Proceedings of the 18th Mediterranean Electrotechnical Conference
MELECON 2016, Limassol, Cyprus, 18-20 April 2016

Playful and Interactive Environment-Based Augmented Reality to Stimulate Learning of Children

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***Abstract*— our study is about how to create educational software using Augmented Reality combined with Bloom's Taxonomy, whose main purpose is to stimulate spatial reasoning improving the learning process of children. To reach this main objective, we have applied an incremental Object-Oriented Hypermedia Design Method, with the purpose to produce a mobile application for a learning basis on Smart-Client architecture. Furthermore, we incorporated operations necessary for cognitive development and effective learning in the logic of the application. Therefore, we applied modern 3D technology approaches such as Unity 3D Game Engine and Vuforia. Additionally, we designed and implemented a Computerized Classification Test based on the Bloom's taxonomy in order to determine the learning results. The validation of our proposed solution has been engaged by testing them in two representative public schools. The results demonstrate that this educational software for learning stimulates the cognitive development and improves the comprehension of children, with an effective quantitative assessment based on a constructivist paradigm.**

Keywords—Augmented Reality; educational software; Bloom Taxonomy; Vuforia.

I. INTRODUCTION

Augmented Reality (AR) environments have proven to be relevant and valuable in many cases of educational learning process [1]. It allows the establishment of new conditions of images and provides a visual representation, where physical and digital objects coexist and interact in real time [2]. Recent studies demonstrate that AR environments contribute to cognitive development of children by providing a playful and interactive environment. As a result, the scientific community has stressed out the importance of their use in the primary education field, emphasizing the variety of ways in which they may be applied [3].

Particularly, there has been great interest to implement Augmented Reality in the teaching-learning process as shown for instance in 2002 [4][5] and also between 2006 and 2008 [6][7]. Shortly later, some authors have developed software for children combining Augmented Reality and Taxonomy of Bloom [8][9][10]. Selected authors proposed applications-based interactive books that incorporate AR environments [1][11][12][13]. This method has also been used with special-needs children [14][15][16]. In more recent works [2][3], proposed an exploration of how a new teaching practice impact students. However, in the literature review, it appears that the authors do not show the self-assessment scheme for students in which case it can apply the qualitative assessment instead of quantitative assessment.

The research hypothesis of this study is based on the concept that AR increases concentration levels and stimulates children's learning, if there exist a self-assessment that is able to evaluate their real learning. Consequently, the basic question leading this study is about what may be the most efficient evaluation method to determine benefits of learning with Augmented Reality versus simple traditional learning?

This study focuses on how to create a methodologic procedure to construct a playful and interactive environment that is able to stimulate the learning of children using AR. This environment should be framed with the intellectual skills that children acquire as indicated by Bruner, Feuerstein, and Vygotsky [17][18][19]. To perform the present study, we designed and implemented an adaptive hypermedia system, which contains the tutorial, the content, the teaching-learning process, and the self-assessment, using 3D Virtual Reality and AR to link the digital world with the real world.

From the point of view of Software Engineering, we applied an incremental methodology based in Object Oriented Hypermedia Design Method and Unified Modeling Language. For this implementation the targets were designed in Adobe Photoshop CC, which has been loaded into the Qualcomm platform, in files with Vuforia Software Development Kit (SDK). In addition, a Unity 3D Game Engine has been integrated. This resulted in an interactive and attractive application with three-dimensional models and a great power in image recognition represented in AR. Additionally, we implemented a self-evaluation process incorporated in the software, based on Computerized Classification Test (CCT) concepts, leveraged on the structured Bloom's Taxonomy [20]. The results demonstrate that our educational software increases concentration levels and stimulates the learning of children with an effective quantitative assessment based on a constructivist paradigm.

The main contribution of this research has been the creation of educational software for the study and learning of the Solar System with AR. Furthermore, Bloom's taxonomy has been used for measuring the learning results. Additionally, we created an assessment test based on CCT concepts, which allowed to perform a quantitative evaluation.

The remainder of the article has been organized in the following manner: the related work is exposed in Section 2. The theoretical framework that founded this research is described in Section 3. Section 4 explains the experimental design. In Section 5, experimental results are presented.

978-1-5090-0058-6/16/$31.00

Section 6 finishes with the conclusions and the proposal of potential future achievements in this working field.

II. Related Work

In recent decades there has been great interest in implementing AR in the teaching-learning process. Since 2002, some authors proposed several developed systems applied to education. Shelton [4] describes a research project where the system supports teaching undergraduate geography students about earth-sun relationships. Kaufmann [5] proposes a software application called Construct3D, where a three dimensional geometric construction tool on the collaborative system is used by the students. Shorty later, some authors [6][7] have developed similar software.

A similar study, [8], described the evaluation of several games developed for Mobile Learning. This study has been supported by an emerging paradigm of instruction focus on Bloom's Taxonomy. In the same context, Schmitz et al., [10], proposed an analysis of the educational games for learning that may impact children`s motivation and knowledge. Finally, Gutierrez, J., et al. [9], proposed an application of architectural drawing in order to improve spatial abilities of engineering students and furthermore presented an evaluation of the efficiency and efficacy of such technologies. Comparing the mentioned studies with our work, we assessed the knowledge of students on the basis of the five domains of Bloom. Additionally, we developed an evaluation by applying the concept of an unpublished and empirical Computerized Classification Test, which has been included in the educational software application. Finally, we performed a validation comparing learning outcomes of children in the traditional scheme, versus learning outcomes used AR and CCT assessments.

Some authors proposed application-based interactive books that incorporate AR environments. For instance, interactive books of teaching geometric figures as proposed by Kirner et al., in [11], and a book with colorful three-dimensional contents proposed by Clark [12]. In [1] techniques are used to create an interactive book for teaching the alphabet to children. In the study proposed [13] it is demonstrated that the tools developed for AR education have had a twofold use incorporating additional domains such as tourism.

A few years later, AR was also used with special-needs children [14]. Furthermore, it has been considered instrumental when limited resources do not allow the stipulation of personalized attention [15]. Lastly, its use in the learning of more complex tools for beginners has been regularly confirmed [16]. In this regard it is emphasized that AR may be considered a relatively new technological concept that is able to be applied practically on a high variety of educational fields, given the enormous progress that technology has presented in recent years [16].

Recently (i.e. in 2015), Barma et al. [2], proposed an exploration of how a new teaching practice involving a serious game based on an interactive AR solution would impact students in a Physics class. On the other hand Xiaodong et al. [3], performed a teaching scheme that includes AR based on the model of motivational design, social psychology, and a computational model of creativity, which explains the domain-relevant knowledge of creative design which helps students to build scenes.

Finally, mentioning all the previous studies and their advantages towards AR, the study of [3][21], states that the educational community clearly does not understand the likely impact of AR. In that same study, the importance of the positive impact in the educational effectiveness of the use versus the absence of use of AR is clearly stated. We sustain and extend the full potential of AR to enrich the available educational tools of students.

III. Theoretical Framework

A. *Theories of stimulation of cognitive development of children*

This study is based on the theoretical ideas of Bruner [17], who affirmed that learning is an active social process in which the students build new ideas or concepts based on their knowledge. The theoretical premise of Bruner, "learning for discovery" happens when the students in the process of learning connect their experiences to their existing mental constructions.

A further claim that supports scholars cognitive development is the "significant learning" referred by Ausubel [22] who states that "significantly learning refers to the processes knowledge construction by meaning". This approach complements the theory of cognitive modifiability of Feuerstein [18], who states, that "every human being is modifiable". For this to happen it is necessary to understand the mediation by means of a teacher responsible.

Another important contribution that sustains the present research is the theory by Vygotsky's [19]. Vygotsky identifies a developmental level with respect to the reached conquests, called "the level of real development". Another level related with the capacities that are on the way of being acquired called "the level of potential development", and also discusses "the resolution of a problem under the mediation of an adult or another partner, using resources, strategies, among other external mediators".

According to these researchers [17][18][19][22], the constructivism theoretical approach constitutes an adequate scenario for developing scholar's cognitive development through the application of AR, generating highly interactive and participative environments where the scholars are able to transform, build, experience ideas, and be involved actively in their learning process.

B. *Augmented Reality for the development of educational software.*

Augmented Reality is an approach that is used to define a vision through technological devices such as computers, smart phones, tablets, etc., of real world physical environments, of which natural elements are combined with virtual elements or information in 2D or 3D, in order to create a mixed reality on real time [23][24]. This technique is a recent development in the field of the ubiquity of mobile devices. Although it has been a relatively short time in the market, it is already one of the areas of the industry with the highest growth. One of the most fundamental areas in the application of Augmented Reality is education, since it allows teachers and students to learn by experience, given that objects in 2D and 3D could be extremely difficult to access in the real world [25]. Researchers imply that AR has a great potential and numerous benefits to improve the process of children's teaching-learning in order to develop more successful cognitive processing [25][26].

Our research project consists of an educational software application focused on teaching how the Solar System works, in which case the student is able to interact with a tablet to visualize each of the planets, their rotation, and their natural satellites besides other related characteristics. Furthermore the application demonstrates the distinctiveness of each planet subject of study. These issues may be assessed after studying the behavior of each planet by taking a computerized classification test (CCT).

C. Skills and Competencies of the Social Studies with Bloom's Domains.

In this study, we have been considered the five domains of Bloom [20] with respect on the following skills: (1) Knowledge: To know the Sun as a star and each one of the surrounding planets that form the Solar System; (2) Comprehension: To describe how the Solar System is formed through the identification and the characterization of each one of the planets and their moons; (3) Application: To use the images to observe the characteristics of each one of the planets of the Solar System; (4) Analysis: To analyze the well-known star's importance as "Sun"; and (5) Synthesis: To conclude that the planet Earth is a living planet inside the Solar System in comparison with all other planets.

D. Computerized Classification Test (CCT)

To explore the aforementioned theories, we have considered in our educational software the computerized classification test (CCT), in order to understand and apply through assessment tests the macro-skills and the Bloom's domains. According to [27][28], a CCT is administrated by the computer for the purpose of classifying exams. The most common CCT classifies tests as "Pass" or "Fail", while other tests includes more than two categories as tested results. As the term may generally be considered to refer to all computer administrated tests for classification, CCT is usually used to refer to interactively administrated evaluations.

Therefore, five categories were considered as results of the test, considering the five distinctive Bloom's domains, generating a test of fifteen questions with different values for each category.

E. Object-Oriented Hypermedia Design Method (OOHDM) and Development Tools.

In this project, OOHDM has been used to carry out the whole design and implementation process of the educational software based on multimedia [29]. For the analysis process, the IEEE-830 software requirements specification was used. The UML standard of modeling has also been used.

As development tools we used: (1) *Unity 3D Game Engine*: Unity is an engine and multimedia editing-environment that is user-friendly and versatile. Unity offers modules capable of publishing applications to many platforms, as well as web-based applications using the Unity plugins [32][33][34]. As we illustrated in Fig. 1, this is the core development of the educational software. It integrates and unifies the Vuforia framework with AR techniques, 3D object modeling, 2D and 3D Math, and the CCT for the self-assessment tests, each of all running over the Android platform. (2) *Android SDK*: This set of software development tools allowed the creation of the educational software with Unity for the Android platform [35]. (3)*Vuforia SDK*: This set of software development tools allowed the building of an AR application for mobile devices and digital eyewear with targets and 3D models integrated with Unity, running over Android platform [36].

IV. Experimental Setup

A. Execution Educational Software Architecture

Figure 1 illustrates and describes the platform where the application of educational software has been executed. The application architecture is based on the ubiquitous computing of Smart-Client type. Here, the data is stored locally and therefore may perform queries and operations of the database on the mobile device. The application generated was an APK, which is installed on the mobile device with the Android Operating System. This application has been developed over the Unity 3D Game Engine platform with MonoDevelop, which consumes libraries QCAR SDK of the Vuforia platform. This in turn, generates a packet with the database of the targets achieved in the development of web portal Vuforia Qualcomm. There the images were processed with the defined characteristics for recognition AR charging 3D models according to the selected planet.

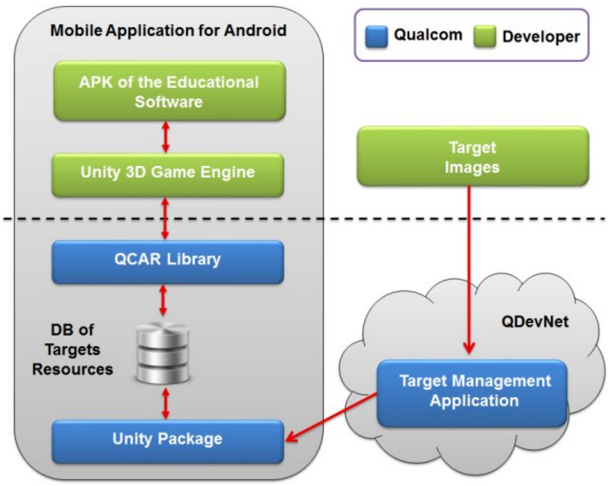

Figure 1. Augmented Reality Application Architecture

B. Abstract Interface Design

According to Pressman [30] and Rossi [31] abstract models specified the organization and the complement of the interface. Therefore, this project has five view abstract data (VAD) nodes which are: Main Menu, Instructions, Interactive Library, Solar System Information, and Self-evaluation node.

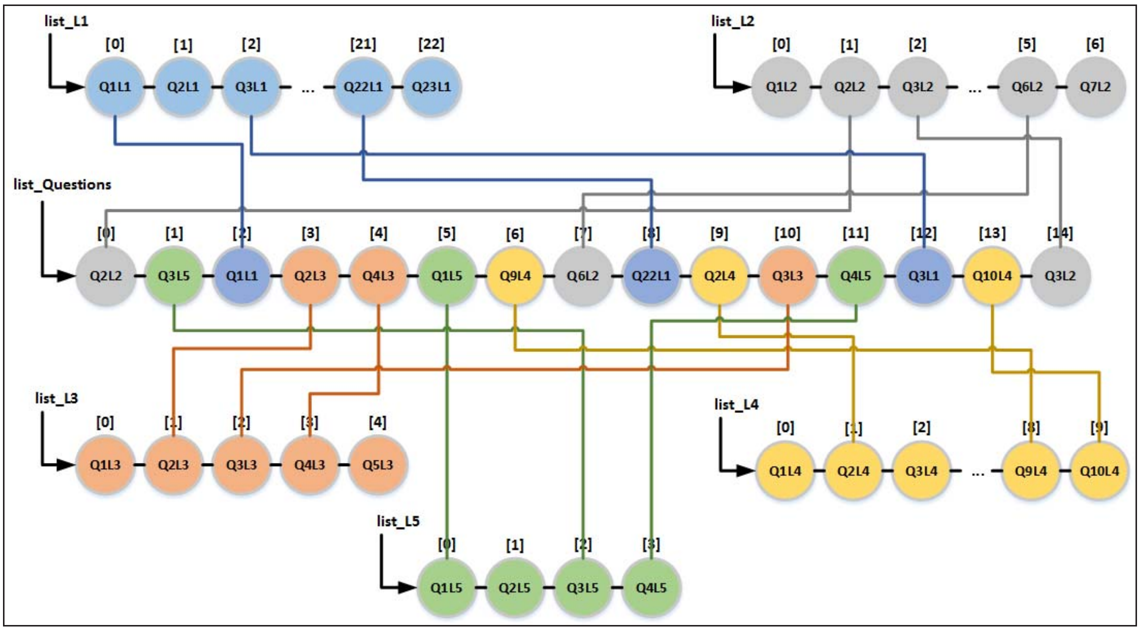

Figure 2. CTT Model of the Application

C. *Application of the Model CTT*

In our study we considered to create a CCT to assess the knowledge of students on the basis of the five domains of Bloom (i.e. knowledge, comprehension, application, analysis, and synthesis). These domains take into account the skills and competencies that children develop in Social Studies in the fourth grade of an elementary school. In order to fulfill such criteria, we designed five data sets of questions, which correspond to the five cognitive levels of Bloom domains.

Each level defined a category that has been managed by a class, which worked with a linked list. There, the data sets of questions were stored, together with the corresponding answers and weights. Each ~~banks~~ of questions and answers had the matching scores, being equivalent with each of the five levels (Level 1 = 1 point for each questions, Level 2: 2 points for each question, and so on). According to the Theory of the Combinations we have selected three questions of each group, in which case we were able to choose the three questions in different ways. Later, we proceeded to classify the questions randomly using a linked list of questions. This process allowed that three questions of each bank or level were loaded, obtaining a test of 15 questions, with different scores. Then, applying a rule of three, the final note has been obtained on 20 points as illustrated with our empirical model in Fig. 2.

D. *Proof of concept and Testing*

Although OOHDM method does not establish proof of concepts, it is necessary to have a quality control to ensure consistency between the use of cases and application. Based on this, we have used Software Engineering testing process oriented at Web applications, proposed by Pressman [30]. The tests were: (1) content testing; (2) User Interface Testing; (3) Navigation tests; and (4) Evidence of components (configuration, performance and security). Part of the analysis is described in the next section. Fig. 3 illustrates the educational video with implemented Augmented Reality. A video of the accomplishment of this study in Spanish with English subtitles has been released below in: https://www.youtube.com/watch?v=TDd53YeQ3iA.

Figure 3. Augmented Reality 3D object scene of the present application

V. EVALUATION RESULTS

In order to contrast our hypotheses, an evaluation of 63 students of fourth grade has been conducted in two elementary schools. The evaluation compared learning outcomes of children in the traditional scheme (i.e. written-test), versus learning outcomes used by the AR software (i.e. software-testing). It is worth to notice that the whole group may have been divided in two parallel classes, but have had similar characteristics in all aspects, such as same area of residence, age, gender, years of education, curriculum content, and even family situation. Therefore, based on these facts it appears to be unnecessary to determine if the learning ability was similar in both groups. These variables, however, allowed to suggest similar conditions of learning of the studied children groups. It should be noted that both written-test and software-testing were established in Bloom's Taxonomy which determines knowledge, comprehension, application, analysis and synthesis. The results are described below.

Figures 4 demonstrate that in a total of 49 multiple choice questions in both tests, failed answers were recorded with a wider range of errors in the first school. In general, the highest number of failed answers appeared in the written-test, compared to the answers of the software-testing. It should be noted that the level of knowledge according to Bloom, in the written-test corresponds to 26 and 12 failed answers respectively. In turn, in the software-testing just 3 and 2 incorrect answers were recorded respectively. A similar behavior is also observed in the remainder levels of Bloom's Taxonomy. Consequently, the line diagram of the written-test is usually above the software-testing of all levels of Bloom's taxonomy. That is why in the written-test there are many wrong answers. We conclude that the software-testing is more efficient because of its tendency is to avoid making wrong answers. Therefore improvements in children’s learning are significant given the software application using AR.

An additional statistical technique of checking, bar charts were plotted for the two schools (see Fig. 5). Evaluating the results one concludes that at all levels there is a corresponding taxonomic average to 38.76% of failed answers when the written-test is applied. However, the taxonomic average of software-testing corresponds to 13.06% of incorrect answers. This means that the software-testing is optimal in 25.07% compared to the written-test. This leads to the conclusion that improvement is given in children's learning when subjected to playful learning processes with innovative software. A similar behavior has been observed in the second school.

As a better estimation method, the kernel density estimator that generates an alternative graphic of higher quality than conventional statistical tests has been applied. It is represented by the mathematical expression:

$$\hat{f}(x) = \sum_{i}^{n} \frac{1}{n} K\left(\frac{x_i - x}{h}\right),$$

Where K is non-negative function and verifies

$$\int_{-\infty}^{+\infty} K(u)du = 1,$$

$$K(-u) = K(u),$$

That it is symmetric from the origin.

A K function that can be used is Gaussian, given by

$$K(u) = \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}u^2}.$$

Applying this technique, Fig. 6 depicts a kernel density estimator using a Gaussian kernel function for both, the written-test to software-testing. We may point out, that the smoothing parameter Bandwidth controls the weight 1/N, around each x. If the bandwidth is low, only the observations x_i, closest to x will be relevant in the estimate f (x). In contrast to the great values, they allow more distant observations of x being also involved in the estimate. Indeed, bandwidth=3,408 of written-test is less than bandwidth=4,301 of software-testing. In the case of the second school, by analogy bandwidth = 0.9736 of written-test is less than bandwidth = 2,821 of software-testing. This indicates a similar behavior to the previous school. This leads to the conclusion, that the software-testing is significantly more efficient for learning at various levels of Bloom's Taxonomy that the written-test.

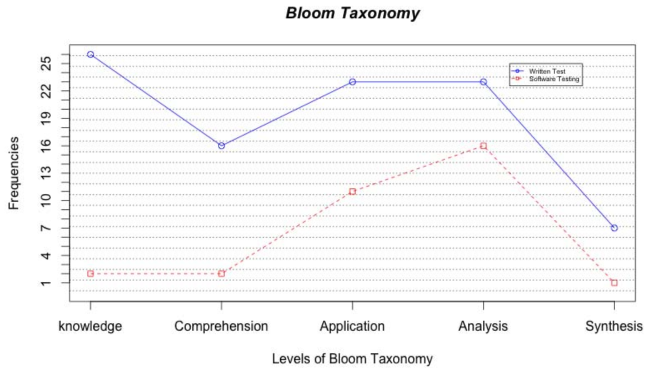

Figure 4. Line Diagrams of results behavior of Bloom Taxonomy, first elementary school.

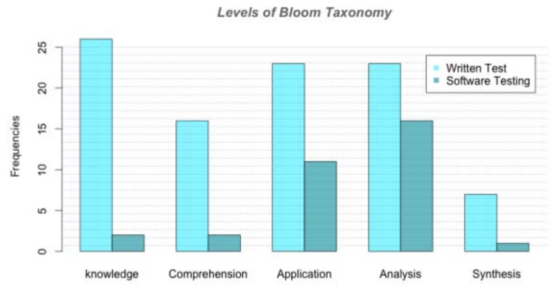

Figure 5. Bar Diagram of results behavour of Bloom taxonomy levels, first elementary school

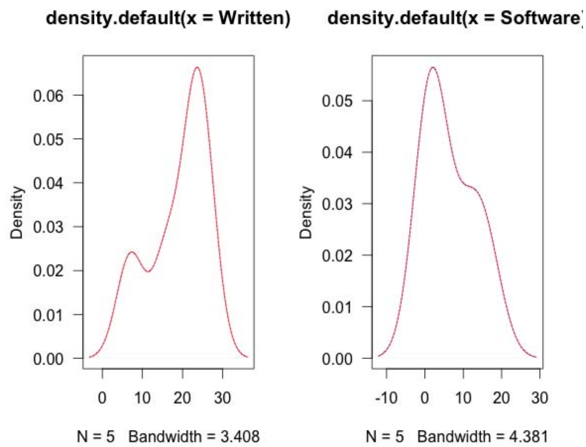

Figure 6. Kernel Densyty Graph of two proof of concept, first school.

Comparing the results of different statistical tools and techniques applied in our study, it appears that there has been a better academic performance in the second school. This is able to be explained due to the use of the constructivist educational model with greater responsibility, hence with the better results.

VI. CONCLUSSIONS

This study has been mainly focused on improving alternative educational skills and techniques for a better learning process for children in the fourth year of elementary schools. To perform this main objective, educational software with Augmented Reality technologies were implemented, following an incremental OOHDM. The most fundamental final result has been 3D educational software containing the tutorial, the content, the process of teaching-learning, using 3D and Augmented Reality to link the digital world with the real world. In order to determine learning outcomes we designed and implemented a self-evaluation of the content, based on the cognitive domain of Bloom. The proofs of concept were evidenced in two elementary schools. After a quantitative evaluation, it has been concluded that the ratings of children have improved significantly after the learning process based on Augmented Reality application.

As future work we plan to add new functionality in the 3D objects, allowing the user to perform rotation to the planets.

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