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Augmented Reality: an Enhancer for Higher Education Students in Math's learning?

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Abstract

In this text, we intend to answer to the following question: is Augmented Reality an enhancer for Higher Education students in math's learning? For this purpose, we define augmented reality and present a state of the art mapped mainly by studies that focus AR in educational contexts. We also describe our research, including methodological aspects in data collection and the creation of 3D contents in AR. Then, we synthesize the analysis of some preliminary data, briefly presenting perceptions and practices of students in math's learning with AR contents. Finally, we conclude that the challenges that are nowadays put to teaching methods, acquisition and subsequent knowledge consolidation may be met, to some extent, by the application of available technologies. These, in turn, should enhance a more complete understanding of contents, leading to knowledge endogenization and also to the internalization of more sustained competencies. Among those technologies, we highlight augmented reality since it can encourage motivation, comprehension and a higher involvement with the contents to be learned. Thus, it may increase the use of information and the access to knowledge, improving digital and info-inclusion.

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Keywords: Augmented Reality; Three-Dimensional Contents; Information and Communication Technologies (ICT); Higher Education students; Maths learning; Knowledge mapping.

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1. Introduction

The term Augmented Reality (AR) was created by Tom Caudell, in 1990, while he was working at Boing[1], and it translates the integration of virtual images in the real world, i.e. the reality is augmented of virtual elements[2,3,4]. The integration of such images is made by the use of Information and Communication Technologies (ICT), through a mobile device with a camera (computer, tablet, mobile phone with android or iOS operating systems) which allows the access to the available contents with AR. Furthermore, the development of such contents encourages higher learning autonomy and the use of systems that support mobile-learning[5]. Besides, the exploration of ICT by the students can promote collaboration, innovation and creativity skills[6].

One characteristic that AR applications offer is the integration and interaction between the real and the virtual, allowing a huge versatility and creativity in applications. For instance, AR allows the development of contents such as books, instructions or presentations, in a conventional way, yet adding graphical elements that an AR application recognizes and that, when displayed, had been programmed to activate additional elements of explanation (for instance: three-dimensional files, explanatory videos and/or images).

AR can be useful in several study and learning areas and it represents a significant added-value in those that demand more practical and experimental interaction, like Science and Engineering Courses[7]. It is also possible to activate contents combining other environments, and not only in the classroom. Thus, AR allows the development of contents in which each individual can access in different circumstances/environments, besides the more common ones (at home, in the office, in the classroom). And, therefore, it encourages the interaction between in situ observation of the real world and the addition of explanatory and theoretical contents (like EcoMOBILE[8]). This flexibility offered by the AR tools allows higher experimentation and exploration of the real, with the introduction of virtual explanations in real. In fact, when exposed to real situations, the AR contents allow students to interpret with higher flexibility the real observation, made in real time. Thereby, learning is centered in the individual and each one can have access to explanations and support in the form of AR contents, which are distinguished from others, and in the moment of the learning process. AR has been applied this way, progressively in the education field, originating books[9, 10].

This format of contents can be adapted to distance learning, either formal or informal, as the contents prepared with displayed themes in real context can be accessed by any individual at any time. For instance, the preparation of contents in the biological area permits that, in a field exploration, the mobile system (based in ICT, mobile phone or tablet) identifies a certain type of plant and gives in situ technical/scientific information about it and in real time. Thus, the field exploration along with detailed information encourages knowledge internalization.

So, we can say that AR technologies allow the integration of theoretical knowledge in real contexts and also allow the integration of real contexts in more theoretical ways of presentation. Significant advantages can result from the approximation/integration of the two formats of information, namely because we materialize concepts, bearing in mind its inherent rigor, and we encourage the perception of more abstract concepts.

2. Augmented Reality in Educational Contexts

AR technologies are closely linked to the ability to calculate and to the computational calculations and, thus, its evolution is related to the development of personal computers. Hence, it is important to start by referring some of the works that at an international and national level have been developed by the application of these technologies, mainly in the area of education and teaching.

With regard to three-dimensional technologies, and although they are still in an embryonic state as far as its application in education/teaching is concerned, they have been being recently implemented and studied, by different authors, in several fields of knowledge (among others: Fonseca et al., 2013; Kamarainen et al., 2013; Wu et al., 2013; Martin-Gutierrez et al., 2012; Kaufmann & Schmalstieg, 2003). However, in order to have an historical and wider perspective of the AR contents and technologies application in the areas of education, training and teaching, we present some studies and applications of the last 20 years.

In 1997, Inkpen presented a study in which specific contents to stimulate learning via computer were developed. These contents were not developed in AR. However, they were precursors in the analysis of the effect of learning based in technologies. Besides the specific development of applications and software to stimulate learning, Inkpen

(1997) analyzed the possibility of working simultaneously in one computer with two mice. The results showed that the motivation and the learning were increased with the group work, enhanced by the simultaneous use of the two interaction devices with the computer (mice) compared with the individual use by each child.

In 2001, in the math's area, Billinghursta and his coworkers developed AR contents, under the name "MagicBook". In 2003, and still in the math's area, Kaufmann and Schmalstieg described the implementation of the "Construct3D" system, which allowed the evaluation of the importance and flexibility of AR, even in collaborative environments, and it also enabled to confirm the importance of such environments in the interaction between students and between students and teacher. That system is composed by three-dimensional contents in the math's area supported by visualization equipment and collaborative work, face-to-face or remote (at distance) – see Figures 1 a) and 1 b) respectively.

Fig. 1. Construct3D System for collaborative learning (a) face-to-face and (b) remote.
Source: Kaufmann & Schmalstieg, 2003.

Continuing with our state of the art, in a chronological approach and by scientific domains, we consider now the engineering areas to refer that Liarokapis et al. (2004) studied the application of AR in projects and manufacturing processes, while Martín-Gutiérrez et al. (2012) studied the application of AR in the electronic engineering area and Fonseca et al. (2013) explored its applicability in the architecture area. Still in 2013, Salinas et al. developed specific software to three-dimensional modeling of mathematical functions. They also carried on a study where they demonstrated the important role of those technologies in the motivation of groups and in the encouragement of collaborative work.

In the analyzed works, some interesting advantages of AR were perceived. In the study of Martin-Gutierrez et al. (2012), it was emphasized the increasement of students' self-learning, which gives the teacher more time to explain more complex questions. In the study of Fonseca et al. (2013), the advantages that AR tools give in the increasement of spatial perception were referred, namely the fact that it offers in situ visualization of hypothetical scenarios to future construction and, thus, an exploration and analysis of different solutions.

In a previous study, about m-learning systems, Ismail and his coworkers (2010) observed the satisfaction expressed by the users of these additional learning tools (of mobile learning). The users felt supported and motivated by the use of mobile applications with accessible language. In fact, the systems commonly used in m-learning, like mobile communication systems, as already mentioned, can, when integrated with AR contents, encourage observations and field explorations, because it is possible to explain the Reality observed with the (Augmented) addiction of virtual contents (among others: tutorial videos, schemes, three-dimensional images). This interaction contributes to higher autonomy in the learning process. Figure 2 presents an example of what we have developed in AR to support the teaching of mathematics.

Fig. 2. 3D representation of a hyperbola by intersection of a plane in a geometric solid.
Source: Centre for Rapid and Sustainable Product Development (CDRSP)©.

The learning/teaching contents, in this specific case of mathematics, can be conceived in a usual way, based on an explanation available on paper that is complemented with the description of equations, based on bi-dimensional images. To these elements can be added contents such as three-dimensional files, videos and explanations of intermediate steps. Thus, it is made the integration between the traditional way of content visualization, through the paper, and the use of AR technology.

3. Augmented Reality in Higher Education: an example at the Polytechnic Institute of Leiria (Portugal)

Assuming that one of the bases our study is to understand if and how certain educational/technological innovations work, we consider that Design-Based Research (DBR) is the most suitable methodology, since it aims at discovering the relations between educational theory, projected artifacts and practice. Our research, focused on students from the Polytechnic Higher Education, provided a triangulation of methods (quantitative and qualitative), data collection techniques (survey by questionnaire and by interview, and observation techniques) and data analysis (documentary analysis, inferential and descriptive statistical analysis, and content analysis). DBR allows and encourages multiple iterations in all stages, resulting in a continuous evolution of the intervention, where knowledge is built in a circular or spiral way[11,12]. Like in any other research in the naturalistic field, there is no preconceived path; the path is built and re-adjusted, if necessary, according to the results of the several planned and consolidated iterations.

A broad consensus about the observable procedures in this kind of study is not yet possible, considering that DBR is quite recent in the educational area. Besides, there are many variations and methods. However, we can present some general assumptions, essential to the implementation of DBR. The following described phases can occur simultaneous or even in a different order: (i) start by formulating a significant problem; (ii) promote the collaboration among researchers; (iii) integrate theoretical relevant contents about teaching and learning; (iv) conduct a literature review to generalize research questions; (v) project an educational intervention; (vi) develop, implement and review the project; (vii) evaluate the impact of the project intervention; (viii) iterate the process; (ix) write the DBR report.

The first stage began in an embryonic phase of this research and was consolidated after a consistent literature review (phase iv), which is still being updated. The second stage includes the pre-test phase, of both the AR three-dimensional contents, made by some teachers of the Polytechnic Institute of Leiria (IPL), and the interview to some professors (note that this survey and its script were discussed and validated by Mathematical Analysis professors and specialized researchers, which we can designate as the panel of experts, according to the Delphi method). Phase (iii) is integrated in the construction of all the research questions and it is closely related to phase (iv), in continuous improvement. Phase (vi) was initiated when AR contents and data collection tools were built, namely the survey by interview to teachers and the survey by questionnaire to students. This phase continued on being developed, whereas data collection tools are still in a phase of implementation. Phase (vii) occurs in the follow-up of previous phases and whenever justified.

The field research phase took several stages, being the first the contact with educational actors directly related to the implementation of AR contents, such as the Principal of the Higher School of Technology and Education of the IPL, the coordinators of several engineering courses of the IPL, the coordinator of the Math's Department, the Director of the IPL Distance Learning Lab, as well as professors of Mathematical Analysis. Some of these educational agents had directly collaborated in the construction of the contents, having selected the topics considered the most relevant to its creation; the other educational agents were informers in the realization of the pre-test of the survey by interview to lecturers. This phase began in November 2013 and had several iterations that culminated recently (in December 2014), in the content implementation in the classroom and in the interview to the lecturers. The AR contents were being built, tested and improved systematically during this period of time, with the use of different applications and tools – programming with AR instructions, three-dimensional edition, and access in the consultation phase. The following figure systematizes the different phases that we have taken into account in the development of the AR 3D contents we have created, applied to the teaching of mathematics.

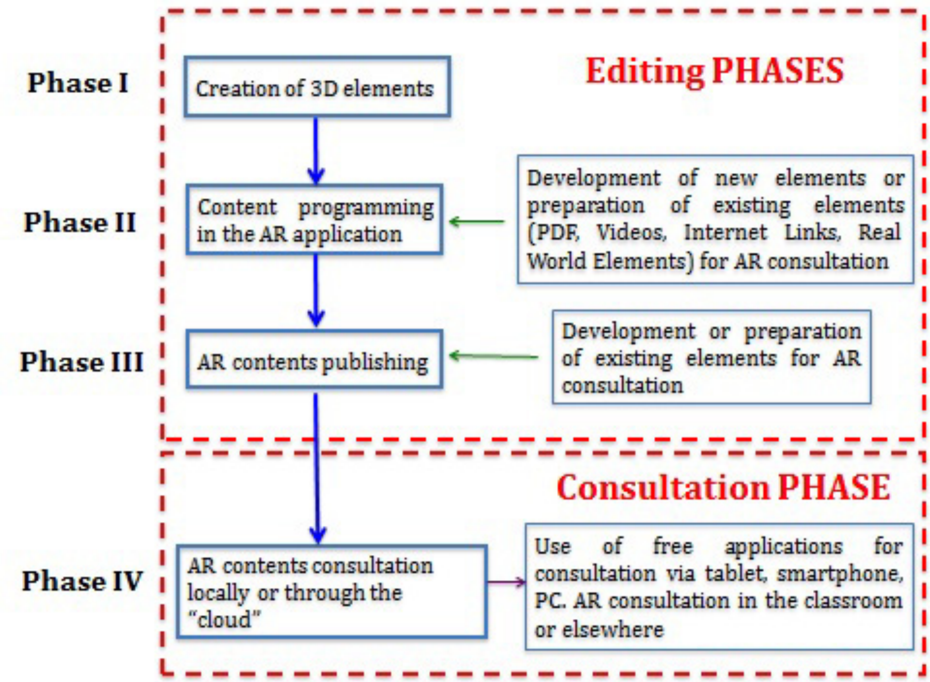

Fig. 3. Phases of AR contents (editing and consultation).
Source: Artur Mateus, Teresa Coimbra and Teresa Cardoso©.

The first three phases (I, II e III) correspond to the implemented procedure with the aim of elaborating and preparing AR contents. Thus, they correspond to an editing phase. Phase IV corresponds to the consultation phase by the final users.

In the editing phase the development of 3D elements (phase I) is considered. In our case, they were created with different applications/software. We had begun the creation of those elements using math's software with the ability of converting three-dimensional functions into neutral files. These files contain the three-dimensional description those functions. So, in this phase, and by the use of those math's applications, several files were created with a neutral format composed by polygon meshes defined by the exterior normal. The formats we tested were: STL (Standard Tessellation Language), OBJ (developed by Wavefront Technologies), and PLY (Polygon File Format). The STL only represents the geometry, whereas the other two formats reflect both the geometry and the color.

However, the STL format was chosen on account of the simplicity of its structure, which allows a simpler and more efficient manipulation (see Figure 4).

ASCII STL[edit]
An ASCII STL file begins with the line

```
solid name
```

where name is an optional string (though if name is omitted there must still be a space after solid). The file continues with any number of triangles, each represented as follows:

```
facet normal ni nj nk
    outer loop
        vertex v1x v1y v1z
        vertex v2x v2y v2z
        vertex v3x v3y v3z
    endloop
endfacet
```

where each n or v is a floating-point number in sign-mantissa-"e"-sign-exponent format, e.g., "2.648000e-002" (noting that each v must be non-negative). The file concludes with

```
endsolid name
```

Fig. 4. A STL file structure. Source: CDRSP©

It is important to underline that the contents that were selected to the construction of the pre-test examples, described in the following section, took into account the fact that they are potentially improved with AR technology, as they have a geometrical component interconnected to the three-dimensionality. On the other hand, the teachers who have collaborated with us know that these concepts are usually those in which students have more difficulties.

4. Augmented Reality: an Enhancer for Math's Learning?

With regard to the applications of AR contents in the classroom, which occurred initially in a pre-test phase in the TP1 Class of Electrotechnical Engineering Evening Classes, 13 tablets and 13 books (Support Manuals) were handed to each student, on June 13, 2014. The lecturer of that class and the lecturer of the unit course in the 2nd term were present at the classroom. There, it was possible to take some pictures, to interact with the students and to witness some significant situations, as seen on Figures 5 and 6.

Fig. 5 and 6. Pre-test of the AR contents application in the classroom. Source: Teresa Coimbra©.

From this pre-test, we can point out that, with regard to the tablets, its use was very intuitive and there was no kind of resistance. Still, there was one device that wasn't accessing to the Junaio application channel, and therefore it was replaced by another device. During the interaction, another device had communication failures, but the student autonomously decided to use his own mobile phone. He then quickly accessed to the application and its channel. The difficulties of accessing to the 3D contents were overcome, which evidences digital skills in the use of mobile devices and suggests that our AR application can be perceived as a system for enhancing accessibility and fighting info-exclusion.

With regard to the contents of the study program of this unit course, they were being progressively presented, with a concept revision character, and the students followed carefully all the oral explanations complementing them with the AR contents available. We observed that about half of the students were curious on testing the new approach of the (AR) contents with their own mobile phones, even when the tablet was functioning perfectly; they did it in a very autonomous and quick way. This, again, evidences digital skills in the use of mobile devices and suggests that our AR application can be perceived as a system for enhancing accessibility and fighting info-exclusion.

There were presented 7 of the 29 examples for 3D interaction that exist in the book/support manual, taking into account the defined objectives of those classes. In each example, it was possible to interact with the content, to interpretate the results, either in a practical perspective, or relating them with their inherent theoretical concepts. This interaction lasted between 20 to 30 minutes, including the time spent to prepare the mobile devices and the specific instructions of use.

At the end of this pre-test session, 10 of the 13 students answered to a survey, which took about 5 minutes. The majority of those students hadn't had any previous contact with that kind of contents, nor had known AR, unless in games or by the media. Nevertheless, all of them stated that they would pleasingly accept the integration of 3D contents in Mathematical Analysis (MA) mainly because "it facilitates learning" and because it was considered "more perceptible" than other pedagogical strategies and technological approaches. The more common questions were about technical issues, and they even wanted to know more about the technology used and the how the contents were built. Hence, not only did they considered the AR application tested as a tool to better understand and access to knowledge, but they also showed great curiosity and interest in the software potentialities, wanting to know more about it.

Furthermore, students reached some important conclusions, as the fact that the device used affects the way of visualizing the contents, either by the size, or by the power consumption, or even by the network access, the screen definition, or the brightness (outside, or of the device). Even if it was the first time that the majority of the inquired students interacted with this technology, the way they did it was quite intuitive. There was no need for very detailed explanations because each student went on discovering several ways to use the given examples. Many students seized the opportunity to install Junaio application on their mobile phones or tablets, so that they could test AR contents in their own devices and in other contexts outside the classroom. This is another evidence of students' digital skills, suggesting once more that the AR application we developed increases digital literacy and enhances info-inclusion.

The inquired students revealed great autonomy in the use of the contents, creating personal ways to interact with the devices and making videos of what they were visualizing in order to have another perspective of the contents. At the end of that class, they were all able to use this technology with no difficulty. Some of the most heard comments were: "Classes should all be like this"; "The best Math's class I've ever had"; "This way, we can better visualize the concepts and better understand the theory"; "This is perfect to see 3D graphics"; "The topics are easier to understand because we can better visualize and interact"; "It would be good to use this during exams"; "All the classes like that could also be disturbing, unless the teacher is able to control the class". Hence, from the students' words, we can assume that the majority of them has a favorable view about the fact that the interaction of AR contents can promote the understanding of those same contents.

5. Conclusions

Even if this is an exploratory study, which corresponded to the first cycle of DBR iterations, and more specifically the pre-test phase of 3D contents created for MA classes, we can sustain that, in this specific context, AR is an enhancer for math's learning. We are certainly aware that there are many aspects that need to be improved, which will happen in the next cycle of DBR. To illustrate, and to synthetize, when brightness conditions are low, it is not always possible to focus automatically, nor to access with greater detail to the presented examples. These restrictions should be prevented and overcome, in order not to affect a better visualization of AR contents. On the other hand, AR contents will surely be improved, bearing in mind not only the students' feedback, who experimented them during the pre-test, but also the lecturers' contributes, whose interviews will also be analyzed.

Referring to a Portuguese saying that mentions that "a picture is worth more than a thousand words", then a three-dimensional picture will be worthy of many more. So, we believe, after our literature review and by the preliminary analysis of some of our data, that a three-dimensional picture submerged in the real world is worth more than any other (picture or word). Or, as it was recognized by the students, the AR makes it easier to understand mathematical concepts because it caters for a better visualization and interaction. Thus, we can conclude that three-dimensional technologies, such as AR, enhance the teaching and learning of mathematics in the Portuguese polytechnic higher education. In a word, AR applications may increase both the use of information and the access to knowledge, improving digital and info-inclusion.

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LANSYS, LDA.

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