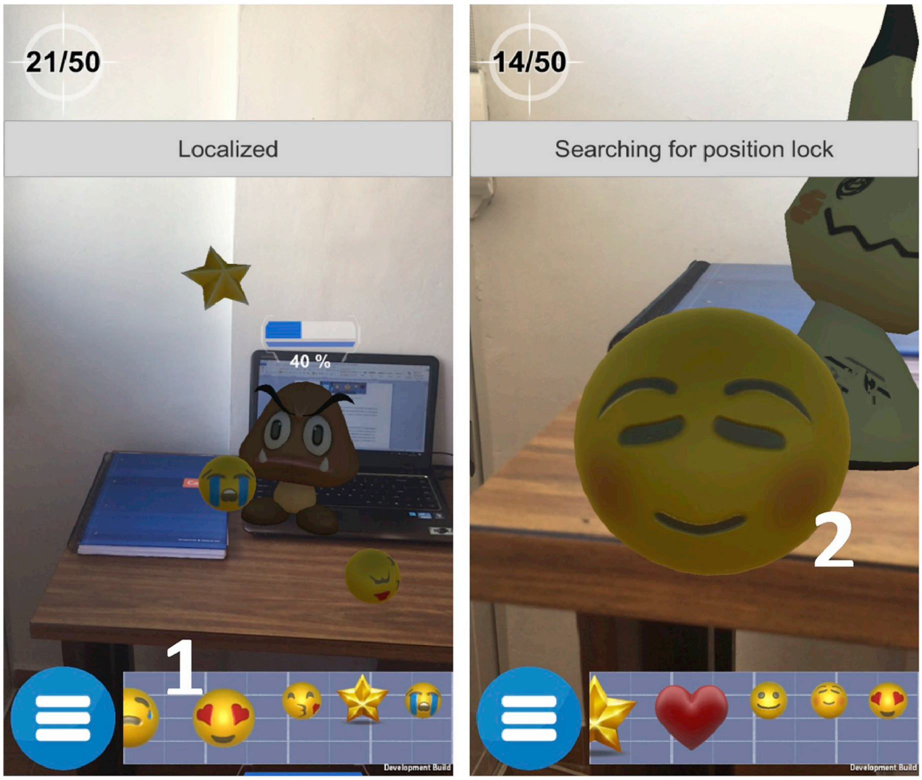

Fig. 7. Recovered objects.

Fig. 8. Final information of the game.

the total points are shown (5).

In the competitive game when a thrown object hits a character, it updates its desired emotional level positively, negatively or neutrally (as shown in Fig. 4). When a character reaches its desired emotional level, it is captured by the player who has contributed most to this situation, i.e. the player who threw the highest number of adequate objects for the character to reach its desired final emotional state.

The EmoFindAR competitive mode has characteristics related to the definition of “healthy competition” given by Shindler (Shindler, 2009): “a short activity in which the prizes of the winners are not substantial and which has to be focused on the learning process instead of the final results (classifications)”. EmoFindAR was therefore designed under five basic principles, which aim to ensure healthy competition in teaching (Shindler, 2009).

- Be undertaken for a prize of symbolic value.
- Be done in a relatively short period of time.
- Provide diversity of topics and tasks to be carried out.
- Offer and give the feeling to all participants of having a chance to win, and
- Assign a visible value to the process, quality and evaluation of learning.

In addition to the competitive mode we also designed collaborative game dynamics that requires the joint intervention of two players to capture a character. In this case a character must receive the impact of two objects from different players in a given time window that starts when the first object hits the character, forcing the other player to throw another object before the time limit expires. This type of restriction was designed to force participants to carry out planning activities (deciding which character to capture, identifying their emotional state and deciding on the objects to be thrown), coordination (synchronizing their throws) and discussing the results after the coordinated actions.

In this regard the game is designed to meet the six conditions for successful collaborative learning identified by Szewkis et al. (Garcia et al., 2018; Szewkis et al., 2011):

- The existence of a common goal. By having all the participants act on the same elements of the augmented space to reach a common object provides an environment of social interactions where children can learn through collaboration.
- Coordination and communication between peers. The participants must interact and create an orderly communication thread to achieve the common goal (Gutwin & Greenberg, 2004). Each 3D character is captured in collaboration, therefore, children must coordinate their tasks to achieve the desired emotional state of the character.
- Positive interdependence between peers. Participants feel more confident in achieving success when they work as a team, which can be used to promote a joint negotiation process and resolution of conflicts allowing positive support for collaborative learning (Wise et al., 2015).
- Awareness of peers’ work. In the collaborative process, all the participants must be able to visualize the actions executed by their peers in order to issue and receive feedback on their actions (Gutwin & Greenberg, 2004). The system provides a common shared augmented space to stimulate this.
- Individual accountability. Each student must acquire responsibility for executing tasks that benefit his group, so that all must be able to visualize the results of the executed actions. This is also supported by the presence of a shared augmented space in which the individual actions of the participants are visible to others in real-time.
- Joint rewards. As all team members receive the same reward or punishment in a collaborative process, all are thus encouraged to improve collaboration in order to achieve the goal, which is to win the game together (Zagal, Rick, & Hsi, 2006).

Finally EmoFindAR contemplates Csikszentmihalyi’s flow theory (Csikszentmihalyi & Csikzentmihaly, 1991) to get the participants to be completely immersed in the activity they perform, avoiding frustration or boredom. To achieve this effective intrinsic motivation, the game was designed to provide a correct balance between the challenge of the proposed MAR activity and the abilities of primary school children as follows:

- Understandable goal: A clear achievable objective was defined, capturing all the characters in the augmented world allowing children to rapidly design strategies and actions (competitively or collaboratively).
- Visual attractive design: Some characters recognized by children like Angry Birds or Pikachu, were included to better capture the concentration and focus of the participants.
- Spatial orientation challenge: a certain degree of challenge was introduced by forcing the participants to use spatial orientation and search skills in two ways. Firstly, at the level of the characters, by incorporating non-static characters that move around the augmented space, so that the students have to look for their new positions in a very dynamic way. Secondly, at the level of the projectiles, not having an unlimited number to launch but instead forcing the participants to search for projectiles in the augmented space.
- Concept-mapping challenge: Depending on its nature, each projectile affects each character differently. This forced the students to identify the projectile that generated the greatest gain at the level of emotions on each 3D object, thereby obtaining the greatest amount of points in the shortest possible time.
- Mixed-reality challenge: The use of a MAR scenario forced children to understand in real time the combination between the physical and the digital spaces. This is a cognitive overload that the participants had to deal with and provided an additional level of challenge.

4. Experimental study

The general objective of the experimental study was to evaluate EmoFindAR in a primary school context. Using the goal question metric (GQM) template (Basili, Caldiera, & Rombach, 2002), our objective is defined as: compare two gamification modes (competition vs collaboration) in order to evaluate the impact of the mode on the forms of communication and interaction between the participants from the point of view of MAR technologies in the context of primary school children.

Various studies of emotional intelligence in education have been carried out and the influence of this non-cognitive capacity on the students' success is recognized due to the fact that it positively affects various aspects of human performance, such as psychological health, social interaction and improving the participants' commitment and motivation (Mayer et al., 1999). On this basis, EmoFindAR implements a gamification scenario with the idea that users can learn in a different fun way about acquiring basic emotional states. It also seeks to encourage friendly competition and improve communication and socialization skills, which will lead to higher levels of academic achievement and personal well-being (Tsay & Brady, 2012; Yildirim, 2017).

4.1. Participants

In the experiment, a group of 38 fifth-grade primary school children aged between 9 and 11 years participated (Mean (M) = 10.42, Standard Deviation (SD) = 0.59). The children were selected following a simple random sample procedure within the available population of fifth-grade students in a primary school and were randomly grouped into pairs to form a total of 19 groups. Additionally, written parental consent was obtained for the experimental evaluation and the children participated voluntarily.

4.2. Apparatus

EmoFindAR is based on three main technologies, Unity[1] as a videogame development platform, the Photon Unity Networking (PUN)[2] package for the network multiplayer gaming infrastructure and the augmented reality SDK Placenote,[3] which has a layer of persistent visual mapping and 3D positioning. The devices used to deploy the game were Apple iOS 11 smartphones.

4.3. Procedure and experimental design

As a preliminary step for the experiment to evaluate the applicability of EmoFindAR, we proceeded to scan the physical location (classroom space), which is an essential Placenote requirement and was done only once before the sessions started (see Fig. 9).

The experimental study followed a within subjects repeated measures design with one independent variable (game mode) at two levels (collaborative and competitive) and with the order of application of the game mode randomized to avoid order effects. The experiment was carried out by pairs of children (see Fig. 10). Each pair played in both the competitive and collaborative modes in an estimated total time of 15 min gameplay. The short game mode duration was selected to comply with the school's requirement of not interrupting the children's normal academic activity for more than 45 min. This duration is also in line with the current popular time filler games recommended as pedagogical tools when teachers have a few minutes to spare. They can also be used as a warm-up or end-of-lesson activity. Short and simple games should not be neglected because, as pointed out in (Martinovic et al., 2014), when playing a variety of even simple games children develop a repertoire of cognitive schemas that are useful for various learning tasks.

In each game mode the children carried out the following activities:

- Competitive: the winner was the player who captured the highest number of characters.
- Collaborative: each pair had to agree on the character to be captured and the objects to be thrown. In a set time, each one would then throw an object at the target character. The successful completion of this game mainly required a joint strategy to collaboratively capture all the characters in the shortest possible time. In this mode all the participants are winners.

In order to obtain the children's opinions regarding the user experience of the game modes, a Likert questionnaire was applied after completion of each iteration (see Table 1). This questionnaire uses some of the evaluation constructs present in the usability evaluation USE (Lund, 2001) and game experience evaluation PIFF questionnaires (Takatalo, Häkkinen, Kaistinen, & Nyman, 2010). The possible answers were represented in a graphical form, according to the Fun Toolkit (Read & MacFarlane, 2006):

In addition to applying the questionnaires, an observational template (see Table 2) was used to obtain information about mood, physical activity, social interaction, use of the tool and oral comments made during the activity for each mode (Mayer et al., 1999). In this process, two observers evaluated these measures at the beginning, middle and at the end of the game (Evl.1, Evl.2, Evl.3).

Finally, for the collaborative game, a rubric (see Table 3) was applied to observe the quality of the collaboration during game play (Meier, Spada, & Rummel, 2007). Each evaluated item was assigned a quality measure as follows: −2 very bad, −1 bad, 0 neutral, +1 good, +2 very good.

[1] https://unity3d.com/.
[2] https://www.photonengine.com/en/PUN.
[3] https://placenote.com/.

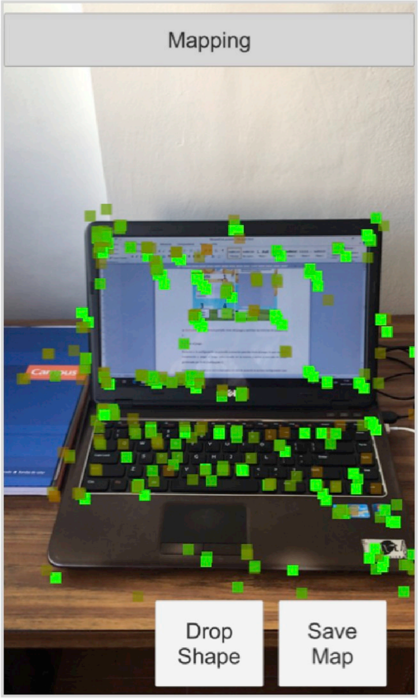

Fig. 9. Graphic interface of Placenote app.

Fig. 10. Experimental evaluation by children.

5. Experimental results

The questionnaires and the observational templates applied in the experimental study allowed us to obtain quantitative and qualitative data related to the applicability of the EmoFindAR game. The results of the questionnaires are detailed in Section 5.1 and the observational results are described in Section 5.2:

5.1. Questionnaire results

Each child answered two questionnaires referring to each game mode individually (see Table 1). For the first five questions listed in Table 1, two null hypotheses were defined, the first related to questions C1Q1, C1Q3, C1Q4 and C1Q5 and the second related to

Table 1
Game mode evaluation questionnaire.

Code	Questions	Scale
C1Q1	How much fun did you have in the game?	1. Nothing, 2. Little bit, 3 Somewhat, 4 Quite and 5 Much
C1Q2	How easy was it to handle the game?	1. Super difficult, 2. Difficult, 3. Normal, 4. Easy and 5. Super easy
C1Q3	How much would you like to play this game again in the classroom?	1. Nothing, 2. Little bit, 3 Somewhat, 4 Quite and 5 Much
C1Q4	How much would you like to play the game again outside the classroom?	1. Nothing, 2. Little bit, 3 Somewhat, 4 Quite and 5 Much
C1Q5	How much would you like to play this game with friends?	1. Nothing, 2. Little bit, 3 Somewhat, 4 Quite and 5 Much
C1Q6	In which subject fields would you like to play the game?	Free answer
C1Q7	What would you change to make it more fun?	Free answer

Table 2
Observation template for each game mode.

Code	Event	Scale	Boy	Evl.1	Evl.2	Evl.3
P1Obs1	Affect	0 Bored/sad 1 Flat affection 2 Cheerful 3 Euphoric	**A** **B**			
P1Obs2	Physical activity	0 No movement 1 Nearly zero movement 2 Shows movement 3 Very active movement	**A** **B**			
P1Obs3	Social interaction	0 Play individual 1 Respond to the interaction 2 Directs the interaction 3 Produce a collaborative game	**A** **B**			
P1Obs4	Use of the tool	0 It has no interest 1 Explore passively 2 Explore with interest 3 Explore and propose new ideas	**A** **B**			
P1Obs5	Satisfaction	0 Negative comments 1 No comment 2 1 positive comment 3 $>$ 1 positive comment	**A** **B**			

question C1Q2.

H0a. The children's enjoyment level is not affected by the game mode.

H0b. The game's ease of use is not affected by the game mode.

The answers provided are summarized in Fig. 11 in the competitive and collaborative modes. A Wilcoxon signed-rank test was performed to verify whether the difference of means of the two repeated measures is significantly different from zero for each

Table 3
Template for the observation of communication in the collaborative game.

Code	Dimension	Boy A	Boy B
P2Obs1	Maintain mutual understanding		
P2Obs2	Dialogue management		
P2Obs3	Information set		
P2Obs4	Reaching consensus		
P2Obs5	Division of tasks		
P2Obs6	Time management		
P2Obs7	Technical coordination		
P2Obs8	Reciprocal interaction		
P2Obs9	Orientation of individual tasks		

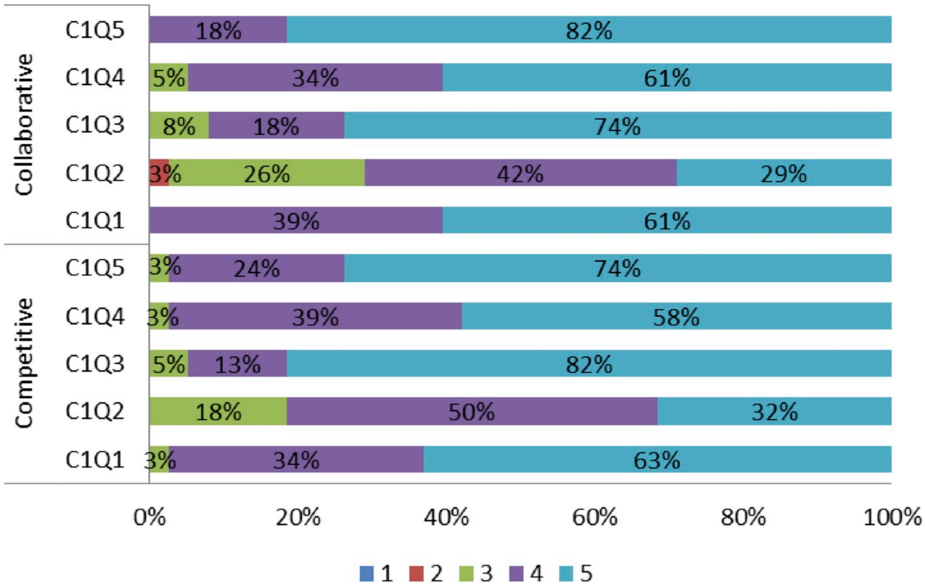

Fig. 11. Results questionnaire no. 1.

evaluated dependent variable, i.e., whether the game mode has an effect on the dependent measured value. This test is equally powerful to a repeated measures ANOVA. The p-values, shown in Table 4 prevent us from rejecting the null hypotheses, H0a and H0b, i.e., there are no statistically significant differences between means (p-value<0.05, 95% confidence interval) in all the evaluated questions.

These statistical results indicate that the collaborative and competitive gaming modes are equally perceived by the participants. The main objectives of Questions C1Q1, C1Q3, C1Q4 and C1Q5 were to evaluate the enjoyment level of the game. In C1Q1 the fun level was assessed, where the children rated their enjoyment very positively (with scores 4-quite or 5-much) for both the competitive (97%) and collaborative (100%) modes. In fact, none of the children rated their enjoyment at the minimum scales, 1 (nothing) or 2 (little bit). When asked if they would like to play this game again inside (C1Q3) and outside the classroom (C1Q4), children consistently expressed their willingness to do so in both modes, with more than 90% of the scores provided being in the categories 4-quite or 5-much for both modes (see Fig. 11). In C1Q5, children also expressed very high levels of willingness to play with friends, 98% (competitive) and 100% (collaborative) of the children chose 4-quite or 5-much willingness levels. Question C1Q2, was defined to measure each mode's ease of use. In this case 82% (competitive) and 71% (collaborative) considered that playing the game was 4-easy or 5-super easy. Finally, the questionnaire had two open questions (C1Q6 and C1Q7): the first (C1Q6) asked about other educational

Table 4
Results of the signed-rank Wilcoxon test between the two game modes (*P < 0.05).

Dependent variable	Mean competitive	Mean collaborative	p-value
H0a-C1Q1	4.61	4.61	1.00
H0b-C1Q2	4.13	3.97	0.31
H0a-C1Q3	4.76	4.66	0.36
H0a-C1Q4	4.55	4.55	1.00
H0a-C1Q5	4.71	4.82	0.10

subjects in which children would like to play the game. The most frequent subjects were mathematics, Spanish, Valencian and social sciences in both modes. Question C1Q7, about changes to be made to the game, produced several suggestions, including more characters to capture in the game, more objects to throw and 3D objects with special effects or animations. Several children also wanted to play for longer in a larger physical area and with more players. Only one child in the competitive mode wanted to reduce the game's complexity.

5.2. Observational results

Each observer completed three templates for each pair of children. The first two evaluated each game mode separately (see Table 2) and the third evaluated the quality of the collaboration in the collaborative version (see Table 3).

Based on the observational template (see Table 2), a null hypothesis was formulated for each parameter evaluated, obtaining a total of 5 hypotheses, as detailed below:

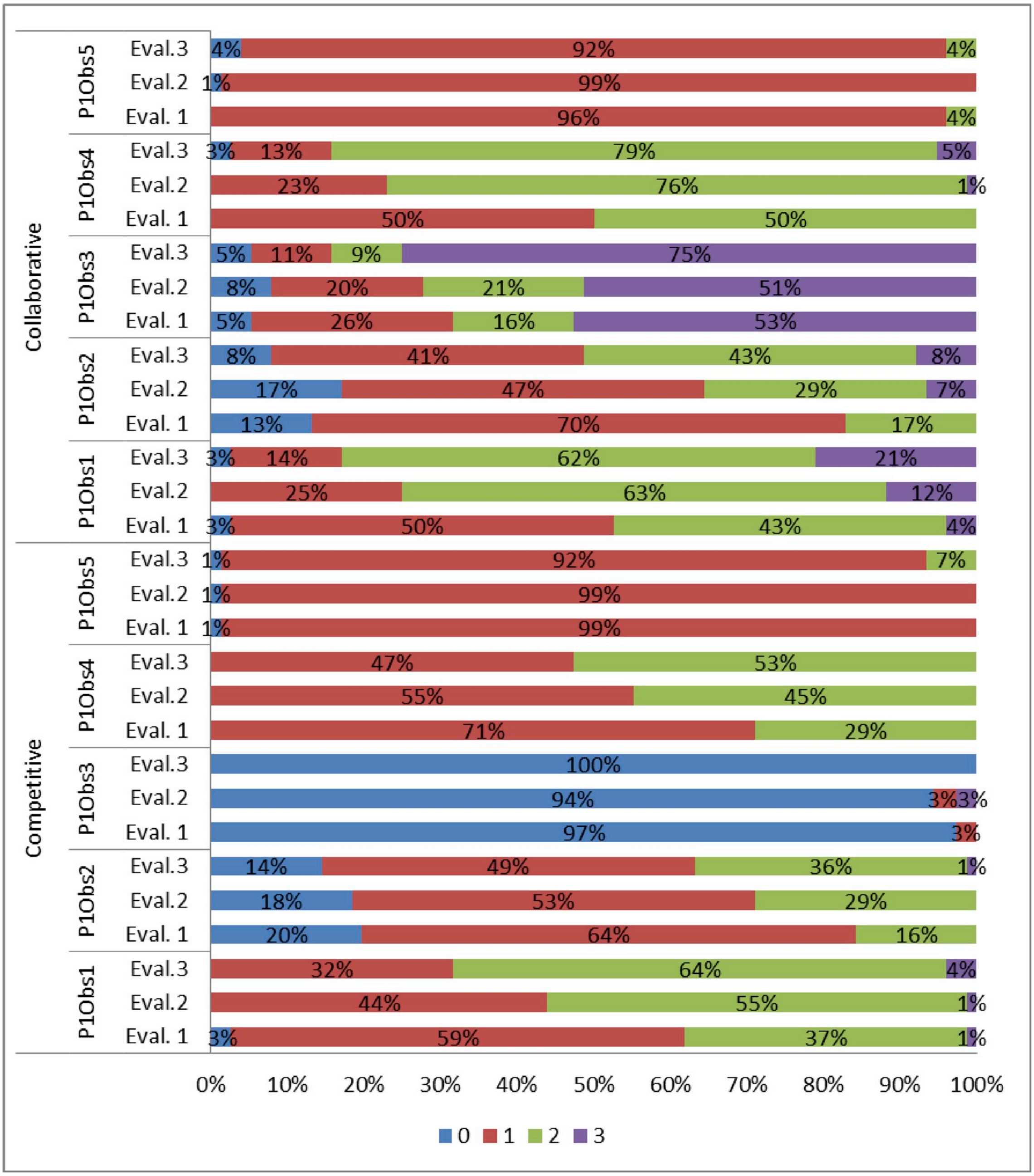

Fig. 12. Results observations template no. 1.

H0c. The children's mood during game play is not affected by the game mode.

H0d. The level of physical activity is not affected by the game mode.

H0e. The degree of social interaction is not affected by the game mode.

H0f. The interest expressed by children is not affected by the game mode.

H0g. The level of satisfaction measured by oral comments during game play is not affected by the game mode.

The data reported in Fig. 12 details the values observed for each parameter at three given times at the beginning (Eval.1), middle (Eval.2) and at the end of the game (Eval.3) for both modes (see Table 2).

A signed-rank Wilcoxon test was applied to evaluate whether the difference of means of the two repeated measures is significantly different from zero for each evaluated dependent variable (see Table 5).

According to the results, the null hypothesis H0g may not be rejected at 95% confidence level (p-value>0.05) because the means difference is not significantly different from 0 and the rest (H0c, H0d, H0e and H0f) are rejected (p-value<0.05), with the collaborative game having significantly higher average values in these statistically significant dimensions.

According to the results, the two game modes raised the children's mood. They started playing at a low level and ended with a mood ranging between cheerful and euphoric. The collaborative version had a higher number of euphoric children than the competitive one (21% vs. 4%). The results of the physical activity (P1Obs2) indicate that in both modes (collaborative 37% vs competitive 51%) the subjects showed in general low levels of physical activity at the end of the game. Regarding the social interaction parameter (P1Obs3), the competitive version encouraged all the children to play individually (100%), while most of them (75%) had social interactions in the collaborative game. The use of the tool (P1Obs4), indicates that the two game modes motivated the children to be interested in its technical aspects, with a higher percentage in the collaborative version (53% competitive and 79% collaborative). Finally, they expressed few positive spontaneous oral comments during the activity (P1Obs5) (7% competitive and 4% collaborative), revealing that most oral communications were related to the planning and strategy definition phases during the game.

To evaluate the quality of the collaboration between each pair of players, several null hypotheses for the parameters of the second observational template were formulated (see Table 3):

H0h. The level of mutual understanding sustained by the children in the game is neutral.

H0i. The quality of dialogue management shown by the children in the execution of the game is neutral.

H0j. The set of information used by children in the game is neutral.

H0k. The level of consensus generated by the children in the game is neutral.

H0l. The division of tasks managed by the children in the game is neutral.

H0m. The time management controlled by children in the game is neutral.

H0n. The technical coordination of the children in the game is neutral.

H0o. The level of reciprocal interaction of children in the game is neutral.

H0p. The orientation of individual tasks by children in the game is neutral.

Fig. 13 illustrates the results of the second observational template defined for the collaborative game version and Table 6 shows the results of the statistical t-tests for a sample that were applied to the data from the observational template No. 2, to verify whether there were significant statistical differences with respect to the neutral value (0).

The results show that all the parameters, except for time management, present a significant statistical difference (p-value<0.05) with respect to the neutral value (0), which leads to rejecting the null hypotheses H0h, H0i, H0j, H0k, H0l, H0n, H0o, H0p and accepting H0m.

The children made clear contributions to their peers, which led them to maintain an acceptable level of mutual understanding (P2Obs1) between good (58%) and very good (11%). When executing the actions collaboratively, most of the children (75%) created an orderly and fluid communication flow (P2Obs2). Regarding the management of information (P2Obs3), the children searched for and obtained relevant information, achieving high levels of information management (57% good/very good). In addition, 47% of the children reached good/very good consensus levels (P2Obs4), agreeing as a team the 3D objects to be captured and thrown. It is also worth mentioning that 59% of the children divided the work into equitable tasks (P2Obs5), e.g. when finding the position of the character to be captured in the augmented space by inspecting sections individually. Only 37% of the children watched the time (P2Obs6) and managed to finish in the shortest possible time, although there was no time limit. The children took advantage of their knowledge of the technology (P2Obs7) to successfully (78%) synchronize the game's features (capture the characters collaboratively). During the game, 59% of the children encouraged others to contribute opinions and perspectives on the game (P2Obs8). Finally, the parameter with the highest results is the Orientation of individual tasks (P2Obs9), since 95% of the children participated actively in the search for the solution to end the game.

Finally, an inter-judge internal validity Kappa Index test was performed to evaluate the agreement between the two observers (see Table 7). The values 0.87 (Template No. 1) and 0.68 (Template No. 2) for the two observation templates indicate very good and good levels of agreement between the data recorded by both observers.

Table 5
Results of the Wilcoxon test, observation of competitive vs. collaborative levels (*P < 0.05).

Dependent variable	Mean competitive	Mean collaborative	p-value
H0c-P1Obs1-Affect	1.56	1.79	<0.01 *
H0d-P1Obs2-Physical activity	1.10	1.27	0.03 *
H0e-P1Obs3-Social interaction	0.04	2.29	<0.01 *
H0f-P1Obs4-Use of the tool	1.42	1.72	<0.01 *
H0g-P1Obs5-Satisfaction	1.01	1.01	1.00

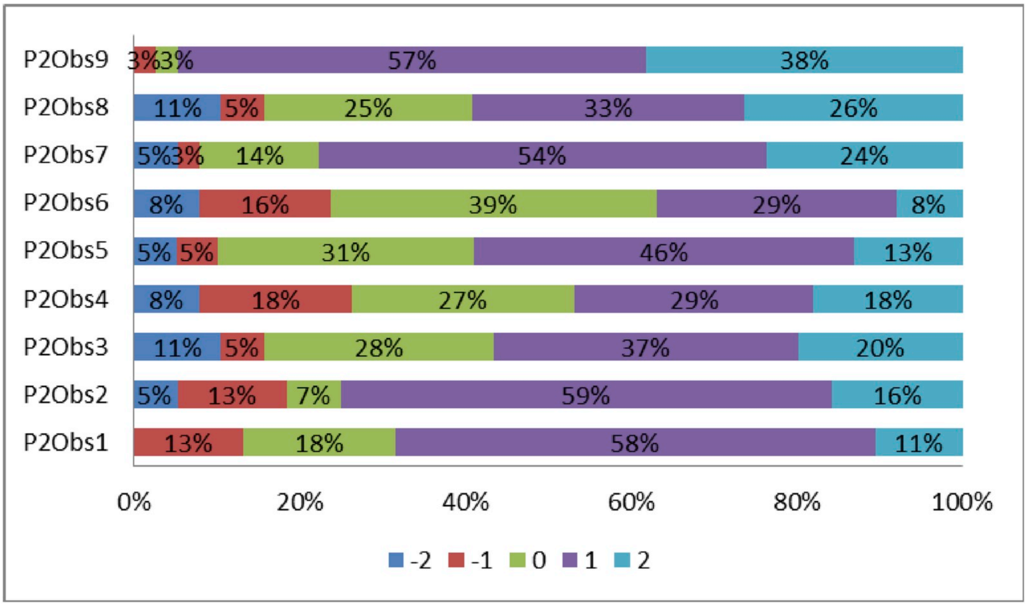

Fig. 13. Results observations template no. 2.

Table 6
Test T for a sample, observation of communication (*P < 0.05).

Dependent variable	Mean	p-value
H0h-P2Obs1-Sustaining mutual understanding	0.66	<0.01*
H0i-P2Obs2-Dialogue management	0.67	<0.01*
H0j-P2Obs3-Information pooling	0.50	<0.01*
H0k-P2Obs4-Reaching consensus	0.32	0.03*
H0l-P2Obs5-Task division	0.57	<0.01*
H0m-P2Obs6-Time management	0.13	0.27
H0n-P2Obs7-Technical coordination	0.88	<0.01*
H0o-P2Obs8-Reciprocal interaction	0.59	<0.01*
H0p-P2Obs9-Individual task orientation	1.30	<0.01*

Table 7
Results Kappa index, observational template.

Kappa	Degree of agreement	Template Obs. No.1	Template Obs. No.2
<0	Without agreement		
0–0.2	Insignificant		
0.2–0.4	Low		
0.4–0.6	Moderate		
0.6–0.8	Good		0.68
0.8–1	Very good	0.87	

6. Discussion

6.1. Multi-user MAR experiences and student engagement

The first interesting aspect to discuss is the potential of multi-user MAR experiences for becoming optimal experiences in terms of Csikszentmihalyi's flow theory (Csikszentmihalyi & Csikzentmihaly, 1991). In this respect, there are several factors that are vital for achieving a state of flow: the activity must be intrinsically rewarding, with clear goals and a sense of progress, with clear and immediate feedback, matching children's perceived skills and with an intense focus on the task at hand. We designed EmoFindAR, as described in Section 3, with these factors in mind and the results are very promising in terms of the ability of multi-user MAR games to improve children's engagement during learning activities. This is consistent with prior research in game-based learning scenarios without MAR in which ludic approaches encourage the intrinsic motivation of students, leading them to commit to homework (Hamari et al., 2016; Hwang, Wu, & Chen, 2012). However, in this respect, one of the main contributions of our study is to show that both the competitive and collaborative MAR modalities can also support intrinsically rewarding multiplayer game-based learning scenarios, giving educators an additional and inexpensive technological tool to implement new mobile educational scenarios.

The cognitive challenges designed in the activity were well balanced with respect to their abilities. This resulted in children not showing any signs of boredom or frustration during the activity. It was observed that most of the participants enjoyed executing the competitive and collaborative tasks, which led to the creation of a fun environment, which is justified in the results obtained. Of course, these results must be taken with some caution as the activity was not performed repeatedly, nor were the children's interventions very long. The impact on their motivation of more and longer game sessions remains to be studied.

In particular, the RQ-A research question about feelings and emotions shown by children during competitive and collaborative gamification activities is supported by the null hypotheses H0a, H0c and H0g. In this respect, both the competitive and collaborative versions resulted in high levels of enjoyment. Both modes equally captured the children's attention, created a fun game environment and intensified their positive mood. Children were willing to play again not only in their school environment but also outside the classroom, which demonstrates the potential of MAR games to support learning scenarios in many outdoor contexts. It is important to note that although the children rated their enjoyment of both modes equally (H0a), i.e. they perceived both games as equally fun as both external observers gave a significantly higher score to the observed enjoyment in the collaborative mode (H0c), due to the significantly higher number of external signs of enjoyment in this version. This reveals the importance of successful collaboration to promote mutual social bonds between children. This result is consistent with the study of McNaughton and his team (McNaughton et al., 2018), in which they emphasize that collaborative face to face exercises facilitate the development of skills like critical thinking and communication. In addition to this, EmoFindAR, also proposes including emotional intelligence concepts in the game, opening the door to future developments in which children can not only express emotions during game play but also identify and learn about emotional awareness and regulation.

Finally, a correct balance between the challenges present in the game and the children's abilities to analyze the problem, plan a course of action and collaboratively execute the plan are key to motivational learning scenarios in which all the participants feel that they took part in achieving the goals. However, these signs of enjoyment were not expressed verbally during the play session (H0g). According to the observers, they were concentrated on the task and did not make explicit comments of satisfaction until achieving the final goal in both modes. These results could be improved by adding more gamification subgoals and including challenges, puzzles or quests during game play with greater complexity to give them more enjoyment, implementing some of the characteristics proposed by other authors (Amory, 2007).

6.2. MAR usability

According to the ISO 9241-11 standard, usability is defined as "the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use". In this regard, our game was oriented to the results of the user experience, this being a broader concept than usability, since it considers the cognitive, affective, social and physical aspects of the interaction, which go beyond the quality of the task, efficiency and user satisfaction (Cockton, 2012). The game's ease of use (RQ-B) is thus supported by hypotheses H0b and H0f. The general design of the game is oriented towards creating learning situations that allow primary school children to obtain certain skills and knowledge, adopting game manipulation functionalities according to their age.

The two EmoFindAR modes differ in the way game characters are captured, the collaborative version being more challenging as coordinated actions are required. It is therefore no surprise that the children perceived the competitive version as slightly easier, as this mode involves only individual actions that do not require synchronization, collaboration and communication with other players. However, despite the higher level of coordination required by the collaborative actions, the results showed no statistical differences between the modes (H0b), which indicates that primary school children found it easy to carry out the designed interaction in the augmented 3D space. One of the collaborative mode's advantages is that it motivated the children to explore the tool with more interest than in the competitive version (H0f). During the planning phase in the collaborative version they spent more time exploring for the available objects and the next target to be captured. It should also be noted that the fact of having an augmented space increased their motivation and both game styles instantly captured their attention. This interpretation supports the conclusions of Lamanauskas and his team (Lamanauskas et al., 2007), which, supported by his prototype Arise, claims that AR learning platforms are attractive, stimulating and exciting for students. EmoFIndAR achieves this result by including animated 3D objects in a dynamic and interactive 3D space.

6.3. Collaborative MAR games to promote communication

Collaboration plays an important role in children's daily life. As it was already discussed in the introduction, people learn and work better in collaboration, rather than individually, and collaboration has the potential to create rules that are agreed by all the participants, which leads to creating communication threads between them. In this approach, EmoFindAR's collaborative gamification has a greater impact on children's coordination and communication (question RQ-C), supported by the H0e hypothesis. Children playing competitively are inclined to concentrate individually on achieving the goal, which is to win the game. On the other hand, a simple collaborative game design encourages children to communicate and coordinate activities to achieve a common goal.

The collaborative version of our game positively influenced the occurrence of communication and social skills. They consistently communicated in an ordered sequence of statements and spoke in turn (H0h, H0i). The game features allowed them to have alternative views that had to be evaluated as a team. They had the chance to express their preferences and reach an adequate level of consensus (H0k). To reach the end of the game, they grouped the relevant information that helped them to reach the final solution (H0j) and divided the work into both individual and joint tasks (H0l), such as: searching for characters, selecting the object that intensified the character's emotion and synchronized throwing. The technical coordination was important (H0n), as the game motivated the children to use their knowledge and skills to manipulate, coordinate and synchronize the game's main functionalities and communicate with each other to solve problems. The orientation of individual tasks was the most important parameter (H0p), since almost the entire population participated in the game actively, showing interest in their tasks and enjoying the cooperative work involved. The children encouraged each other and were willing to contribute their opinions and perspectives, such as selecting the 3D object to launch that could have the greatest impact on the emotional state of the target game character (H0o). It should be noted that since the design did not include a time limit, they did not pay attention to the available time (H0m).

EmoFindAR collaborative gamification shares some similarities with other experimental games that support social interactions through AR (Cheng, Wang, Cheng, & Chen, 2019; Gironacci, Mc-Call, & Tamisier, 2017), however, our proposal involves a different style of interaction with coordination and synchronization activities in real time and the visualization of a single shared augmented world on all players' devices, without the need for fiducial markers in the physical space, another advantage for this technology.

6.4. MAR games to promote physical activity

Children need tools that encourage physical activity and minimize sedentary behavior. Active games are a viable alternative to sedentary behavior and are recommended by several authors (Lanningham-Foster et al., 2009). These games have the potential to encourage users to perform traditional physical activities, such as walking, jumping and jogging. In this regard, our game provides a multiplayer scenario to capture characters anywhere in the physical space. The physical space incorporated into the game is in the real world and is configurable, which means that the play area does not require AR markers. In the present evaluation, even though a limited physical space was used, the collaborative style enhanced the level of physical activity (H0d) because the children had to move around during the planning phase in search of the next target. However, this result has to be taken with caution because of the reduced physical space in our experiment and the limited duration of the game sessions. It cannot be claimed in this respect that a collaborative learning style is better in terms of promoting physical activity because a competitive scenario could also be designed focusing on promoting physical activity. The only conclusion that can be drawn from our experiment is that the planning phase during collaboration contributed to an additional level of physical activity in our particular game design. Further evidence will be obtained on this in future experimental studies to determine the aspects of collaborative/competitive learning modalities that contribute most to promoting physical activity.

6.5. Design guidelines for MAR games

The results obtained taught us different lessons for the design of competitive/collaborative MAR games for primary school children.

Game time management (DG1): Our game design did not use time as an additional challenge because it was thought that the children would have potential usability problems in this first experience with a MAR game. However, as they demonstrated good usability skills with MAR, it is thus feasible to introduce time as a game challenge to evaluate its impact on the quality of the collaboration (division of work, time management, etc.). Educational games should also incorporate a time limit for the different sections in order to control this resource (Whitton, 2009).

Provide the right scaffolding (DG2): Another aspect to consider is the complexity of the game from the children's point of view. The collaboration dimensions should be adapted to their actual skills and age to allow them to play according to their abilities. To do this, the game should allow students to select scaffolds according to their abilities in order to balance their emotions, because if a task is too easy you may experience apathy or boredom, while if it is too difficult it can cause an anxiety state. With this characteristic, the environment takes into account the different user knowledge and experience, providing equal opportunities for all the students to participate (Whitton, 2009).

Mixed competitive-collaborative modes (DG3): The EmoFindAR collaborative game promotes socialization and communication skills. These skills can be improved by incorporating competitive dynamics into the collaborative game. This would encourage each group to communicate and collaborate even more to win the game when competing against other groups. The most effective educational games are those that involve some aspect of collaboration, allowing students to work on their strengths, develop critical thinking, validate their ideas and appreciate a variety of individual learning styles, skills, preferences and perspectives (Whitton, 2009).

Dynamic 3D objects (DG4): The 3D objects in the augmented space are attractive to children, but they could incorporate additional features to make the MAR game even more dynamic and appealing, as several children suggested after playing the game. This could include more explicit visual changes in the game characters to reflect their emotional state more vividly. This aspect is involved with Intrinsic Motivation, which involves simulations, fun challenges, a sense of wonder and curiosity, which leads to students wanting to learn instead of having to learn.

Minimize distractions (DG5): Game-based learning must incorporate three essential characteristics of good computer games: challenge, fantasy and curiosity. With these features added to an augmented space, creative challenges can be posed that are meaningful to students, who thus they are more likely to stay concentrated and not lose focus on what they are doing.

Face-to-face Gaming (DG6): Educational games with competitive and collaborative activities must create a physical interaction between the players, where the users meet face-to-face to execute a particular game session, which will allow children to put emotional and social skills into practice. In a face-to-face context, it is also possible to have much more control over when and where students interact with the game (Whitton, 2009), thereby minimizing the risks of addiction.

Support active learning (DG7): Augmented play themes may be diverse, however, the context should provide opportunities for exploration, problem solving and inquiry, which will allow students to evaluate ideas, apply strategies, obtain feedback, and practice and consolidate their learning (Whitton, 2009). As mentioned above, we found high levels of communication and interaction during the planning phase of the collaborative version of our game, which indicates the potential of problem-solving learning scenarios as effective ways of triggering socialization and communication between children. In addition, our prior research with a robotic companion (Garcia et al., 2018) confirmed that providing these opportunities creates intrinsic motivation-driven learning environments.

All these recommendations will open up interesting areas of research on the design of collaborative and competitive MAR gamified learning environments for primary school children. We also believe that these guidelines will help to create dynamic scenarios for multiplayer games that children will enjoy, and thereby activate their feelings in a positive way and improve their performance in the classroom.

7. Limitations

In the experimental evaluation of EmoFindAR some limitations were found that could lead to future works. Regarding the game design, not considering topics with a more diverse set of 3D objects could diminish children's attention if the activity had a longer duration. Having a single game level could also have affected the enjoyment, since there were no higher levels of complexity to offer more challenging scenarios for the most skilled children.

Additionally, in the experimental evaluation, the children were given a maximum time of 15 min to complete the activity in the competitive and collaborative game modes. This may have had an impact on the observation and evaluation of factors related to socialization, communication and emotional intelligence. The longer playing time could have had negative effects related to boredom that were not observed in our evaluation.

Finally, it would be interesting to carry out a long-term evaluation of the game to obtain additional results and thus be able to analyze other factors that could have an impact on motivation levels, be it the novelty of MAR technology, the design of the EmoFindAR game or the integration of the competitive and collaborative modalities, among others.

8. Conclusions and future work

In the present work, a multiplayer game using MAR has been implemented without using fiducial markers, which limit its deployment in large physical spaces. EmoFindAR's competitive and collaborative versions allow the identification and manipulation of basic emotional states, which can be used to improve socialization, communication skills and emotional intelligence in primary school children.

According to the results obtained, both game modes are intrinsically satisfactory for children, since they trigger positive emotions such as enthusiasm, enjoyment and curiosity, among others, factors that improve the participants' mood and help increase the degree of involvement.

At the comparative level, we observed that the collaborative game version has a greater impact on emotional affection, social interaction and interest, since the game design makes children collaborate in a synchronized way to capture the characters. The collaborative game is a viable alternative for the acquisition of communication skills, since it eliminates individualized play and motivates children to create dialogues and interact with others to achieve a common goal. At a more general level, the augmented reality technology without markers used in this study is suitable for implementing multiplayer game scenarios that integrate competition and collaboration modes in educational applications. EmoFindAR will be expanded in the future to implement different game themes, with a configurable number of participants and different complexity levels.

In future experimental evaluations we will define a new study that involves a higher number of players, a longer game duration and a larger physical space in order to explore the impact of these factors on the user experience, collaboration and effectiveness of learning in a real context in primary education. We also plan to use this technology in the context of emotional and affective intelligence, proposing multi-player pervasive intelligent environments for promoting social skills. Basing our work on the foundations of empathy from a psychological and pedagogical point of view, we would like to develop a new generation of educational approaches based on ubiquitous games to effectively teach empathy skills to children and teenagers and thus help to reduce incidents related to bullying.

Finally, in a different context, we are planning to apply this technology in the field of hospital ludotherapy to create augmented reality games to enhance children's socialization during hospitalization.

CRediT authorship contribution statement

Lissette López-Faican: Methodology, Software, Formal analysis, Investigation, Writing - original draft, Writing - review & editing. **Javier Jaen:** Conceptualization, Methodology, Formal analysis, Writing - original draft, Writing - review & editing, Supervision.

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