Manipulating Virtual Objects With Your Hands: A Case Study on Applying Desktop Augmented Reality at the Primary School

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Abstract

Augmented Reality (AR) offers many opportunities as an interactive tool to improve learning and teaching processes. This paper presents a pilot study conducted on third graders where a series of AR contents about Natural and Social Sciences have been used as a teaching tool. The main objective of the application is to help the students to learn complex concepts that present a difficult understanding. A user centered approach was followed to create the AR contents, where several teachers collaborated on its definition. The AR application combines 3D models and animations, mini games and quizzes. An evaluation of the educational contents was made from the point of view efficiency (academic achievement), usability and motivation. Results confirm that the use of desktop AR has had a positive impact on the learning and teaching process and reinforce the vision of AR as an affordable and feasible technological tool to support the students' learning activities.

1. Introduction

Nowadays, lack of interest and motivation in students towards classical academic practices represents a key factor in academic failure in developed countries. There is a growing gap between the teaching procedures and the technological way of life of students [1]. Besides, true learning is experiential. The more senses that are involved (sound, sight, touch, emotions, etc.), the more powerful the learning experience is [11]. In this context, augmented reality (AR) can play an important role supporting experiential learning and giving the students an appealing technological tool to support their learning activity.

AR is similar to the virtual reality (VR) paradigm. Several formal definitions and classifications for AR exist (e.g. [14],[16]). AR combines three-dimensional (3D) computer-generated objects and text superimposed onto real images and video, all in real time. Azuma [2] proposes a definition of AR as a variation of virtual reality. Thus, AR supplements reality, rather than completely replaces it. With AR applications it is possible to show the user a common space where virtual and real objects coexist in a seamless way. From a technological point of view [2] AR applications must fulfill the following three requirements: combination of real and virtual worlds, real time interaction and, accurate 3D registration of virtual and real objects.

As the Horizon Report 2011 [9] states, augmented reality is a capability that has been around for decades, that is reaching a maturity level that could mean a time to adoption of around two to three years. However, there are limited references to quantitative results of the application of this technology in real educational scenarios. Majority of these results are based on the employment of expensive and exotic hardware that make these previous experiences of limited application [19][22][12].

Basic desktop AR, implemented on regular PCs equipped with a webcam, is the more feasible hardware setup to introduce this technology in real educational settings. In this case, the manipulation of fiducial markers controls the interaction with multimedia contents, while visualization is received on the computer screen or in an interactive whiteboard.

There are a limited number of published studies about the practical application of AR pedagogy (desktop AR). This work is oriented to provide additional data about the impact of this technology on the learning and motivation of participant students. Also a usability study was conducted to evaluate the developed AR applications. These AR applications were developed to support the teaching and learning activities of a Natural and Social Sciences course on the Primary School (third grade). First of all some related work and a description of the educational contents is presented. Next, interface design and

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system architecture are introduced. Finally, validation protocol, results and conclusions are provided.

2. Related work

As Dünser et al. [5] note, although AR has been in studied for over forty years it has only been recently that researchers have begun to formally evaluate AR applications. They reviewed research publications between the years 1993 and 2007 related to the AR field, finding that only ~8% described a formal user evaluation. This means that in a more restricted scope, as the educational application of AR, there are a small number of contributions that focus on user evaluation.

With respect to the immersive nature of the visualization display, there are interesting considerations regarding using desktop AR (visualization in the computer screen). Liarokapis and Anderson [13] note that participant undergraduate students at two departments of Informatics and Information Science in UK preferred the monitor-based augmentation compared to the head mounted display (HMD) based augmentation which they found distracting and difficult to use.

Sometimes, the benefit of AR in educational contexts is linked only to promote motivation and engagement among students. For example, Juan et al. [8] developed an AR game for learning words. Thirty two children played the game (using an head mounted display display) and the equivalent real game. Comparing the results of the two games, they did not found significant differences between the two games except for one question: 81% of the children liked most the AR game.

Design of educational contents must be very careful done. Park et al. [18] indicate that students' learning performance is significantly higher when seductive details are presented under the low cognitive load condition (narration). Their findings suggest that the cognitive processes of selecting relevant information and organizing this information into a coherent mental model can be affected not only in a negative way by seductive details, but also in a positive way if learners have enough free resources to use this non-redundant and interesting, but irrelevant learning material.

In this context, it is important to consider the possible novelty effect associated to a new technology like AR. Seo et al. [21] note that while 3D interactive graphics seems natural even to very young children (due to their exposure to 3D games), AR based contents are very surprising, thus drawing great interest and curiosity (at least for now). This situation represents an important issue due to the difficulty of separating the novelty effect from the true benefit of delivering AR based educational contents.

Active or passive interaction with AR contents is an important element of study, especially in the context of primary education. Kerawalla et al. [10] conducted a study to compare the use of AR, using the virtual mirror interface (desktop AR using an interactive whiteboard as display), with traditional teaching methods to teach 10 year olds about the interrelationships between the earth, sun and moon. Their analysis of teacher–child dialogue revealed that the children using AR were less engaged than those using traditional resources, perhaps due to their passive relation with AR contents in this study.

Freitas & Campos [6] conducted a study on the design and evaluation of augmented reality for teaching 2nd grade-level concepts like means of transportation, types of animals and similar semantic categories using and interface similar to the virtual mirror used in Kerawalla's work. Results suggested that AR is effective in maintaining high levels of motivation among children, and also has a positive impact on the students' learning experience, especially among the weaker students, showing some contradiction with Kerawalla's results.

This work tries to provide additional experience in the application of AR technology in an educational context similar to [10] and [6] (primary education), following the approach of the virtual mirror paradigm previously described, and using AR as a tool to support teacher's explanations, making emphasis in the analysis of the impact on users through academic achievement, usability / satisfaction and motivation..

3. Didactic contents

The development of the didactic contents presented in this paper was agreed with the Department of Education of the Comunidad Valenciana (Spain). A team of experts from the Department of Education helped in the selection of topics and the basic ideas that oriented the development of the AR application. It was really a collaborative effort, where using a series of prototype applications, the final design was obtained.

The didactic content has been designed according to the Decree 111/2007 from the Generalitat Valenciana (the regional government) that establishes the curriculum of primary education for the Comunidad Valenciana [7]. The chose subject was "Knowledge of the natural, social and cultural environment".

As the first introduction of this technology in the Valencian public school system, the nature of this work is also exploratory. After some initial prototypes were developed, they were evaluated by a panel of teachers that were selected to conduct a preliminary study. They identified some additional functionality that was incorporated in the final version and some usability issues where detected and fixed. The augmented reality application has been conceived as a tool for supporting teachers during their explanation, and as an auxiliary resource for the students that can be used for individual learning and to provide a framework for team activities. According with the resources and equipment available in schools different activities around these AR contents can be accomplished.

The developed AR system whose name is Realitat3 consists of an AR engine and six AR applications: skeletal apparatus, water cycle, plant development, frog metamorphosis, solar system and the senses. All applications have the same screen layout, as seen in Figure 1, facilitating the inclusion of future new contents. Thus, in all applications, at the top right of the screen there is a set of icons that provide some basic functionality. They are common tools, such as changing the zoom level of the 3D model that appears on the mark or the on/off switch of the audio system which can be accessed with the mouse (or touching on the interactive whiteboard). Other tools are, to show the application user guide, to quit the application and to display a context-sensitive help.

Finally, it is worth to mention a feature that has proved to be very useful for the teachers. It is the possibility of stopping the tracking of the AR marker. It allows freezing the position of the 3D model on the screen, without holding the AR marker. This feature was suggested by the teachers participating in the preliminary evaluation of the application, and finally included in the official version.

Moreover, the left side of the screen is reserved to include menus that change depending on the content that is loaded. This way, in an animated content, these menus are the controls of the animation (start, next step and play all) whereas in a non-animated content these menus give access to the different activities: “Game”, “Visualization”, “Consultation” and “Questionnaire”.

Also, under these menus, there is a rectangular area reserved to show informative texts. And just under this area, there is a small square that is used to show 2D images which help for a better visualization of the content. Finally, in the lower side of the screen, there is also another rectangle reserved to show more detailed explanations in text format. This text can be listened if the audio button is on.

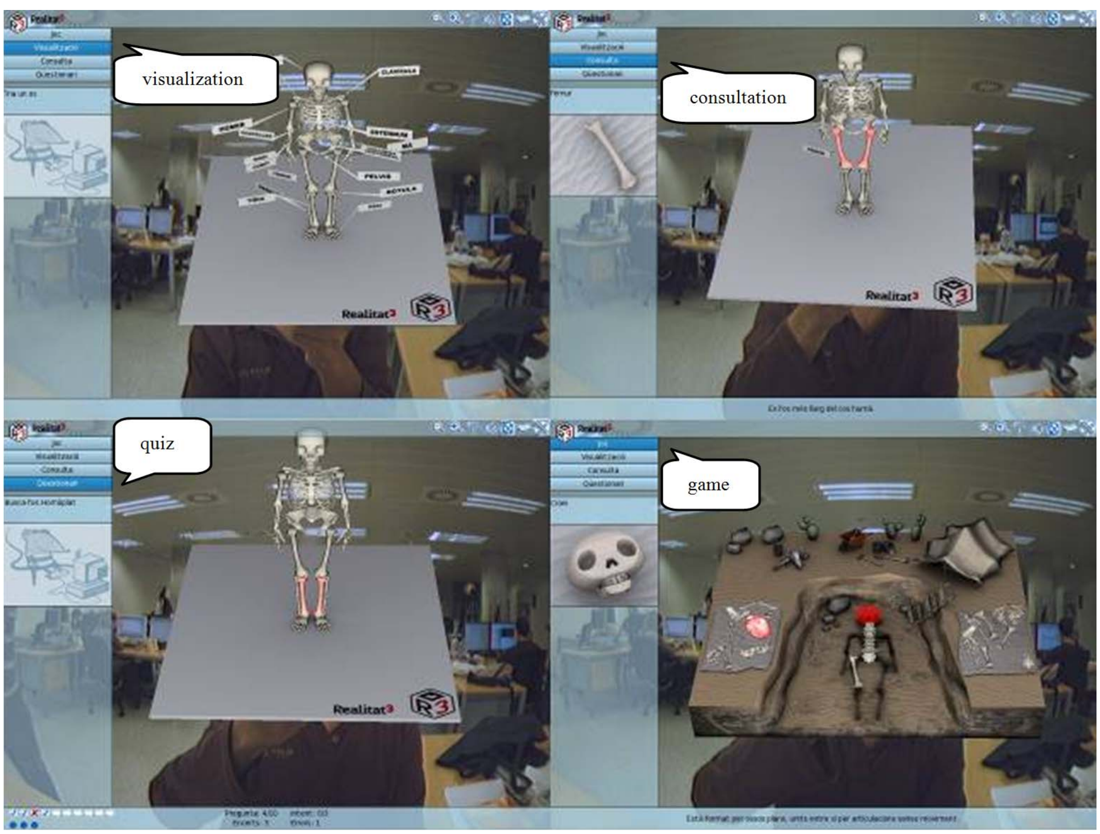

Figure 1. Skeleton activities: visualization (1st row, left), consultation (1st row, right), questionnaire (2nd row, left) and game (2nd row, right)

3.1. An example of AR application: skeletal apparatus

This application shows the skeletal apparatus in detail, in order to help teacher and students in their teaching/learning process. Thus, the application is divided into four activities. The first one, “Game”, is a kind of archaeological excavation that appears over an AR marker. Game objective is to place a set of bones, which someone has dug up, into its original place. The way to do this is by clicking with the mouse on the bone that user wants to place and then on the correct silhouette part, as seen in the bottom right of Figure 1. In addition, a detailed bone image is shown at the left side of the screen when user selects it. It also presents text information about the bone at the bottom of the screen. The second activity, “Visualization”, shows a human skeleton over the AR marker. It also shows the most important bone names using arrows and text. Each arrow points to the referred bone, as seen in the upper left of Figure 1.

By using AR, the application lets the user observe every skeleton bone from every angle, which can facilitate teacher explanation and student understanding. Moreover, this application provides additional information about the bone by clicking with the mouse on it. This information is presented at the bottom of the screen as a text and at the left of the screen as a 2D detailed view

The third activity, “Consultation”, lets teacher to ask their students about the lesson. This activity is thought to be used both individually by the student (if they have their own PC) and over an interactive whiteboard (IWB). In both cases, the teacher asks the students for a bone and then, the student has to click with the mouse (or touch on the IWB) on the correct skeleton position.

The fourth and final activity, “Questionnaire”, helps the students to self-assess their learning. System asks the user for ten bones, and she/he has to locate them in the skeleton. So, different sounds are played when the user is right or fails. Note that the application does not consider an incorrect question until the user fails three consecutive answers.

4. Software architecture

It is worth to highlight that the augmented reality application described previously will be distributed as a package of the Lliurex 10.09 operating system. Lliurex is a Linux distribution which is based on Ubuntu Lucid Lynx (10.04). The AR contents, that are catalogued using the SCORM standard, will be distributed through an educational portal

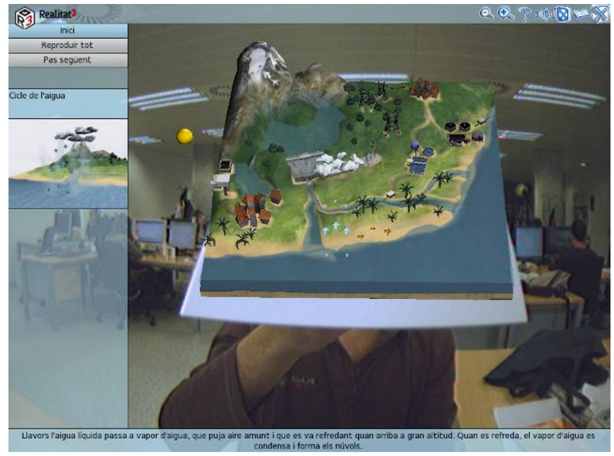

Figure 2. Water cycle application.

The whole system has been developed using OGRE as its graphics engine and a set of public libraries like OIS to manage input devices, Audiere to manage sound streams, tinyXML to manage XML configuration files, v4l2 to capture video from a webcam under Linux, MyGUI to develop the graphical user interface and OpenCV to develop our own AR engine under Linux.

In order to support the development of AR applications our research group has developed a software library called HUMANAR, which is described with all detail in [15]. Although there are several public libraries with AR capabilities, we decided to develop our own library to overcome some drawbacks present in some public libraries (jitter, bad performance with variable illumination, support of infrared markers, etc.).

HUMANAR is a C and C++ language software library that uses computer vision techniques to calculate the real camera viewpoint relative to a real world marker. This method can be divided in three parts: camera calibration, marker detection and calculation of marker position and orientation (pose estimation).

Camera calibration consists in determining the intrinsic camera parameters and the distortion parameters. We use different captures of planar checkerboard patterns and the Zhang´s method [23] for this purpose. Marker detection consists in binarizing the grab camera frame using an adaptive threshold [17] in order to find the marker contour where the connected components must be extracted.

Next the perimeter of each contiguous region of black pixels is traced to produce a chain representing an object border. A set of line segments are then fitted to these points, in such a way that all border pixels are within some minimum distance of a line segment. If the resulting polygon is sufficiently large and has exactly four sides, it is considered a candidate marker and passed on to the identification process.

Marker pose estimation is obtained using the Levenberg-Marquardt (LMA) [2] algorithm. This algorithm provides a numerical solution to the problem of minimizing a function, generally nonlinear, over a space of parameters of the function. These minimization problems arise especially in least squares curve fitting and nonlinear programming.

5. Results

To analyze the impact of Realitat3 on the learning process, three parameters have been selected to be studied: efficiency (academic achievement), usability and motivation. Their analysis is detailed in the next points.

5.1 Efficiency

Efficiency has been evaluated from the point of view of new knowledge assimilation. The group under study consisted of 21 students, 12 boys and 9 girls, of third grade of primary education. For the experience the first ten thematic units of the "Knowledge of the natural, social and cultural environment" subject were analyzed (each thematic unit takes around two weeks to be completed, and the whole academic year is organized in 14 thematic units, where we obtained data from the first 10 units). Realitat3 was used by the teacher to support his/her explanations. Students used the application by turns on the interactive whiteboard. Units 6 and 7 used the frog metamorphosis (Figure 4), and water cycle AR contents (Figure2) respectively. For evaluation, a quasi-experimental design scheme based on interrupted time series was used.

Results show that the two thematic units with the best mean qualifications (range from 0 to 10), match with those in which Realitat3 was used (Figure 3).

Table 1. Selected thematic units.

Thematic units	Mean score (std. dev.)
#1 The human body	6.0 (2.4)
#2 A healthy diet	6.3 (2.0)
#3 The five senses	5.2 (2.4)
#4 Classifying animals	7.1 (1.8)
#5 Plants	7.9 (1.2)
#6 The living beings and their environment	8.0 (1.3)
#7 Water on the Earth	8.2 (0.9)
#8 Landscapes	6.0 (2.2)
#9 Living together: villages and cities.	6.4 (1.6)
#10 At work: from agriculture to industry	5.2 (2.3)

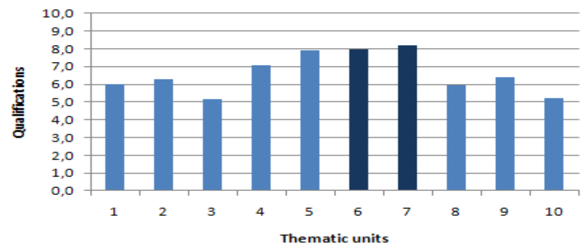

Figure 3. Mean scores for thematic units. In thematic units 6 and 7, AR contents were used.

Although there was no statistically significant difference with other units with high scores, participant teachers expressed a positive opinion with the experience of using AR contents, and thought that it really had a positive impact on the class.

5.2 Usability/satisfaction

To evaluate usability and satisfaction of students, a questionnaire with a smiley Likert scale of 5 levels was used [4] (Table 2). Questions QU1-QU5 assess usability, while QS1-QS5 assess satisfaction. This questionnaire was passed when all students had received classes with Realitat3 and used it.

Table 2. Usability and satisfaction questionnaire.

Q#	Question	mean val. (s.d.)
QU1	I prefer the classic book to using the new material (reversed value)	4,1 (0,94)
QU2	I found it easy to see the geometric shapes with this technology	4,7 (0,66)
QU3	I believe that this material will help me to make a better examination	4,4 (0,97)
QU4	It has been easy to learn to use this material	4,4 (0,87)
QU5	I would like to use this material at home	4,7 (0,7)
QS1	In this class I have been more attentive than in other classes	3,7 (1,02)
QS2	This class has seemed to me to be useful and interesting	4,6 (0,59)
QS3	I would like to take more classes as those of today	4,4 (1,08)
QS4	It is easier to follow the teacher's explanation in a class of this type	4,6 (0,50)
QS5	In class today I behaved better than in other classes	3,5 (0,81)

5.3 Motivation

The assessment of motivation was performed using the subscales "competition", "interest" and "effort" from the Intrinsic Motivation Inventory (IMI) test [20].

The scheme used was the classic pre-test before receiving educational content with Realitat3 and post-test once used the system (IMI questionnaire was filled at same time that the usability one).

Tables 3 & 4 show the used questionnaires. Each question was scored on a smiley Likert scale of 5 levels. All questions in the pre-test are related with the post-test questions in the same order. As an example “I think I am good at school” question in the pre-test is equivalent to “I think I was good learning with Realitat3” in the post-test.

Effect size [3] results are presented in Table 5, where pre-test and post-test mean values and standard deviation are presented. Effect size of 0.2 to 0.3 usually are considered to be a "small" effect, around 0.5 a "medium" effect and 0.8 to infinity, a "large" effect.

Table 3. Intrinsic motivation inventory pre-test.

Q#	Pre-test question
Competence	
Q1	I think I am good at school
Q2	I think I do pretty well at school, compared to others
Q3	I am satisfied with my performance at school
Q4	I am pretty skilled at school
Q5	I think I am pretty good at school
Interest	
Q6	I think school is quite enjoyable
Q7	I think school is very interesting
Q8	I think school is fun
Q9	At school I often think about how much I enjoy it
Q10	I think school is boring (reversed value)
Effort	
Q11	I do my best at school
Q12	I try very hard to do well at school
Q13	It is important to me to do well at school
Q14	I put much effort in school

Figure 4. Frog metamorphosis AR content

Table 4. Intrinsic motivation inventory pos-test.

Q#	Question
Competence	
Q1	I think I was good at Realitat3
Q2	I think I did pretty well with Realitat3, compared to others
Q3	I am satisfied with my performance while learning with Realitat3
Q4	I was pretty skilled learning with Realitat3
Q5	I think I was pretty good learning with Realitat3
Interest	
Q6	I think learning with Realitat3 was quite enjoyable
Q7	I think learning with Realitat3 was interesting
Q8	I think learning with Realitat3 was fun
Q9	While I was learning with Realitat3, I often thought about how much I enjoyed it
Q10	I think learning with Realitat3 is boring (reversed value)
Effort	
Q11	I did my best while I was learning with Realitat3
Q12	I tried very hard to do well learning with Realitat3
Q13	It was important to me to do well learning with Realitat3
Q14	I put much effort in learning with Realitat3

Considering a sample composed by several observations for the same individuals in different times where a normal distribution in the initial data is assumed, a paired sample t-tests (t Student), with a 95% confidence interval ($\alpha = 0.05$) was applied.

To avoid the problem of multiple comparisons (also known as the multiple testing problem) a Bonferroni correction was applied taking into account that each criteria (competence, interest, effort) are evaluated using at least five questions. So $\alpha_i = 0.01$ was used.

Table 5. *t* test results on motivation questionnaire. Critical value for t:2.85 (two tailed test).

Questions	Pre-test mean value(s.d.)	Post-test mean value(s.d.)	Size effect	*t* Student
Competence				
Q1	3.67 (0.97)	4.57 (0.68)	1.07	3.02
Q2	3.62 (0.92)	3.24 (0.83)	-0.44	1.56
Q3	3.81 (1.08)	4.81 (0.51)	1.18	3.74
Q4	3.19 (0.98)	4.14 (0.85)	1.03	3.21
Q5	3.62 (1.07)	4.05 (0.86)	0.44	1.82
Interest				
Q6	4.33 (0.80)	4.62 (0.59)	0.41	1.24
Q7	4.57 (0.51)	4.81 (0.40)	0.52	2.02
Q8	4.57 (0.75)	4.81 (0.40)	0.40	1.15
Q9	4.38 (0.86)	4.52 (0.98)	0.15	0.76
Q10	4.33 (1.02)	4.90 (0.30)	0.76	2.54
Effort				
Q11	4.14 (0.65)	4.19 (0.68)	0.07	0.23
Q12	4.05 (0.80)	4.48 (0.81)	0.53	1.75
Q13	4.76 (0.44)	4.10 (0.83)	-0.99	3.57
Q14	4.19 (0.75)	4.33 (0.80)	0.18	1.72

The variation of the competence, interest and effort variables between the pre-test and post-test was analyzed. The alternative hypothesis, according to the above data, is that the valuation of each issue is better in the post-test than in the pre-test, while the null hypothesis is that the observed differences in these ratings are due to chance.

Results for *t*-tests are presented in Table 5, where the average and standard deviation of student ratings in pre-test and post-test are provided. The column "*t* Student" has the value of the t statistic, and thus to discern whether to accept or reject the alternative hypothesis.

If the "t statistic" value is inside of the confidence interval, which is defined by 2.85 (two tailed test with Bonferroni correction), the null hypothesis is accepted, and there is no statistically significant difference between the two samples.

Thus, analyzing Table 5 it is noted that there are statistically significant differences in Q1, Q3 and Q4 questions, so in this case it is accepted the alternative hypothesis, meaning that post-test assessments on these questions are better, and in general can be assumed an improvement in the "competence" variable. Respect to the "effort" variable, only Q13 question shows a statistically significant difference. On the other hand, it is not observed a significant improvement in the "interest" variable.

6. Discussion and conclusions

In general, both teachers and students have shown a very positive attitude to the Augmented Reality technology, being their first contact with it.

We think that this pilot study does not reflect the whole potential of AR technology as its direct use by students was very limited, because basically the AR technology was used to support the teacher explanations, and students took direct contact with the AR contents a limited time.

The quasi experimental design applied in the efficiency study was chosen due to the constraints imposed by the participant school. This meant that was no possibility to use a control group and implement a more robust experimental design. Usually the main weakness in the interrupted time-series design is the design's failure to control for effects of history. The main conclusion that can be extracted from Figure 3, where the mean scores for thematic units are charted, is that those units that employed augmented reality contents behave very well with respect to the rest of units. This qualitative conclusion is reinforced by the feedback received from the participant teachers. They felt that augmented reality contents caused a positive effect on students. However there is a clear limitation in the study that can be hindered by the novelty effect associated to a first contact with the new technology and the heterogeneity of the contents in the "Knowledge of the natural, social and cultural environment" subject.

With respect to usability, as the results in table 2 show, students found Realitat3 easy and natural to use. According to the results, students clearly opt for the use of the new technology (QU1 is reversed in representation). They think that its use was simple and transparent, as seen from QU2 and QU4. According to question QU3, the majority of students recognize that this tool can help them positively in improving their results, and mostly would like to use these technologies at home too (QU5).

With respect to the satisfaction evaluation of this type of technology, students show a greater attention in class, accompanied by a notable interest in the subject being taught. QS4 is especially interesting, as students recognize that it is easier to follow the lessons taught in this way. Again, the comments provided by the participant teachers confirm the results provided by the questionnaire.

Motivation results were significant for the variable "competence" that showed an important improvement, with an effect size [3] bigger than 1.0 for Q1, Q3 and Q4. Also question Q10 presents and important increment with an effect size of 0.76, although there in no significant statistical difference with pre-test.. It is important to note that pre-test values in "interest" and "effort" were already quite high, indicating that this group had a positive attitude with great interest. So it was difficult to improve these initial high values. The results in Q13 could be due to the fact that students knew that their contact with augmented reality contents would be limited to only several weeks.

During next academic year it is expected to conduct a more deep study using each student the Realitat3 application in an individual way. Good usability and satisfaction results suggest that a more direct and active involvement of students with the AR application could provide better results. Finally, this relatively passive contact with AR contents could justify the limited impact on student's motivation measured through the Intrinsic Motivation Inventory instrument.

Learning and teaching procedures have to evolve to take into account the way of living of digital natives, even the youngest ones. Outdated teaching methods create a barrier for some students that are accustomed to interact with modern technological gadgets and computers. Augmented reality can be a cost-effective technology (at least desktop AR only requires to add a webcam and the proper software to an IWB setup) to provide students with attractive contents to support the understanding of difficult concepts.

Teachers involved in the experience indicated that although the didactic contents supported only a limited interaction, the biggest impact on students was linked to the physical manipulation of a marker that controlled the behavior of the virtual content provided by the application. The usability and satisfaction questionnaires support this indication. Also, from the point of view of the participant teachers, the physical manipulation of fiducial marks is an advantage for the adoption of this technology. The simple idea of manipulating a cardboard marker to interact with digital contents can break the barrier to incorporate new educational applications to the classroom for teachers with limited digital competences.

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