DESIGN OF A MOBILE AUGMENTED REALITY GAME IN THE FRAMEWORK OF PROBLEM-BASED LEARNING

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Abstract

There is a growing call for the introduction of problem-based learning methodologies in engineering curriculum in order to promote students learning and lead them to achieve 21st century skills. This paper presents a case study about three computer engineering students who designed an Augmented Reality (AR) game in the framework of their final project before graduation. Supervised by higher education teachers from a Polytechnic Institute of Portugal, the students took the challenge of designing a mobile AR game to promote students’ interest to learn about our Universe. In order to develop the application, the engineering students had to use interdisciplinary knowledge related to mathematics, databases, programming and information systems, amongst others. Furthermore, it demanded the use of new tools and technologies. Another big challenge was the fact that some contents such as 3D modelling and game programming were not learned in the scope of their course, which brought greater challenges to this project. Despite the demands of the project, the students succeeded in the creation of an AR game. In the course of the application development, the game designers had the opportunity to perform several experiences with primary school students in order to test their feedback about the game and improve it after each experience in the field. We conclude that with the problem-based learning methodology the engineering students were able to implement knowledge from their course and, also, to acquire new knowledge in order to succeed in the design of the AR application.

Keywords: Engineering education, problem-based learning, mobile games, augmented reality.

1 INTRODUCTION

There is a growing call for the introduction of problem-based learning methodologies in engineering curriculum in order to promote students learning and lead them to achieve 21st century skills. In fact, problem-based learning pedagogies and student-centred learning are considered to be the future of engineering education. For example, in [1], the authors sustain that Problem-based Learning (PBL) is an active engagement pedagogy that is very relevant for engineering education. According to these authors, PBL provides the engineering students with the opportunity to resolve design solutions. In this sense, this approach is considered to better prepare the engineering students for their future professional practice, which usually does not occur in traditional engineering pedagogy [2]. In the context of PBL, students need to articulate about what they know and about what they need to learn more [3]. In this regard, they have the responsibility to seek for relevant information and process it in order to develop a viable solution or prototype.

Augmented Reality is an emerging topic that has been gaining prominence due to its potential to combine the real world with virtual objects [4] and to engage students in practice-based activities [5]. The increasing improvements in mobile devices permits the use of Augmented Reality applications, which gives an easier access to this tool [6]. However, there is a gap in the literature about the use of Augmented Reality within mobile games and applications [7]. In particular, the design of mobile augmented reality applications targeted to formal learning environments is missing, which means that it is relevant to keep developing research in this matter.

This paper presents a case study concerning three computer engineering students who designed an Augmented Reality (AR) application (app) in the framework of their final project before graduation. Supervised by higher education teachers from the Polytechnic Institute of Portugal, the students took the challenge of designing a Mobile Augmented Reality (MAR) game to promote students’ interest to learn about the Universe. This is a challenging real-world problem that demands a final product or prototype. In order to concretize this challenge, students had to work cooperatively to search relevant
information and contents from their engineering course and, also, had to learn new contents outside the scope of their course to achieve the objectives of the project. These tasks involve 21st century skills required for engineering curriculum, such as: problem analysis, problem solving, communication, teamwork, interdisciplinary knowledge, participant-directed learning, critical thinking and creativity, just to name a few. This is one of the main reasons PBL pedagogies are recommended in engineering education.

Our research contributes to literature by highlighting how three computer engineering students designed a MAR game, in the framework of PBL pedagogy, targeted to promote students’ interest to learn about the Universe. In this regard, our research question is: What knowledge was necessary for the students to succeed in the design of the MAR game? In particular, what curricular knowledge was used and what new knowledge was acquired by the students to design the desired/requested prototype? What engineering skills were developed when designing the game?

In this paper, we begin by introducing the background and context of this study that is framed in a broader pedagogical interdisciplinary intervention project, which is based on a constructivist approach of learning (http://www.academiacap.ipt.pt/). The following sections concern the PBL pedagogy, the methodology, the case study about the design of the MAR game and findings and results of the study. Finally, conclusions and implications for the future are presented.

2 CONTEXT OF THE STUDY

In this section, we present the broader pedagogical intervention project and, in particular, the PlanetarySystemGO game.

2.1 The Academy of Science, Arts and Heritage (AcademySAH)

The Academy of Science, Arts and Heritage (AcademySAH) is a pedagogical intervention project that focuses on establishing a constructivist approach of knowledge of the students, with higher education teachers’ supervision, in a laboratory environment [8]. This project was proposed to the Instituto Politécnico de Tomar (IPT), in central Portugal, by the first author of this paper and approved by the IPT Directive Board at 2013.

This is an interdisciplinary project related to STEAMH (Science, Technology, Engineering, Arts, Mathematics and Heritage) subjects that is coordinated by the first author of this paper [9]. The team members are higher education teachers in the areas of electrical and computer engineering, mathematics, biology, physics and chemistry, graphic arts, arqueology, amongst others. Besides promoting hands-on activities during students’ holidays at a Polytechnic Institute campus and at primary schools, the AcademySAH also welcomes projects of higher education students under the supervision of the team’s project staff. In this context, several hands-on experiments and prototypes, including mobile games, are designed to promote STEAMH learning. Examples are “Sonicpaper” [10] and “SolarSystemGO” [11].

Concerning the SolarSystemGO game, in [11] the authors present a preliminary study about the implementation of this first version that was performed in an informal learning environment, during students’ school holidays in the Polytechnic’s campus. First conclusions are that this approach is very efficient to catch children’s attention and promotes learning of interdisciplinary subject matters related to our Solar System. With this experience in the field, our next challenge was to upgrade the game in order to provide the users with more diversified experiences. Also, our aim is to perform the game in formal learning environments and finally in a teachers’ professional development context.

2.2 The PlanetarySystemGO game

The PlanetarySystemGO is a Mobile Augmented Reality (MAR) application (app) targeted to promote learning about the Universe. This is a location-based MAR game, in which the players starting from a star, and guided by the app, find the orbits and the planets of a planetary system. At each stage of the game (finding the orbit, “hunting” the planet and answering the question) the player gains points. Figure 1 presents the sequences of the game in the particular case of our Solar System.
This version is an evolution of a previous one entitled SolarSystemGO, initially designed to promote STEM learning in the framework of our Solar System. The new architecture of the PlanetarySystemGO is intended to enable the user to have different experiences every time he plays the game. Also, in this new version, the creation of a back-office allows the possibility of including information about the universe bodies such as stars and planets, textures and sounds, amongst others. In particular it is possible to introduce new multiple-choice questions, according to the Planetary System in study. For example, this characteristic gives the possibility for teachers to adapt the application to any level of school syllabus and develop a set of multiple-choice questions to assess students’ learning about the subject they intend their students to learn [12].

3 PROBLEM-BASED LEARNING

Literature recommends the introduction of innovative strategies of learning that better prepares the students for the 21th century challenges. In this regard, in [13] it is sustained that it is crucial to shift from traditional programmes of training towards “designing more real-world problems as anchors around which learners achieve the learning outcomes through the process of actively working on unstructured problems” [13, p. 12], as illustrated in figure 2.

![Figure 2. A model of curriculum shift](image)

According to this author, the introduction of real-life problems is a way of leading the students to “learn how to learn”, which is included in problem-based learning principles. In fact, if learners are active problem solvers of real-life problems and teachers are mediating coaches, “the learning paradigm would shift towards attainment of outcomes desired in a knowledge era” [13, p. 12]. In particular,
problem-based learning curricula may respond to industry requests that sought for attributes such as problem-solving, communication, teamwork and interpersonal skills.

Problem-based learning is considered an active engagement pedagogy that is very relevant for engineering education [1] because it better prepares the engineering students for their future professional careers. Problem-based Learning (PBL) pedagogies have been defined and studied by several authors. For example, in [3] it is stated that:

PBL is an instructional (and curricular) learner-centered approach that empowers learners to conduct research, integrate theory and practice, and apply knowledge and skills to develop a viable solution of a defined problem. [3, p. 12]

According to this author, there is the need of the existence of a tutor to guide the students' learning process and, also, the selection of interdisciplinary problems to solve is critical. In this direction, it is crucial to use real-world problem scenarios and to engage students' motivation and independent learning by promoting collaborative learning [13]. This author highlights that “learning to learn and lifelong learning are important goals” and that there is an increasing demand for workers to develop communication skills. In this regard, in [14, p. 6] the authors refer the development of specific skills that are desirable outcomes of an undergraduate education:

1. Think critically and be able to analyse and solve complex, real-world problems;
2. Find, evaluate, and use appropriate learning resources;
3. Work cooperatively in teams and small groups;
4. Demonstrate versatile and effective communication skills, both verbal and written
5. Use content knowledge and intellectual skills acquired at the university to become continual learners.

The same authors state that:

PBL fosters the ability to identify the information needed for a particular application, where and how to seek that information, how to organize that information in a meaningful conceptual framework, and how to communicate that information to others [14, p. 7].

In summary, PBL approach is considered an innovative strategy that better prepares the students to correspond to the 21st century challenges, leading them to achieve specific skills recommended to succeed in future careers. In particular, PBL is an engagement pedagogy that is very relevant for engineering education. For this reason, it is crucial to introduce this approach in higher education institutions, in order to better prepare the students for the challenges of real-life [14].

4 METHODOLOGY

In this research, we use a qualitative methodology and an interpretative approach by means of a case study [15]. According to [16], a case study is an empirical investigation that looks at a contemporary phenomenon within its real-life context. Participants in this paper are three engineering students who developed the MAR game in the school year 2018/2019.

Data collection includes participant observation (authors of this paper are participant observers), informal interviews and the written report presented by the students in the end of their project. Participant observation and informal interviews took place in the meetings with the students in order to develop the game and, also, during the implementation tests that occurred with primary school children in informal learning environments, and in a formal learning environments at a primary school with a 4th grade class (Table 1).

<table>
<thead>
<tr>
<th>Table 1. Implementation tests of the game.</th>
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<tbody>
<tr>
<td><strong>Date</strong></td>
</tr>
<tr>
<td>World Children's Day</td>
</tr>
<tr>
<td>AcademySAH summer edition</td>
</tr>
<tr>
<td>Visit to a Primary school class</td>
</tr>
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</table>
The implementation test in real-world environments, with the targeted public of the game, were crucial for the game designers to assess its impact in the public and, also, to diagnose problems related to its performance. After each experience in the field, a reflection was performed with the engineering students’ supervisors in order to plan how to upgrade the game to achieve better results in the next experience.

5 DESIGN OF A MOBILE AUGMENTED REALITY PLATFORM

The PlanetarySystemGO, is a MAR platform created with the Unity3D game engine. In this section, we begin by giving an account about the architecture of the PlanetarySystemGO platform that was developed by the three engineering students, in the school year 2017/2018, supervised by the authors of this paper (Figure 3). For a detailed description of this architecture, the interested reader is directed to [17].

The architecture of the PlanetarySystemGO platform, represented in Figure 3, is divided into three components: Web platform, database server and mobile app. The Web platform communicates with the mobile app and is responsible for the data management on the server side and provides the graphical interface for the management of database. Furthermore, it manages the planets and planetary systems; and it provides each gamer results, including the score. The back-office system allows the instructor to insert, or create, planetary systems at will and, also, the events related to the game experiences. The events include the option of choosing a particular planetary system; the parameters of the game such as GPS coordinates of the star in the real world and scales of the objects; and the multiple-choice questions that will appear in the app. The contents of the mobile app are the events, that are composed by a star and by a set of planets that orbit the star. The camera of the mobile phone is the sensor responsible for capturing reality in order to overlay it on the virtual scenario that includes the planetary systems.

The web application includes the webservice with the JSON API (JavaScript Object Notation Application programming interface) necessary to communicate with the app and the back-office to manage the information included in the database. The database is managed by the SQL server. The web application is running in a server with windows server.

The following table (Table 2) presents the contents of the curricular units used to develop the PlanetarySystemGO platform.

<table>
<thead>
<tr>
<th>Curricular Contents</th>
<th>Competences</th>
<th>Technologies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Programming</td>
<td>Algorithms and problem solving, Object oriented programming, Data structures and algorithms, distributed systems</td>
<td>Programming languages and frameworks</td>
</tr>
<tr>
<td>Internet technology</td>
<td>Web development</td>
<td>ASP.NET, HTML, CSS, Javascript, JSON, webservice</td>
</tr>
</tbody>
</table>
The above contents were included in the Curricular Units lectured in the Computer Engineering course frequented by the three students during three academic years (September to June). As observed in table 2, students had to use interdisciplinary contents to develop the MAR platform. Furthermore, this project demanded the use of new tools and technologies and more new contents such as AR, 3D modelling and game programming that were not learned in the scope of their course. In particular, Unity engine that uses C# programming language was not included in the Computer Engineering course. Also, they did not learn about game programming.

6 CASE STUDY ABOUT THE DESIGN OF THE AUGMENTED REALITY APP

In the school year 2017/2018 three higher education engineering students chose the PlanetarySystemGO, amongst other proposed projects, in the framework of their final project before graduation. The challenge was to upgrade the first version of the SolarSystemGO game, initially developed by another group of students in the school year 2016/2017 [18]. This was a static version that included our solar system and a single set of questions all embedded in the app. The proposed new version included additional challenges that lead the new group of students to design a platform, which triggered the design of a new architecture.

In order to comprise the objective of the project, several tasks were proposed to the engineering students:

1. Survey of the state of the art in the scope of the project;
   1.1. Astronomy knowledge;
   1.2. Update knowledge on the previous project, including the application SolarSystemGO;

2. Development of the information system that communicates with the PlanetarySystemGO application;
   2.1. Back-office implementation in order to:
       - Build new planetary systems;
       - Create pedagogical events with planetary systems;
   2.2. Implementation of the app:
       - Perform simulations of planetary systems provided by the back-office;
       - Inform the back-office about the results of the pedagogic event;

3. Test and operation of the system in a real environment in order to assess the impact of the game and improve it for the next test;
   3.1. Tests implemented in informal learning environments;
   3.2. Tests implemented in formal learning environments;

4. Written project documentation.

In order to design the mobile app, the option was to use the Unity engine, which uses C# programming language. To acquire the skills required to fulfil the proposed challenge, the students had to conduct knowledge research from their curricular units, which they did as a team by assigning tasks among them. To learn new knowledge such as Unity and C# programming language they used several tutorials available on the Internet.

During this process, some meetings were conducted with the supervisors to place questions and decide the next steps. After this stage, they were challenged to start developing the app and to bring a
version to test in the Polytechnic campus. After several tests and upgrades, the first big challenge was to implement the game in the World Children's Day, that took place in June 1st 2018, at Mata dos Sete Montes (Tomar city). In this experience, five groups of children, accompanied by their teachers had the opportunity to play the game (Table 1). A second experience in the field happened a few weeks later in a full afternoon during the AcademySAH summer edition, with nineteen children at the Polytechnic campus. After these two important implementation tests in the field, where the students observed and reflected about the game performance, they had the opportunity to fix some problems that were diagnosed and to keep upgrading the game until it finally was ready to be implemented in a formal learning environment, which finally took place on October 2018, in a 4th grade primary school class, with twenty students, their teacher and a second teacher interested in assisting the experience (Table 1).

This last experience was also the last task required to students (proposed in the initially project’s tasks: 3.2) before writing the final report. Pictures of figure 1 resulted from this last experience that was very appreciated by the students and the teachers. Finally, the written report was developed and presented in a public examination.

7 RESULTS, DISCUSSION AND CONCLUSIONS

This paper presents the case study of three computer engineering students who designed a MAR platform in the context of their final project before graduation and in the framework of PBL approach. This was an interdisciplinary challenging real-world problem that demanded a final product or prototype. The students were supervised by higher education teachers from a Polytechnic Institute of Portugal.

In order to concretize this challenge, students had to work cooperatively to search relevant information and contents from their engineering course and, also, had to learn new contents outside the scope of their course to achieve the objectives of the project. These tasks involved 21st century skills required for engineering curriculum as stated by several authors (e.g., [14] and [1]). In fact, to design the game, students became active solvers of real-life problems with the supervision of mediating coaches, which is in line with [13]. In this context, the students acquired and developed skills, included in the goals of higher education, such as think critically, ability to use appropriate learning resources, work cooperatively in a small group and communication skills, amongst others, as stated by [14]. For this reason, PBL is an active engagement pedagogy that is very relevant for engineering education [1] that better prepares them for their future careers. With this approach, learners were empowered to conduct research, integrate theory and practice, and apply knowledge and skills to develop a viable solution of a defined problem [3].

The above referred skills were crucial to succeed in the development of the MAR platform in order to be implemented in a formal learning environment as was the case of the last test that occurred in a primary school. For example, communication skills were used since the design of the tasks to solve the problem. During the implementation tests in the field to assess the impact of the prototype, this was a fundamental skill, together with social skills, because they had to communicate with each other, with the supervisors and with the public who participated in the test. Also, after each test implementation, a reflection was performed with the supervisors, where the students showed critical thinking and the ability to design a new solution.

In order to develop the MAR platform, the engineering students had to use interdisciplinary knowledge related to mathematics, databases, programming and information systems, amongst others. Furthermore, it demanded the use of new tools and technologies. Another big challenge was the fact that some contents such as AR, Unity, C#, 3D modelling and game programming were not learned in the scope of their course, which brought greater challenges to this project.

We argue that PBL is the pedagogy used in the design of the PlanetarySystemGO platform by the engineering students. In fact, students worked cooperatively to identify what they need to learn in order to solve the problem, they engaged in self-directed learning, applied their new knowledge to the problem, and reflected on what they learned and the effectiveness of the strategies employed, as observed in [19]. We conclude that with the problem-based learning methodology the engineering students were able to implement knowledge from their course and, also, to acquire new knowledge in order to succeed in the design of the AR application. Based on the results of this study, we propose to extend this experience to other curricular units by promoting collaboration with higher education teachers of different subject matters.
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