An Augmented Reality Information System Designed to Promote STEM Education

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***Abstract*—The PlanetarySystemGO is an information system that is being designed to promote STEM education in the context of planetary systems of the Universe. Besides providing information about the celestial bodies of the Universe, it also provides information about its dimensions being possible to explore different scales. The information system includes a mobile augmented reality location-based game and a web application with a back-office. The game that can be played with a smartphone consists in a sort of planet hunt in an outdoor space. The players need to walk in the real world to find virtual objects, which are celestial bodies such as stars or planets that appear on the screen of the mobile device. During the several stages of the game, information about the celestial bodies is provided and a set of multiple-choice questions needs to be answered. The player gains points as he succeeds by either finding the planets' orbits, the celestial bodies or answering the questions correctly. The back-office is responsible for administering learning objects and data management through a web application running in a web browser. Through the back-office, teachers can introduce contents about the celestial bodies that they intend their students to learn and also the set of multiple-choice questions that they find appropriate in order to evaluate their students' knowledge about these contents. Therefore, the PlanetarySystemGO may be implemented in any level of school curricula to promote STEM learning.**

Keywords – Mobile augmented reality; location-based games; serious games; STEM; planetary systems.

I. Introduction

There is an increasing call to promote STEM (Science, Technology, Engineering and Mathematics) education to better prepare students to the increasing challenges of the real world [1]. In this regard, the integration of the subjects included in the STEM acronym is defended in the literature and is part of the school curricula in several countries [2].

Augmented Reality (AR) is an emerging technology that permits to combine the real world with virtual objects and runs interactively in real time [3]. In addition, AR games have the potential to engage students in practice-based activities [4]. Based on a literature review on the use of AR technology to support STEM learning, Ibáñez and Delgado-Kloos [5] refer that few studies provided students with assistance in carrying out learning activities. The same authors sustain that researchers need to design features that allow students to acquire basic competences related with STEM disciplines. Moreover, there is a gap in the literature about the use of Mobile Augmented Reality (MAR) applications in formal learning environments such as schools [6,7].

This paper presents an information system that is being designed to promote STEM education in the context of planetary systems of the Universe, such as our Solar System. The PlanetarySystemGO information system architecture includes a MAR location-based application and a web application with a back-office. The MAR application can be used on mobile devices such as smartphones or tablets that have camera, Global Position System (GPS), gyroscope and accelerometer. It consists of a serious game that is a sort of planet hunt in an outdoor space. The players need to walk in the real world to find virtual objects, which are orbits of planets and celestial bodies such as stars, planets or satellites that appear on the screen of the mobile phone. The back-office provides the necessary definitions required for the mobile device is responsible for managing learning objects and data management through a web application running in a web browser. Through the back-office, teachers may introduce the contents about the celestial bodies they intend their students to learn about and also the set of multiple-choice questions that they find appropriate in order to evaluate their students' knowledge about these contents. Therefore, the PlanetarySystemGO may be implemented by teachers in schools according to the grade level they teach.

The paper is structured as follows: section 2 presents the background and context of the study, section 3 the functionalities of the PlanetarySystemGO information system, section 4 its architecture, and finally conclusions and future work are presented.

II. Background and Context of the Study

The Academy of Science, Arts and Heritage (AcademySAH) is a pedagogical intervention project that occurs at the Instituto Politécnico de Tomar (IPT) since 2013, and focuses on establishing a constructivist approach of knowledge (www.academiacap.ipt.pt). The team members are higher education professors in the areas of electrical and computer engineering, mathematics, biology, physics and chemistry, graphic arts, archeology, amongst others. Besides several activities in the community targeted to students and teachers, the AcademySAH also promotes projects of higher education students from IPT, under the supervision of the team's project staff in order to develop hands-on experiments and prototypes, including mobile games, amongst others.

Some examples intended to promote learning about STEM are "Sonicpaper" related to sound [8], and "SolarSystemGO" related to our Solar System [9]. In a preliminary work related to the implementation of the SolarSystemGO game, which was a version hard coded on the app, the authors concluded that AR games catch children's attention and promotes learning of interdisciplinary subjects related to our Solar System.

The PlanetarySystemGO is an upgrade of SolarSystemGO to an information system that includes new functionalities such as the possibility of including other planetary systems of the Universe [10]. With game based-learning purposes, the PlanetarySystemGO information system is being designed in the framework of Problem-based Learning. This is an active engagement pedagogy that is very relevant for engineering education because it better prepares the engineering students for their future professional practice, since it promotes students learning and leads them to achieve 21st century skills such as problem analysis, problem solving, communication, teamwork, interdisciplinary knowledge, participant-directed learning, critical thinking and creativity, amongst others [11]. Every school year, a new group of computer engineering students takes the challenge of keeping upgrading the information system, in order to improve its performance and to include new functionalities.

In the school year 2019/2020, the main challenges proposed to the computer engineering students were to introduce more features in order to:

- increase the MAR game's immersive experience

- make the back-office more user-friendly to teachers

- take advantage of the web application as a resource to be used by the teachers in the classroom.

In this regard, several tasks were proposed to computer engineering students in the context of their final project before graduation. Among them are the inclusion of asteroids and moons, new multimedia contents related to the celestial bodies and the development of the web application to provide an interactive modelling of the Solar System on a georeferenced map. Three groups of computer engineering students choose the PlanetarySystemGO as their final project in order to improve its performance and include more functionalities. The students were supervised by higher education teachers from IPT (four first authors of this paper).

III. FUNCTIONALITIES OF THE INFORMATION SYSTEM

In this section, we describe the functionalities of the PlanetarySystemGO information system by highlighting the MAR application, and the web application that includes a back-office. All those components work as a whole and interact with each other, in order to comprise the goals of the information system, which is to provide learning about planetary systems in an interdisciplinary way.

A. *The location-based augmented reality application*

The location-based MAR application can be used on mobile devices (e.g., smartphones or tablets) that have a camera, GPS, gyroscope and accelerometer. Because it requires GPS it is an outdoor game. Players need to walk in the real world to find virtual objects that consist of orbits and celestial bodies such as stars, planets, satellites or asteroids, amongst others. The real world is captured by the mobile camera and the user's location is tracked by GPS technology.

Learning objects are celestial bodies, orbits of planets, information about the celestial bodies, sets of multiple-choice questions, amongst others. An event is characterized by a planetary system parametrized with the following definitions:

- GPS coordinates of the star in the real world,

- scale that defines the game's arena and the size of the celestial bodies including the orbital radius of each planet circulating around the star,

- information about the celestial bodies included on the chosen planetary system,

- multiple-choice questions about the celestial bodies included on the planetary system.

There are two types of game modes: autonomous game and game provided by a previous planned event. In the first one, when the player starts the game (e.g., holding a smartphone) his location in the real world (gathered by GPS coordinates) will be the location of the star of the planetary system in the virtual world. Moreover, the game arena must be defined by choosing a certain scale according to the player's preferences and the outdoor space available to walk in the real world. The scale corresponds to the orbital radius of the last planet. In the case of our Solar System it corresponds to the Neptune's orbital radius.

The second type of game mode is defined by an event that was previously prepared by the teacher through the web application. In this case, the teacher choses the GPS coordinates of the star of the planetary system in the real world, that may be for example the center of the school campus where the students are inserted in. Moreover, the scale arena and the dimensions of the planets, their velocities around the star, the information about the celestial bodies that teachers intend to transmit to the students and the set of multiple-choice questions to assess students' knowledge about the characteristics of the celestial bodies, amongst other definitions. Each predefined event is associated with an identification code that will be used in the mobile device to download the application, in order to play the game according to the teacher definitions (Figure 1). Before starting the game, students choose a nickname that will serve to catalogue data collected during the game, which will be available to the teachers through the back-office. In this mode, the star and the planets are in the same position for all the players. Students should start the game as close as possible to the position defined for the star of the planetary system in the real world.

The game may be played in online or offline mode. Internet is only necessary to download the autonomous game or the event predefined by the teacher. The offline mode minimizes problems related to lack of internet in outdoor spaces and performance issues related to interconnectivity. When the game, provided by an event predefined by the teacher, is played in offline mode, the information is stored in the device and sent to the back-office when it gets online. Therefore, teachers will have access to all the information about the performance of their students during the game. If the game is played online, the teacher will have information about the position of the students and their performance in real time through the web application.

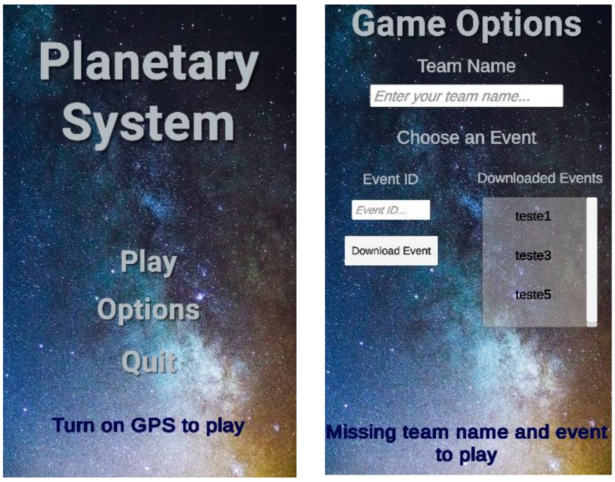

Fig. 1. Starting the game.

The game should start with the player's position in the real world representing the star. In this case, the star will be the first virtual object that appears in the screen of the mobile device. After capturing it, a question about its characteristics appears with 4 answer options (Figure 2). When pressing the wrong answer, the option is blocked and turns its color to red. When the correct answer is selected, it turns its color to green and the player receives points. If he chooses the right answer in the first choice, he receives 4 points, 3 points in the second choice, 2 points in the third choice and 1 point in the fourth choice.

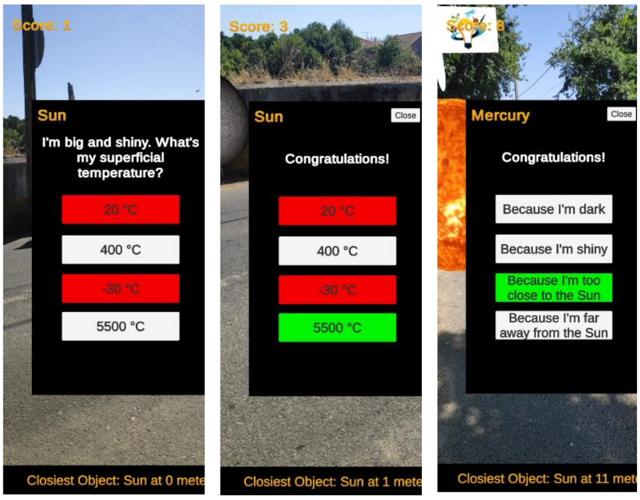

Fig. 2. Multiple-choice questions about the Sun and Mercury.

After answering the question about the star, the goal is to “travel” through the planetary system to find other orbits and celestial bodies such as planets or moons and answer the respective questions. Moreover, if the player touches the celestial body, information about its characteristics appears in the mobile device screen. The player gains points when he finds the orbit, captures the celestial bodies or answers correctly the questions about them. Figure 3 presents some sequences of the game when the planetary system is our Solar System. In this sequence, the player accumulated 37 points.

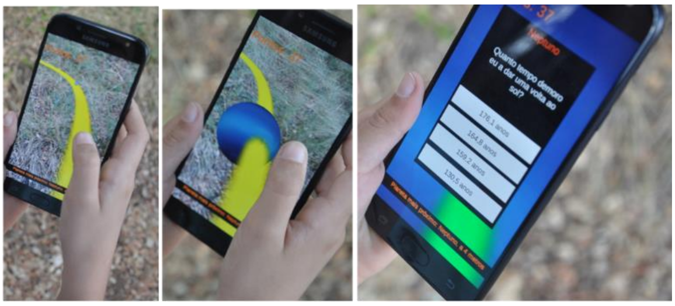

Fig. 3. Sequences of the game.

Figure 4 shows the Moon circulating around the Earth and the respective question. Moreover, it is possible to see its shadow on the Earth. Once the orbits are found, they turn their color from yellow to green, and the celestial body gets bigger as the player gets closer to it. Finally, after correctly answering the question, the body is identified with a flag containing the AcademySAH logo. With this information, the player knows which celestial bodies he already captured and the ones he still needs to find.

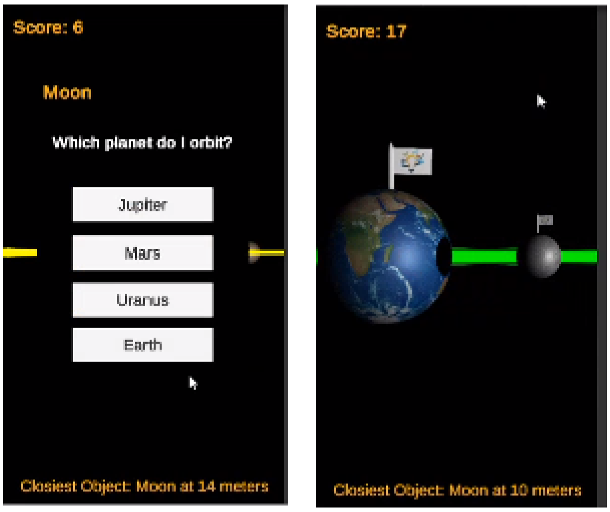

Fig. 4. Question and the Moon circulating around the Earth.

The MAR game has been implemented in informal and formal learning contexts, including several primary schools, and has proven to engage the students to play it and also to be very effective in promoting students' interest in learning about the Solar System [10]. The in-service teachers of the classes, where the game was implemented, also considered that it was adequate for the school context and that this was a more effective way of teaching students about these contents in a much more motivating way.

B. The web application

The web application has evolved with the addition of tools to allow the planetary systems modelling over any part of the world on a georeferenced map. In this regard, a given point on the map is defined as the star and the application provides the planetary system modelling on the selected location. Moreover, it can be used by teachers in the classroom without having to go outdoor, as is the case of the MAR game that needs GPS. In this regard, it is possible to view the celestial bodies (which are in motion) with different levels of detail through a menu and by manipulating the map zoom (Figure 5). The inclusion of celestial bodies and planetary systems that group them together in repositories allows teachers to prepare their own lessons or sharing pedagogical contents among them. In this regard, we define three types of repositories in the information system: The public repository that is accessible to all users; the repository of an organization (e.g., school or group of schools) that is accessible only by the teachers of that organization and the private repository that is accessible to an individual person.

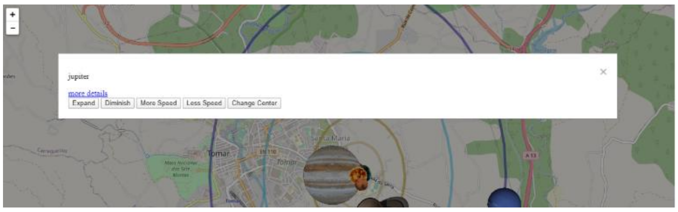

Fig. 5. Interaction with the Solar System on a Map of Tomar, Portugal.

Next, we summarize some examples of functionalities that may be provided by the back-office:

- clone celestial bodies (includes physical characteristic such as textures, orbital radius, velocities, and also information about the celestial bodies and questions to assess students' knowledge)
- clone planetary systems already parametrized in the repository
- introduce new planetary systems and celestial bodies
- introduce information about the celestial bodies
- introduce multiple-choice questions
- provide information about the results of the game

Events are created by the web application that gather all the information provided by the back-office. After playing the game, all the information such as scores, the questions with more correct answers and number of attempts to answer correctly a question, if the players searched for information about the celestial body, etc, will be available in the back-office. Therefore, the teachers can evaluate the performance of their students during the game. For example, Figure 11 shows the graphics that resulted from an implementation of the game that took place in a primary school, where the application was played with 6 teams, with each team using a mobile phone.

By using a menu, different interactions are provided, such as changing the scales of the planetary system by using "Expand" and "Diminish" buttons, and also moving the Solar System centre (the star) with the planets to another place on a map (e.g. school), which is achieved by using the "Change Centre Button". Figure 5 shows the Solar System on Tomar city (Portugal) and Figure 6 shows the Solar System on Malaga city.

Moreover, it is possible to change the planet's speed by using "More Speed" and "Less Speed" buttons. This feature allows an interactive way to model the Solar System on a map in a web environment with georeferenced data. Besides exploring science contents related to the Solar System, we propose to explore mathematics. Teachers may use different scales to model the Solar System. Furthermore, they can use the map scale to ask students the distance of the orbits from the Sun on the map, amongst other possibilities. In addition, if the map represents their local community, the teacher can teach contents of the Solar System based on previous knowledge of their students related to their community. For example, the Sun may be placed on the school and the planets may circulate around the Sun overlaid on the map of their municipality. Thus, the teacher may discuss with the students where the orbits of each planet are placed on the map according to a chosen scale. For example, research if it is near their homes or heritage monuments that they recognize, and also relate the size of the planets on the chosen scale with the size of real objects that they recognize.

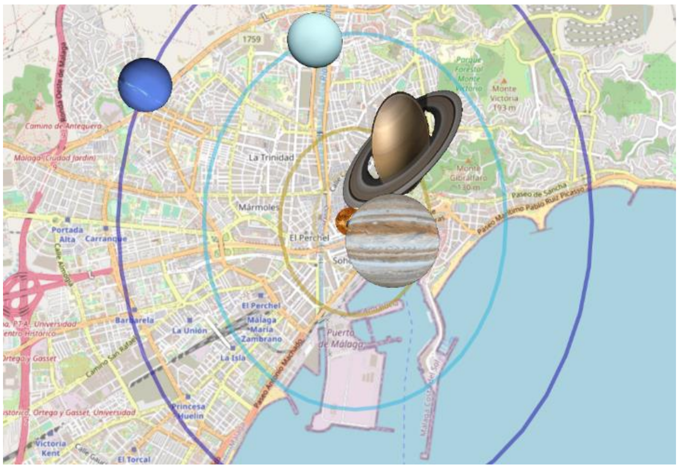

Fig. 6. Modelling the Solar System on Malaga city (Spain).

With the described functionalities, teachers can provide different parametrizations of the planetary systems just by pressing buttons, which will be automatically visualized on the simulation provided by the web application. Moreover, they can create an event with a chosen parametrization that they intend to explore with their students, which afterwards will run on the MAR application.

C. *The back-office*

With the inclusion of an information system that communicates with the MAR application, it is possible to provide the player with different experiences every time he plays the game. In this regard, the back-office is responsible for managing the information that will be made available in the MAR application. Moreover, teachers may introduce the contents that they find adequate to teach their students. Furthermore, all data collected by the MAR application during the game will be send to the back-office, in order for teachers to assess students' performance when playing the game.

Learning objects, associated to celestial bodies, provide information about their characteristics through multimedia, such as text, images, or animations. In addition, they include sets of multiple-choice questions to be answered by the player. Celestial bodies and the planetary systems that group them together are stored in repositories included in the back-office (Figure 7). By pressing the celestial body, it is possible to see or to introduce information about its characteristics (Figure 8).

In the menu of the celestial body (Figure 7) it is possible to visualize the existing multiple-choice questions (Figure 9) or to edit and insert new sets of multiple-choice questions (Figure 10).

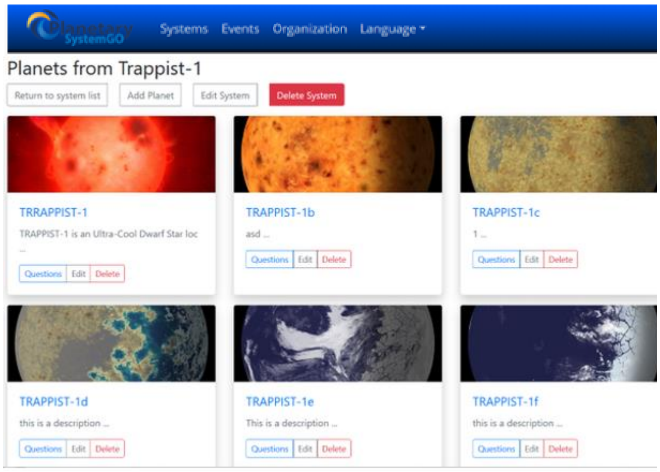

Fig. 7. Part of the repository that includes the Trappist System.

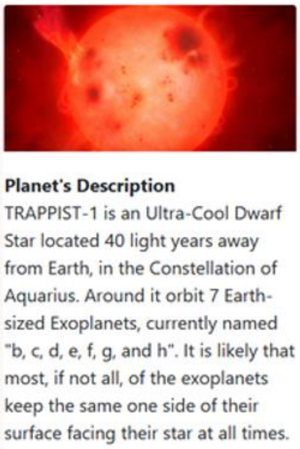

Fig. 8. Information about the Trappist star.

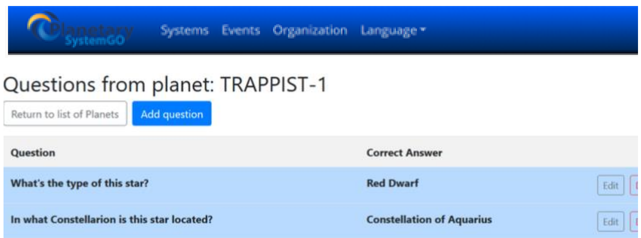

Fig. 9. Questions about Trappist star.

Fig. 10. Edit question about the Trappist star.

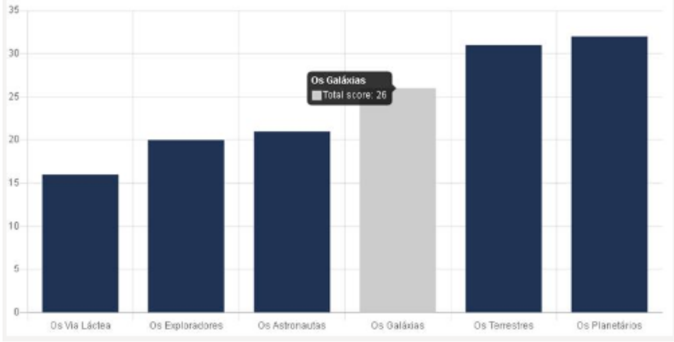

Fig. 11. Team results obtained from the back-office.

As can be seen in the figure, the winning team (Os Planetários) won 32 points and the worst ranked team (Os Via Láctea) got 16 points. By placing the mouse cursor over the graphic, the exact punctuation is revealed, as can be seen in the team "Os Galáxias" that scored 26 points.

IV. Architecture of PlanetarySystemGO

In this section, we describe the PlanetarySystemGO architecture. The PlanetarySystemGO information system is mainly composed by two components, android application and a web application, that share data on a common server. The MAR game is played on the Android application developed in Unity. The web application runs on a WAMP server (Windows, Apache, MySQL and PHP) and includes a back-office and front-office accessed by several web browsers (Figure 12).

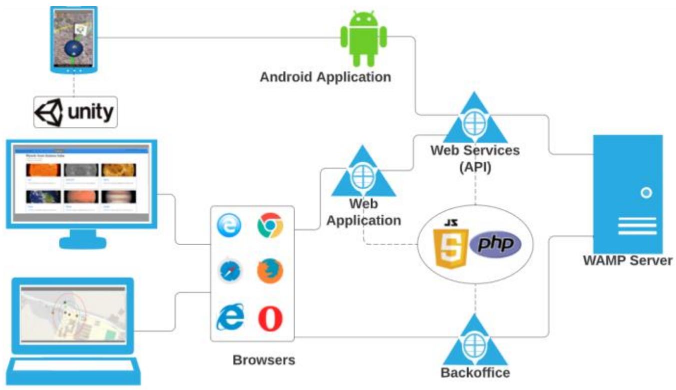

Fig. 12. PlanetarySystemGO architecture.

The server provides an API (Application programming interface) through REST (Representational State Transfer) web services to be consumed by the Android application. All communication in this API uses JSON (JavaScript Object Notation) standards for data representation.

V. Final Considerations and Future Work

This paper presents an information system that is being designed to promote STEM education in the context of the planetary systems of the Universe, such as our Solar System. Through the back-office, the information system allows the introduction of school contents, for example related to the Solar System. Therefore, teachers can introduce information about the celestial bodies of the Universe and also a set of multiple-choice questions in order to assess students' knowledge about the contents they intend them to learn.

The contents introduced in the back-office will be available to be used in the MAR application. After playing the game, all the data collected by the MAR application is accessible to the teachers through the back-office, namely the scores of the players, the answers that students gave to the questions including number of attempts to get the correct answer and the time it took to answer correctly, and also if they consulted the available information about the celestial bodies.

Furthermore, the web application can provide the modeling of the planetary systems on a map by placing the star on a certain coordinate. Moreover, it parametrizes the planetary system with a chosen scale by giving dimensions to orbital radius and diameters of the celestial bodies. By just pressing a button from the menu of the web application it is possible to change the location of the planetary system to another location of the map. Teachers can use this application in the classroom to explore different scales for example in the map of the region where the school is inserted in. Therefore, students may have an idea of the dimension of the planetary system comparing for example the orbital radius of planets with distances on the map that they recognize because it belongs to the environment where they live including the school where they go five days in a week.

Because of the COVID 19 pandemic, it was not possible to perform implementation tests with the whole information system in schools. For example, we intend that teachers use the PlanetarySystemGO to introduce contents and to use them to teach their students in order to assess its impact on schools. If this scenario continues, we will prepare an online intervention because the web application can be used in videoconference by sharing the screen of the teachers' computer with the students.

However, several tests of the MAR application with our Solar System where successfully implemented in primary schools [10]. Because of these good results already obtained during the implementation of the MAR application with previous versions, we believe that the PlanetarySystemGO information system will be successfully implemented in schools. In fact, teachers can use the PlanetarySystemGO to teach school contents and also to assess students' knowledge about those contents at any level of school curriculum. The MAR application is a location-based game that needs to be played in an outdoor space with mobile devices, but the web application can be used in the classroom. Finally, we argue that teachers may use the different components of the PlanetarySystemGO information system, that interact with each other, to prepare interdisciplinary classes related to planetary systems, according to the school level they teach.

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