

TOWARDS A MIXED REALITY LEARNING ENVIRONMENT IN THE CLASSROOM

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Abstract: In this paper, we present a novel study that emphasizes the use of Augmented Reality (AR) as a natural complement for the Virtual Reality Learning Environment (VRLE) model, towards a general acceptance of Mixed Reality Learning Environment (MRLE) in the classroom. Handheld devices help this scheme serving as general purpose computers available for use by other applications. AR has not been explored deeply enough to have full acceptance of use in the classroom. We present an application in which a tablet PC was used to evaluate our game, working with multimodal interaction provided by a tactile screen and an accelerometer. It can be played in two modes: combining AR and non-AR (NAR), and only NAR. Seventy-three children of primary school tested the system. For the learning outcomes, there were no statistically significant differences between both modes, but the AR mode enhanced highly user satisfaction and engagement. This confirms our hypothesis that AR can be an excellent complement to VRLE for the use in the classroom.

1 INTRODUCTION

Education is a field of research that can benefit extraordinarily from technology. The Virtual Reality Learning Environment (VRLE) is well established as an educational tool (Lee et al., 2010), while Augmented Reality (AR) is not as spread yet. AR could be a strong complement to this traditional approach to education, and learners could enrich their experience with a Mixed Reality Learning Environment (MRLE) (Pan et al., 2006) in the classroom.

Many VRLE applications have been developed (Yang et al., 2010; El Sayed et al., 2011). However, while some researches in the field of education state that VR is "extremely close to reality" (Inoue, 2007, p. 1), such is not still the case of AR. We attribute this to the fact that it is very modern in comparison to VR, and to the few easy to use, low cost, updated AR tools for educators that can be found.

Handheld devices offer excellent capabilities to be used for education, and have a great perspective of future (Billinghurst and Henrysson, 2006). In our opinion, tablet PCs can be an excellent tool that helps AR to have good acceptance as a complement to VRLE. Tablet PCs are usually equipped with several sensors



Figure 1: Child playing one of the AR games, catching the water drop main character.

and mechanisms for rich Human-Computer Interface. They generally include a camera, a tactile screen and inertial measure units such as accelerometer and gyroscope. Thus, they can be used in a wide range of education areas, reducing the cost of custom hardware.

As far as we are concerned, there is still too much separation between the fields of AR research and education inside the classroom. We believe that the latter could benefit from the great contributions of handheld AR applications. Our initial hypothesis is that AR can be a good complement to VRLE for educational pur-



Figure 2: Child playing one of the NAR games, starting the game of the falling suns.

poses to improve learning. With this study, we want to prove or reject this hypothesis.

In this research, we propose the case of use of a game. Many computer games have been developed for learning purposes, but very few perform a deep analysis, as several researchers have highlighted (Connolly et al., 2011; Freitas and Campos, 2008). Some researchers have also pointed out the lack of a coherent theory of learning and underlying body of research in the development of educational applications (Shaffer et al., 2004).

In this paper, we present a handheld game that not only uses AR, but also combines it with non-AR (NAR) parts –including video games– as a case of VRLE. Video games are a subject widely studied in the past. For desktop computers, different subjects can be learnt such as volcanoes (Woods et al., 2004), mathematics and geometry (Kaufmann and Schmalstieg, 2003), organic chemistry (Fjeld et al., 2007), or endangered animals (Juan et al., 2011a). For handheld devices, many AR applications have also been presented. For example, for learning heritage temples (Wang et al., 2009), math and literacy skills (O’Shea et al., 2009), or how to recycle (Juan et al., 2011b).

The innovate aspect of this study relies on the research of a scenario with practical usability in the classroom. We emphasize the convergence between AR and VRLE to form a MRLE, as a very suitable tool for educators that can improve the outcomes of VRLE and support meaningful learning. We also believe that tablet PCs are very appropriate to put MRLE into practice, as they are affordable, allow AR applications and provide multimodal interaction.

This paper is structured as follows. Section 2 comments the design and description of the game. Section 3 explains the materials and methods involved in the study. Section 4 describes the study carried out and the evaluation measures. Section 5 analyzes the statistical results. Finally, in section 6, we present our conclusions and future work.

2 THE GAME

We developed our game following certain learning theories and pedagogical background, that we explain in this section.

2.1 Game Design

For the design of the game, the experiential learning theory of Kolb was used, which stated that “learning is the process whereby knowledge is created through the transformation of experience” (Kolb, 1984, p. 38). The experiential learning consists of the following steps: a concrete experience (do), a reflective observation (observe), an abstract conceptualization (think), and an active experience (plan or testing in new situations). Our game was designed based on the underlying idea of using experience for learning.

In our game the player assumes the mission of completing the cycle of water, and she has to perform different activities. For example, the player has the concrete experience of collecting suns to raise the temperature; with a reflecting observation with the feedback of the game; creating an abstract conceptualization as a result of receiving all the information, in this case, evaporation. And what is very important, the student has an active experience using the game.

Our game also applies Gardner’s theory of multiple intelligences (1983), in which at least seven types of intelligence are considered: logical-mathematical, visual-spatial, linguistic, bodily-kinesthetic, musical-rhythmic, interpersonal, intrapersonal.

Some works have pointed out the importance of considering national curricula to develop educational computer games (De Freitas and Oliver, 2006; Law et al., 2008). We have taken into account the national curricula for our game, as stated by the national primary education law in the Spanish Royal Decree 2211/2007, on July the 12th.

2.2 Description of the Game

The aim of the game was to reinforce the learning of children in the subject of water, including its composition, the water cycle and water pollution. These topics were shown in the same way they had been studied at school.

The game was divided in a series of mini-games, several of which were for each step of the water cycle. There were also video and audio explanations at the beginning of mini-games that showed the rules and goals to complete it, and at the end to show they completed them. These interludes helped linking all the mini-games together in a story thread.

The game could be played in two modes, called AR and NAR. Both modes were essentially the same, but the interface and the way the users played changed. In AR mode some mini-games were played with AR technology –not all mini-games were appropriate for AR–, while in NAR mode all mini-games were played as traditional video games.

All AR mini-games shared some common characteristics. Children had to collect objects (suns to evaporate, thermometers to allow the rain, water pollutants to clean the river, etc.) that could be found in one of the ten markers disposed in the surrounding area, focusing on the markers with the handheld device in a see-through configuration. As part of the classroom decoration, markers were placed on decorative pictures printed on paper. Once they pressed on the correct object in the screen, if there were more objects to collect, they were rearranged to the markers in the classroom in a systematic fashion.

The equivalent NAR version was developed imitating the behaviour and the user experience of the AR mode. Objects were shown in the center of the screen with one of the decorative pictures as background, and left and right arrows to pass to the next or to the previous object in the same order as it would in AR mode.

The game consisted on seven mini-games, including an initial part that served as an introduction to the game and gave the children a chance to familiarize with the AR interface. Each mini-game represented a step in the water cycle, and there were also two mini-games where the children learned about the composition of water and water pollution. Three of the mini-games could be played in AR and NAR modes, while the rest were only NAR.

3 MATERIAL AND METHODS

For the evaluation of our study, we needed to build both custom hardware and software to provide a multimodal interface. This section explains the hardware built and the software developed.

3.1 Hardware

For the evaluations we used the handheld device *HP Slate 500 Tablet PC*. The dimensions of the device were 23x15x1.5 cm, and it had a weight of 0.68 kg. Its processor worked at 1.86 GHz, and it had a 2 GB DDR2 SDRAM memory cell. Among its interfaces we could find a 8.9” capacitive touch screen and an outward facing 3 Megapixel camera capturing at 30 fps.

The accelerometer board *1056 - PhidgetSpatial 3/3/3* from *Phidgets* (<http://www.phidgets.com/>) was used to measure static acceleration accurately in two axes. It was connected via USB to the tablet PC. The dimensions were 36x31x6 mm, which made it to be easily enclosed with the tablet PC. The need for this device was due to technical problems with the built-in accelerometer, for which HP did not provide any usable driver. At the time we bought this device, it was one of the very few available in the market. Nowadays there are several alternatives that are known not to suffer from this problem, such as the iPad 2 or the Samsung Galaxy Tab 10.1.

We had a total of two identical devices available to use with the children during the evaluations of colors blue and white.

3.2 Software

To develop the system we decided to use OpenScene-Graph (OSG) toolkit 2.9.5 to use its high capabilities to import, animate and render 3D objects with high performance in C++ language. The registration was made using the OSG plugin osgART 2.0 RC 3, which used the ARToolKit library (Kato and Billingham, 1999), version 2.72.1. This plugin provided simple access to the camera, and to certain OSG nodes which applied the corresponding transformation matrices associated to markers when they were recognized.

4 DESCRIPTION OF THE STUDY

The developed game described in section 2.2 was extensively played by a group of children who tested all the possibilities offered. This section explains the participants, the measurements and the procedure carried out during the evaluations.

4.1 Participants

A total of 73 children from 8 to 10 years old –with a mean age of 9.07 ± 0.65 – took part in the study: 37 boys (50.68%), and 36 girls (49.31%). They were attending the Escola d’Estiu (Summer School) at the Technical University of Valencia.

4.2 Measurements

Five questionnaires were used for the validation. The first one was the pretest, and the other four were the combinations of playing AR or NAR, for the first or the second time.

The pretest (QPre) was composed of 6 questions designed to evaluate the level of children's knowledge and remembrance about water (composition, cycle and pollutants) from school lessons. The questionnaire also collected gender, age and the grade they had finished.

The questionnaires QAR1 and QNAR1 were similar. Both of them contained the knowledge questions from QPre to be able to compare learning before and after the AR and NAR games respectively. The rest of the questions were about participants satisfaction with the game. Some of them followed a Likert scale, presented as: *a) Very much; b) Quite a lot; c) Somewhat; d) Few; e) Nothing*, with a numerical equivalency linearly ranged from 5-a) to 1-e). Other questions did not have a possible numerical representation, as they had to choose among several options (e.g. *What did you like the most? a) Searching objects with the camera; b) Games that used the tactile screen; c) Games that used the accelerometer*).

The questionnaires QAR2 and QNAR2 were designed to compare AR and NAR games preferences. QAR2 shared the AR specific questions from QAR1. The last question was subjective and children could express their feelings about the game.

4.3 Procedure

The children who participated in the experience were randomly assigned to one of two situations:

- a) Children who played the AR game first and then the NAR game.
- b) Children who played the NAR game first and then the AR game.

Both groups were counterbalanced: 38 children were assigned to group *a*, and 35 to group *b*.

Before playing any game, every child filled in the QPre questionnaire. Next, the first group of children played the AR game. After completing the game, they filled in the QAR1 questionnaire. Then, these children played the NAR game and filled in QNAR2 when finished playing. The second group, instead, played the NAR game first. After completing the game, they filled in QNAR1 questionnaire. Then, these children played the AR game and filled in QAR2 when they had finished. Two children, one of each group, could play simultaneously, since we had two equal devices available.

The questionnaires were filled in in the same room where the activities took place. Two people were in the activities room to clarify doubts from the participants while they were playing the game.

In order to make the experience more immersive, the room was decorated with wall posters and images

according to the subject. For the AR game, the play area had water related prints where the markers were placed. These prints were carefully chosen to avoid possible false positives from the AR marker recognizer.

5 RESULTS

After the evaluation with the children, all data was transcribed to electronic format and analyzed with the statistical open source toolkit *R*.

5.1 Learning Outcomes

Several t-tests were performed to check if there were significant differences in the degree of acquired knowledge during the game. These tests were performed over the *knowledge* variable, which condensed six questions about water counting the number of correct answers. This variable was compared among the questionnaires QPre, QAR1 and QNAR1. All tests in the text are showed in the format: (*statistic[degrees of freedom], p-value*), and ** indicates statistical significance at level $\alpha = 0.05$.

From a paired t-test we obtained that the ratings of the knowledge in QPre (mean 4.17 ± 1.21) were significantly different from QAR1 (mean 5.83 ± 0.45) ($t[34] = -8.09, p < 0.001^{**}$). Another paired t-test revealed that the ratings of the knowledge in QPre (mean 3.71 ± 1.25) were also significantly different from QNAR1 (mean 5.74 ± 1.25) ($t[37] = -9.28, p < 0.001^{**}$). Moreover, a third unpaired t-test showed that there were no differences in knowledge between QAR1 and QNAR1 ($t[71] = -0.82, p = 0.42$). These results mean that there was a significant amount of acquired knowledge in both modes in relation to the pretest, and both achieved a similar amount of it.

The factor of school year was also studied. There were no evidences of statistical significant differences on acquired knowledge between 3rd grade students (mean 5.87 ± 0.50) and 4th grade students (mean 5.80 ± 0.40) ($t[33] = 0.43, p = 0.67$). In addition, there were no findings of statistical significant differences in the factor of gender. Males (mean 5.78 ± 0.53) and females (mean 5.88 ± 0.32) had similar scores ($t[33] = -0.68, p = 0.50$).

5.2 Satisfaction Outcomes

In order to determine if the experiment influenced participants in regard to the level of amusement experienced and satisfaction between the two modes of

game, the variable *satisfaction* was created. It condensed all information of several questions related to fun during the game, ease of use, understanding of the rules and goals and enjoyability of certain aspects of the game. The final score of the variable assigned each question the same weight. An unpaired t-test showed that the satisfaction ratings in QAR1 (mean 4.73 ± 0.47) were not statistically different from QNAR1 (mean 4.66 ± 0.63) ($t[71] = 0.28, p = 0.78$). The scores were very high for both games, from what we can say participants enjoyed the experience in both cases and they were engaged to learn in a similar manner.

The preferences for AR or NAR were measured. After playing in AR mode first and then NAR, 65.7% of the children chose AR over NAR, while 94.7% of them chose the same when playing AR in second place. The augment in the proportions was statistically significant ($\chi^2[1] = 9.90, p = 0.002$), but the difference of proportions between AR and NAR in the worst case (AR first) was also significant ($\chi^2[1] = 6.91, p = 0.008$), which means that AR was preferred even if we do not take into account the effects of the order of the games. We can see that AR was preferred over other alternatives, and this was emphasized when it was the last technology to be used.

5.3 Interaction

The preferences of the different types of interaction were measured considering the accelerometer games, tactile games and AR games using the device in a video see-through configuration. A question was asked after playing games in AR mode. When AR was played in first place, the percentages of preferred technology was: AR (54.3%), accelerometer (34.3%) and tactile (11.4%), but when AR was played the last, the order was: AR (73.7%), accelerometer (21.1%) and tactile (5.3%). AR was always the favorite, and relating this to the last question in the satisfaction part, we can see a trend in which the AR preference ratings raised when it was played in the last place. The proportions of AR in both cases were significantly different at level $\alpha = 0.1$ ($\chi^2[1] = 2.99, p = 0.08$). We believe this difference is due to the big impact AR caused to the children. As a consequence, accelerometer and tactile proportions dropped similarly without significant differences.

6 CONCLUSIONS

In this paper we have presented a study that emphasizes the use of AR as a natural complement for

VRLE, which is MRLE. Educational AR researches typically focuses in Human-Computer Interfaces and usability, and the applications are frequently intended for museums. To our knowledge, AR has not yet been seriously studied as a complement to VRLE to be used in the classroom for a long-term use. We believe that MRLEs are very suitable for the classroom and we encourage future educational researches to take it into consideration.

Handheld devices, and tablet PCs in particular are an excellent tool for MRLEs. They usually provide all the sensors needed to build interactive applications and multimodal interfaces, such as cameras, tactile screens and inertial measure units. This makes them to be an exceptional tool that can be used for a wide spectrum of interactive educational applications with more possibilities and versatility than standard desktop applications. Moreover, tablet PCs are usually comparable in prize to desktop computers, both being low cost solutions.

We developed a MRLE application for primary school children, which consisted of a game about water that included multiple interaction forms (tactile screen and accelerometer). It could be played in a combined mode with AR and NAR mini-games, or in full NAR mode.

After playing to the game, children's knowledge was statistically higher than in the pretest, but no significant differences were found between AR and NAR modes. However, the AR mode was much more preferred, and enhanced engagement highly. Furthermore, there was a high level of satisfaction in the two games. This confirms our initial hypothesis that AR is an excellent complement for VRLE and that it can improve some of its outcomes. In our game, this combination of AR and NAR games throughout the story thread and the links between them like the main character was very appreciated.

Playing in AR mode caused very good impression to the children, who improved motivation and were encouraged to be more dynamic during the activity, not being so perceivable in the NAR mode. We could see the big impact that AR caused, as the underlying interaction –AR in a handheld device as a video see-through– was significantly more preferred than accelerometer and tactile screen, specially when it was played in second place.

With regard to future work, we believe that more research in this direction is needed. MRLE in the field of education is still in an early stage. It could be used for many subjects, including Natural Science, Mathematics, History, Technology and outdoor activities. In addition, more engaging games and serious applications that use different input channels (AR marker

tracking, tactile screen, accelerometer, etc.) could be developed with current handheld devices.

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REFERENCES

- Billingham, M. N. and Henrysson, A. (2006). Research Directions in Handheld AR. *Int Journal of Virtual Reality*, 5(2):251–58.
- Connolly, T. M., Stansfield, M., and Hainey, T. (2011). An alternate reality game for language learning: ARGuing for multilingual motivation. *Computers & Education*, 57(1):1389–1415.
- De Freitas, S. and Oliver, M. (2006). How can exploratory learning with games and simulations within the curriculum be most effectively evaluated? *Computers & Education*, 46(3):249–264.
- El Sayed, N. A. M., Zayed, H. H., and Sharawy, M. I. (2011). ARSC: Augmented reality student card. *Computers & Education*, 56(4):1045–1061.
- Fjeld, M., Fredriksson, J., Ejdestig, M., Duca, F., Bötschi, K., Voegtli, B., and Juchli, P. (2007). Tangible user interface for chemistry education: comparative evaluation and re-design. In *Proceedings of the SIGCHI conference on Human factors in computing systems*, CHI '07, pages 805–808, New York, NY, USA. ACM.
- Freitas, R. and Campos, P. (2008). SMART: a System of Augmented Reality for Teaching 2nd grade students. In *Proceedings of the 22nd British HCI Group Annual Conference on People and Computers: Culture, Creativity, Interaction - Volume 2*, BCS-HCI '08, pages 27–30, Swinton, UK, UK. British Computer Society.
- Gardner, H. (1983). *Frames of mind: The theory of multiple intelligences*. New York: Basics.
- Inoue, Y. (2007). Concepts, applications, and research of virtual reality learning environments. *International Journal of Human and Social Sciences*, 2(1):1–7.
- Juan, M. C., Carrizo, M., Giménez, M., and Abad, F. (2011a). Using an augmented reality game to find matching pairs. In *Proceedings of the 19th International Conference on Computer Graphics, Visualization and Computer Vision*, pages 59–66.
- Juan, M. C., Furió, D., Alem, L., Ashworth, P., and Cano, J. (2011b). ARGreenet and BasicGreenet: Two mobile games for learning how to recycle. In *Proceedings of the 19th International Conference on Computer Graphics, Visualization and Computer Vision'2011*, pages 25–32.
- Kato, H. and Billingham, M. (1999). Marker tracking and hmd calibration for a video-based augmented reality conferencing system. In *Proceedings of the 2nd IEEE and ACM International Workshop on Augmented Reality '99*, pages 85–94. IEEE.
- Kaufmann, H. and Schmalstieg, D. (2003). Mathematics and geometry education with collaborative augmented reality. *Computers & Graphics*, 27(3):339–345.
- Kolb, D. A. (1984). *Experiential learning: Experience as the source of learning and development*. Englewood Cliffs, NJ: Prentice-Hall.
- Law, E., Kickmeier-Rust, M., Albert, D., and Holzinger, A. (2008). Challenges in the development and evaluation of immersive digital educational games. In *HCI and Usability for Education and Work*, volume 5298, pages 19–30. Springer Berlin / Heidelberg.
- Lee, E. A.-L., Wong, K., and Fung, C. (2010). How does desktop virtual reality enhance learning outcomes? a structural equation modeling approach. *Computers & Education*, 55(4):1424–1442.
- O'Shea, P., Mitchell, R., Johnston, C., and Dede, C. (2009). Lessons learned about designing augmented realities. *International Journal of Gaming and Computer-Mediated Simulations*, 1(1):1–15.
- Pan, Z., Cheok, A., Yang, H., Zhu, J., and Shi, J. (2006). Virtual reality and mixed reality for virtual learning environments. *Computers & Graphics*, 30(1):20–28.
- Shaffer, D. W., Squire, K. T., Halverson, R., Gee, J. P., et al. (2004). Video games and the future of learning. *Phi delta kappan*, 87(2):104.
- Wang, K.-H., Chen, L.-C., Chu, P.-Y., and Cheng, Y.-M. (2009). A study on the design of augmented reality user interfaces for mobile learning systems in heritage temples. In *Proceedings of the 3rd International Conference on Virtual and Mixed Reality: Held as Part of HCI International 2009, VMR '09*, pages 282–290, Berlin, Heidelberg. Springer-Verlag.
- Woods, E., Billingham, M., Looser, J., Aldridge, G., Brown, D., Garrie, B., and Nelles, C. (2004). Augmenting the science centre and museum experience. In *Proceedings of the 2nd international conference on Computer graphics and interactive techniques in Australasia and South East Asia*, GRAPHITE '04, pages 230–236, New York, NY, USA. ACM.
- Yang, J. C., Chen, C. H., and Jeng, M. C. (2010). Integrating video-capture virtual reality technology into a physically interactive learning environment for english learning. *Computers & Education*, 55:1346–1356.