AN AUGMENTED REALITY APPLICATION TO ENGAGE STUDENTS IN STEM EDUCATION

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This paper proposes a Mobile Augmented Reality application to engage students in STEM education. With a design research methodology, the SolarSystemGO game, initially designed to promote learning about our Solar System, is being developed by undergraduate higher education students supervised by higher education teachers from a Portuguese polytechnic. After several cycles of implementation of the game (design research cycles), which took place over two academic years, we argue that the SolarSystemGO game can be a resource to develop mathematical contents in formal and informal learning environments. Based on our research and experience in the field, we sustain the importance of developing Mobile Augmented Reality games that engage students and motivate them to learn interdisciplinary subject matters adequate to primary school syllabus.

Keywords: STEM education, augmented reality, hands-on, mobile technologies, gamification.

INTRODUCTION AND THEORETICAL FRAMEWORK

The European report Rocard et al. (2007) identifies an alarming decline in students' interest for STEM (Sience, Technology, Engineering and Mathematics), which will compromise future careers in these subjects and consequently Europe's future potential for innovation. More recently, another European report (European Schoolnet, 2018) and other studies all around the world (Breiner, Harkness, Johnson e Koehler, 2012; Office of the Chief Scientist, 2016) continue to identify the same problem.

To face this situation, several authors argue the need to promote STEM integration sustaining that the world needs skills related to these subjects to correspond to the increasing challenges of our century (Breiner et al., 2012; Kim & Bolger, 2017; Office of the Chief Scientist, 2016). In particular, Stohlmann (2018) states that mathematics should be more emphasized in STEM education. In this regard, STEM should be used to innovate the teaching of mathematics (Fitzallen, 2015) as well as to improve its performance (Stohlmann, 2018). In fact, integrative approaches among STEM subjects have positive effects in student's performance, with better results at the primary school level (Becker & Park, 2011). The same authors state that integrating Mathematics with Science, Technology and Engineering leads students to develop meaningful connections between these topics.

Concerning technology, it has potential to integrate mathematics and to promote student's motivation and meaningful learning (Costley, 2014). In a preliminary work, the authors of this paper conclude that technology resources are effective to capture children's attention and can engage students to learn mathematics and science, according to the school syllabus (Costa & Domingos, 2017).

The mathematics education community also recognizes the importance of developing research about integrating technology in mathematics teaching and learning. In fact, latest advances in technology have the potential to enhance the implementation of integrative approaches involving mathematics (Stohlmann, 2018). However, the same author realizes that, despite the advantages of this approach, there is the need to develop more research on this matter. In this regard, at the 10th Congress of European Research in Mathematics Education (CERME 10) it was recognized the need for focusing on emerging technologies such as Augmented Reality in future European Researchers in Mathematics Education (ERME) congresses (Trgalová, Clark-Wilson, Weigand, 2018).

Augmented Reality (AR) is an emerging topic that has been gaining prominence due to its potential to combine the real world with virtual objects (Azuma, 1997; Hwang, Wu, Chen, & Tu, 2016) and to engage students in practice-based activities (Fotaris, Pellas, Kazanidis, & Smith,2017). Huang, Hui, Peylo and Chatzopoulos (2013) introduce Mobile Augmented Reality (MAR), referring that the big improvement of mobile devices enables to boost AR by providing easier and more attractive access to this tool.

However, there is limited research in primary education and a gap in the literature about the use of Augmented Reality (AR) within mobile games and applications (Koutromanos, Sofos, & Avraamidou, 2015). In our research we also did not find any studies that include interdisciplinarity among mathematics and other disciplines in the context of MAR games technologies in primary education. This is the main reason we believe our study will contribute to research by highlighting mathematics in a MAR game initially designed to learn about our Solar System. In this regard, our research question is: how to engage students to learn mathematics in the framework of a MAR astronomy game designed to promote learning about our Solar System?

This study is an extension of a previous work about a MAR astronomy game entitled “SolarSystemGO” (Costa et al., 2018), where the authors conclude that this strategy is effective to capture children’s attention and promotes learning of subject matters such as astronomy. In this paper, we begin by introducing the background and framework of this study. The following sections concern the methodology and data analysis. Finally, findings of our research and future work are presented.

BACKGROUND AND FRAMEWORK OF THE STUDY

This study is inserted into a broader pedagogical STEAMH (Science, Technology, Engineering, Mathematics and Heritage) project (Costa & Domingos, 2018) entitled Academy of Science, Arts and Heritage (AcademySAH) and coordinated by the first author of this paper. Created in 2013 at the Instituto Politécnico de Tomar (IPT) in central Portugal, the AcademySAH is a pedagogical intervention project (http://www.academiacap.ipt.pt/) at the primary school level that focuses on establishing a constructivist approach on students’ knowledge with the supervision of faculty members in a laboratory environment (Costa & Loureiro, 2016).

One of the intervention areas of this broader project is the design of hands-on experiments and prototypes intended to engage students to learn about STEAMH and to support primary teachers in fulfilling their mission of teaching. In this regard, it welcomes projects of higher education students under the supervision of the team’s project staff (faculty members). It is in this context, that several mobile games are designed to promote STEM learning as is the case of the MAR SolarSystemGO (SS_GO) game (Costa et al., 2018).

In this section, we describe the MAR SS_GO game and propose to consider the concepts of relative scales, distances and sizes, in order to explore mathematics in the framework of our Solar System.

The MAR SolarSystemGO game

The SS_GO game consists in a kind of planet's hunt, where the players, starting from a given coordinate (the Sun), and guided by an AR application (app), try to find the orbits of the Solar System planets and satellites in the least possible time, answering questions concerning each of the celestial bodies they encounter (Costa et al., 2018). At each stage (finding the orbit, "hunting" the planet and answering the question) the players score points (Figures 1 and 2). The player with the best score and the best time wins the game.

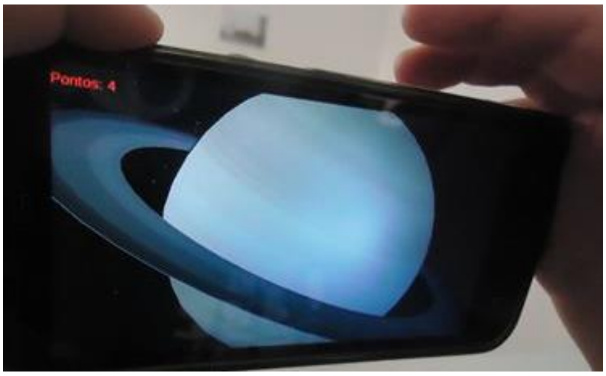

Figure 1. Saturn. This player has four points.

Figure 2. Neptune's question: Blue is my colour. How long lasts my day?

The first version of this game was designed in the school year 2016/2017 by higher education students as part of their final-year project in Digital Content Production (Master's degree) and in computer engineering (Bachelors' degree). A second version was developed in the school year 2017/2018 by three computer engineering students (Manso, Costa, Patrício, & Carvalho, 2019). This new version includes a Web platform that enables the teachers to interact with the system and include contents adequate to school syllabus, such as introducing the information about the planets and the questions according to the grade level of their students. Currently a third version is being developed by two other computer engineering students to improve its performance in order for anyone in the world to be able to play it. Also, it is necessary to provide the teachers with an easier access to the Web platform. When this is achieved our final target is to include the SS_GO game in a teachers' Continuing Professional Development Programme.

Working relative scales, distances and sizes in the framework of our Solar System

Planets' shape and the caracterization of their orbits in our Solar System are included in the curricular contents of primary education in many countries such as Portugal. Most of the time, this subject matter is approached based on images from school textbooks, where either planets' dimensions either their orbital radius around the Sun are not at scale (Costa & Silva, 2016). To achieve a better knowledge of our Solar System, the head of the STEAMH project (first author of this paper) launched the challenge of developing the modelling of the Solar System in the city of Tomar at scale. Inspired in MiMa project (www.mathematicsinthemaking.eu), it was decided to build the Sun and planets at scale and place them in Tomar city, as if the Sun had one meter of diameter. Civil enginneers from IPT designed and built the Sun with one meter of diameter and placed it in the IPT campus at the following coordinates: 39°36'02.4"N 8°23'27.9"W (Figure 3).

The planets were modelled in clay by children, at the Conservation and Restoration laboratory, during their participation in Easter 2016 holidays at the IPT campus (Figure 3). Before starting the activity, the head of the AcademySAH presented a brief introduction about our Solar System inquiring the participants about its dimension. One question was: If the Sun had one meter of diameter what would

be the size of the planets? After listening to children's opinions, it was explained to them that they were going to build the planets at scale according to the Sun's diameter of one meter.

Figure 3. The Sun and the planets built by children in Easter 2016 holidays.

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After building the planets, it was necessary to choose the locations in the city to place the planets according to their distance from the Sun, at scale. In this task, we used internet to mark the orbital radius of each planet searching for strategic places known by the citizens, as presented in figure 4. The first four planets are in the IPT campus. We also propose to discuss other Sun's diameter such as half of a meter, a basket-ball or even a tennis ball. For each case, teachers can reproduce the same activity developing mathematical tasks and discussing the planets sizes and where they could be placed in the map.

Figure 5. Modelling the Solar System on Tomar municipality considering the Sun with one meter of diameter.

But the STEAMH's project team is always designing new activities and one constrain of the above modelling is that the planets are static, which does not represent the reality of our Solar System because the planets circulate around the Sun. This is the reason we decided to use MAR technologies in order to promote a better understanding of our Solar System.

METHODOLOGY

Reeves (2006) argues the "need for a better approach to educational technology research" (p. 95) and sustains that educational technologists should undertake Design Research (DR) methodologies". Design-based researchers "make fundamental commitment via close collaboration (…) to developing interactive learning environments in the contexts in which they will be implemented" (Reeves, 2006,

p. 98). This context is designed and systematically changed by the researchers. DR is relevant for educational practice and "the research always incorporates systematic educational design processes" (Plomp, 2013, p. 17). In this premise, it presupposes the implementation of several cycles of DR. In our study, we intend to design and develop a MAR game in order to promote students' engagement to learn about STEM. In this regard this is a design research development study (Plomp, 2013).

Event	Duration	Date	Location	Children	Teachers
Christmas holidays	1 h	2016	Polytechnic campus	15	-
Summer holidays	3 h	2017	Polytechnic campus	17	-
Children's Day	30 min	June 1, 2018	City Garden	76	11
Summer holidays	3 h	June 2018	Polytechnic campus	19	-
Primary school class	2 h	October 2018	Santarem district	19	2

Table 1. Game implementation tests over two school years

In this research, we use a qualitative methodology and an interpretative approach (Cohen, Lawrence, & Keith, 2007). Participants are children aged 7 to 14 years old and the teachers who accompanied them during the experiences (Table 1). Data collection includes participant observation, interviews and questionnaires. First author of this paper is a participant observer and the second author is responsible for the triangulation and validation of the collected data.

DATA ANALYSIS AND DISCUSSION

In this section, we discuss the five cycles of design research of the SS_GO game that occurred for two school years. With a DR methodology, after each experience with primary students, the game is upgraded to improve it, in order to be implemented in the next DR cycles. One of the challenges of this game is to design the Solar System at scale (for example as if the Sun had one meter of diameter or if it was the size of a basketball, etc), in order to provide the users with an idea of the Solar System dimension, by relating the Sun's diameter with the planets' diameters and their orbits (orbital rays).

The first cycles of Design Research in informal learning contexts (school year 2016/2017)

Because of space limitations it is not possible to present in detail each cycle of DR. For this reason, we present the DR phases of the first cycles (Tables 2 and 3) and the summary of the following cycles.

DR phases	DR activity	Outcome
Preliminary research phase	A need to design and develop a MAR game. Several meetings with the researchers and designers' team to discuss the needs, literature review, and what and how to design.	*SolarSystemGO* prototype.
Prototyping phase	The researchers and designers' team make several simulations in order to test the prototype. Literature review to find out how to improve the prototype and more meetings to promote its development.	Recommendations to improve the prototype. Prototype indoor version.
Summative evaluation phase	First experience with the target public: primary school students. Participant observations, questionnaires and interviews to the students are performed. Reflection and discussion about this experience.	2016 Christmas school holidays in the Polytechnic Campus. Upgrade the prototype in order to design an outdoor version.

Table 2. DR phases of the *SolarSystemGO* game – 1st cycle (1st semester of 2016/2017).

First implementation test to evaluate the impact of the SS_GO game with primary school students occurred in the IPT campus during children's 2016 Christmas school holidays. This first experience was an indoor version with the mobile device. This version had several limitations. For example, the users had to wait a while for the orbits and planets were not easy to track. Only one older student finished the game. Almost all the other students, specially the youngest, gave up playing after ten to fifteen minutes looking for planets that were not easy to find or to track.

This first experience was very important for the game designers (the higher education students) to understand the limitations of the software related to the game's performance and what needed to be corrected and improved for the next implementation test. One important challenge was to develop an outdoor version. After the game designers improved the game, a second test was performed at 2017 Summer holidays at the IPT. Table 3 represent the DR phases of the 2nd cycle of the SS_GO game.

DR phases	DR activity	Outcome
Preliminary research phase	Developing the SS_GO prototype in order to design an outdoor version that engages students. Meeting with the researchers and designers' team to discuss problems related the game's performance.	SS_GO prototype upgraded: outdoor version.
Prototyping phase	The researchers and designers' team make several simulations in order to test the prototype. Literature review to find out how to improve the prototype and more meetings to promote its development.	Recommendations to improve the prototype. Prototype upgraded.
Summative evaluation phase	Second experience with primary school students. Participant observations, questionnaires and interviews to the students are performed. Reflection and discussion about this experience.	SS_GO engages students and promotes learning about the Solar System. Developing the SS_GO prototype in order to be performed outside the IPT Campus.

Table 3. DR phases of the SS_GO game – 2nd cycle (2nd semester of 2016/2017).

In the experience performed in the 2nd cycle, students completed all the tasks assigned to them and answered to all the questions included in the game, showing a great motivation and engagement to play it (Costa et al., 2018). These results lead the researchers to prepare the 3rd cycle with the aim to upgrade the game in order to be performed outside the IPT campus.

Next cycles of design research (school year 2017/2018)

In the school year 2017/2018, another group of students continued to improve the SS_GO game. Two more cycles of DR (3rd and 4th) occurred in informal learning contexts and were very useful for the improvement of the software until finally it was prepared to be performed in a primary school (5th cycle of DR). The formal experience took place with a group of twenty 4th grade students at a primary school (Manso et al., 2019). The activity starts in the classroom with a power point presentation about the Solar System, including planet dimensions and its characteristics. After this presentation, the class is organized in groups. Each group has a mobile phone with the SS_GO app and they go outside to play the game. After finishing the game, they return to the classroom to find out who's the winner. In order to understand the new architecture of this version and the results of the questionnaires applied to assess the impact of the game in the participants, the reader may see Manso et al. (2019).

In the end, students and their teacher answered a questionnaire. Students answered that they enjoyed playing the game and would gladly repeat the experience. In fact, all of them finished the game and answered all the questions about the planets. The teacher referred that the SS_GO game was very adequate to her students and that it was a way of providing the students with a real experience that improves their learning about the Solar System. Also, she was very excited with the possibility of interacting with the Web page in order to design her own information and questions.

FINAL CONSIDERATIONS AND FUTURE WORK

This paper proposes a MAR app to promote interdisciplinarity in the framework of STEM education. The SS_GO game is being developed with a DR methodology by undergraduate higher education students from a Portuguese polytechnic. After several cycles of implementation of the game in informal and formal learning environments, we verified that this game can engage children to play it and to learn about our Solar System. Also, primary teachers consider that the game promotes students' interest to learn school contents. In particular, we argue that this game can be a resource to explore mathematics, namely working the notions of relative scales, distances and sizes.

Our next focus is to develop more mathematical tasks in the framework of the SS_GO game, in order to engage the students and to promote learning about this subject matter. For example, more than working scales with the big numbers of our Solar System it is possible to develop other topics by providing information and mathematical problems using the Web platform. Next DR cycles will be focused on this matter. Final target is to introduce this game in the Continuing Professional Development Programme of the broader STEAMH project. Based in our research and experience in the field, we sustain the importance of developing MAR games that engage students and motivate them to learn interdisciplinary subject matters adequate to primary school syllabus.

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