EVALUATION OF VIRTUAL REALITY AND AUGMENTED REALITY FOR TEACHING THE LESSON OF GEOMETRIC SOLIDS TO PRIMARY SCHOOL CHILDREN

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Abstract

Young students often find it difficult to understand the three-dimensional structure of solids. New technologies that support three-dimensional representations, such as Virtual and Augmented Reality, can provide the basis for implementing teaching tools that will allow students to better understand topics in mathematics involving three-dimensional structures. In this paper we present the methodology used as part of an investigation that aims to evaluate the potential and compare Virtual and Augmented Reality technologies for teaching the lesson of geometric solids to primary school children. Emphasis is given on the development of dedicated tools used as part of the evaluation. Early results indicate that as far as the learning outcomes and the student satisfaction are concerned, both VR and AR technologies show similar promise.

Keywords: Virtual Reality, Augmented Reality, Mathematics, Geometric Solids

1 INTRODUCTION

In many cases student textbooks contain two dimensional graphical illustrations that depict three dimensional structures. However, young students often find it difficult to conceptualize the connection between objects in a real-life and the three-dimensional world, with those of the two-dimensional space [3] hence the use of textbooks is not ideal for teaching topics related to solids. Modern technologies such as Virtual Reality (VR) and Augmented Reality (AR) can provide a solution to the above problem. Virtual Reality is the technology, in which the user enters a virtual world where he participates and interacts with the various objects allowing in that way the improvement of his spatial abilities [7]. According to Kaufmann & Schmalstieg [7] and Martin-Gutiérrez et al. [11], virtual reality technologies promote students' communicative and collaborative skills as well as their psychomotor and cognitive skills. Augmented reality is the new technology which adds virtual information to the user's physical environment and allows the user to use his entire body to interact with the virtual content [12].

Virtual reality in education has had profound implications and has also changed some of the previous teaching ideas [4]. It is worth mentioning that, there are several scientific studies, some of which are those of Sotiriou & Bogner [13], Ibáñez et al. [6] and Martín-Gutiérrez & Meneses [10], linking virtual reality technologies to increased motivation of students, improvements in academic performance and improvements to teaching practices of educators [14]. Augmented reality in education has been linked to specific learning benefits [12]. Chen et al. [1] in a related review paper, conclude that scientific research on educational augmented reality applications increased significantly from 2013 onwards. Specialists have developed three-dimensional geometric tools such as Construct3D, and Handwaver in the teaching of mathematics with the use of Virtual and Augmented reality technologies [2,8].

Despite the extensive use of VR and AR technologies in education, there is a lack of research concerning the systematic development of VR and AR applications for practical training purposes and enhancement of students' spatial abilities in the field of mathematics and particularly in geometry. Furthermore, there are no previous studies where the educational impact of VR and AR is compared. Previous efforts to compare AR and VR technologies include the work of Krichenbauer's et al. [9] who investigated the performance of users in the task of manipulating 3D objects, and the work of Huang et al. [5] who compared AR and VR-based educational activities in relation to applications depicting a Space Museum and a Solar System. Unlike the work reported in [5] and [9], the aim of our work is to provide a concrete framework that can be used for comparing the educational impact of VR and AR for teaching mathematics to primary school students. Our attention is focused on developing dedicated VR and AR applications along with an evaluation methodology that can be used as the basis for staging a comprehensive comparison of VR and AR technologies.

2 DEVELOPMENT OF VR AND AR APPLICATIONS

In this section we present the design cycle adopted for designing and implementing VR and AR teaching applications for geometrical solids. The design cycle (see figure 1) consists of four main steps.

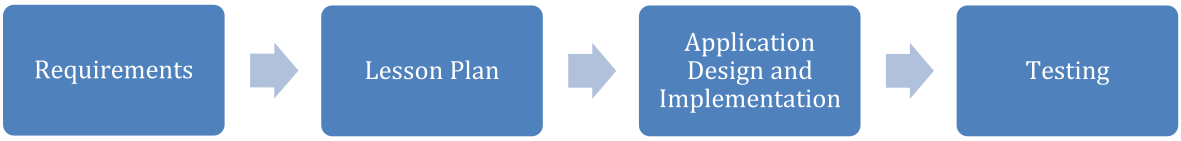

Fig. 1 The main steps in the process of designing VR and AR applications

Step 1 – ***Requirements***: The first step in the process involves a study of the mathematics curriculum and textbooks for primary education along with discussions with mathematics teachers. This information was used in conjunction with personal knowledge and teaching experience of the first author, who is also a mathematics teacher, to develop a complete list of the learning outcomes expected though the delivery of the course in geometrical solids.

Step 2 – ***Lesson Plan***: Based on the learning outcomes defined in Step 1, a lesson plan was created. The lesson plan comprised of three activities: (a) Classification of shapes into solid or plane shapes, (b) Identification of solid shapes appearing in a typical city environment and (c) Identification of solid shapes. The lesson plan was used for generating textbook-based teaching material for geometrical solids.

Step 3 – ***Design and Implementation***: Based on the activities indicated in the lesson plan, suitable scenarios for AR and VR applications were drafted and used as the basis of designing and implementing AR and VR applications using the software ENTiTi Creator. The software ENTiTi Creator allows non-professional programmers to design and implement VR and AR applications that run on mobile phones (with low-cost virtual reality glasses in the case of VR applications) or tablets. Screenshots of the three VR and AR applications developed are shown in figure 2.

Step 4 –***Testing***: The designed applications were tested both by a small number of primary school teachers and students to ensure the correct operation. For example, issues related to the usability, fonts used, operational bugs and functionality were identified and fixed. In addition, as part of the pilot test it was made clear that AR applications should be run on a tablet instead of a smartphone as the increased screen size of tablets was essential to improve the overall experience.

Fig. 2 Screenshots of the three VR (top row) and AR (bottom row) applications implemented and used as part of the experimental evaluation.

3 EVALUATION METHODOLOGY AND PRELIMINARY RESULTS

The aim of the experiment was to test whether VR and AR applications can make the teaching of mathematics more interactive and interesting and whether they contribute to a more efficient learning and understanding of mathematical concepts. Furthermore, we aim to determine whether VR or AR applications are more effective for mathematics teaching activities.

As part of the experimental evaluation 30 primary school students were divided into three groups: The Control Group, the VR Group and the AR Group. Data was collected using the following questionnaires:

Pre-Test Questionnaire: The Pre-Test Questionnaire mainly contains closed-ended questions related to demographic data, technological background and previous experience with VR and AR. In addition, *a series of questions* aiming to assess participants' prior knowledge regarding geometrical solids were included in the *Pre-Test Questionnaire.*

Post-Test Questionnaire: The Post-Test Questionnaire contained the same questions regarding participants' knowledge on geometrical solids as the *Pre-Test Questionnaire so that it was possible to determine the improvement of knowledge gain regarding geometric solids. In addition, the Post-Test Questionnaire* consisted of questions regarding the evaluation of the overall teaching experience in terms of factors related to user attention, presence and enjoyment.

During the experimental evaluation process (see figure 3) all volunteers completed the Pre-Test Questionnaire. Then volunteers from the Control group, VR group and AR group used textbook-based teaching material, VR applications and AR applications respectively as part of a teaching activity about geometrical solids. Finally, all volunteers completed the Post-Test Questionnaire.

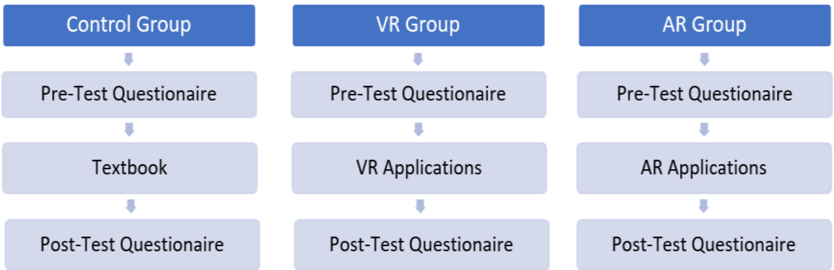

Fig. 3 The main steps for the experimental evaluation.

According to the preliminary results the following observations were extracted:

a) Most students were regular users of computers and smartphones and web-based applications with on-line gaming being their basic activity in the internet.

b) Students from all three groups showed a clear preference in using technological tools rather than textbook material (see figure 4) as part of the lesson on geometric solids

c) All the experimental groups increased their knowledge of solids with the differences being more intense in the groups of virtual and augmented reality than the control group (see figure 5).

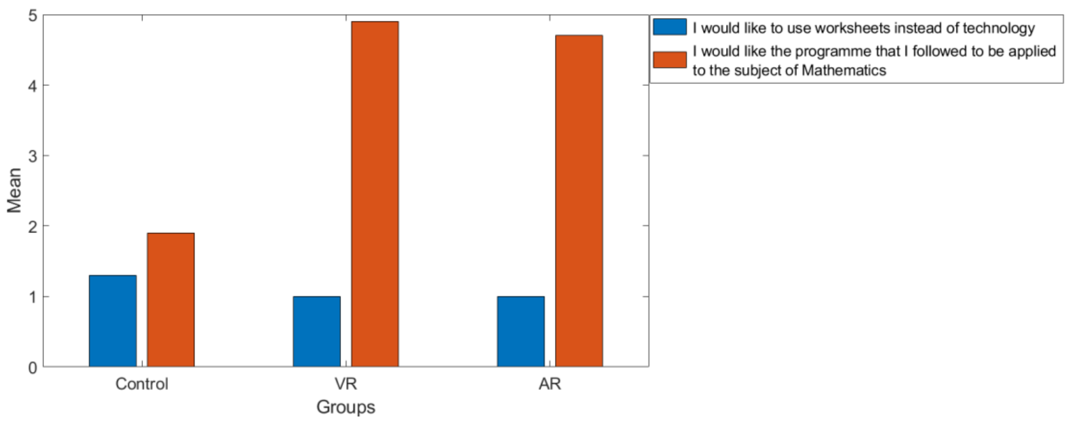

Fig. 4 Preference of students regarding the use of technological tools in teaching. Blue, orange bars indicate the mean values for the questions regarding the impressions of the participants.

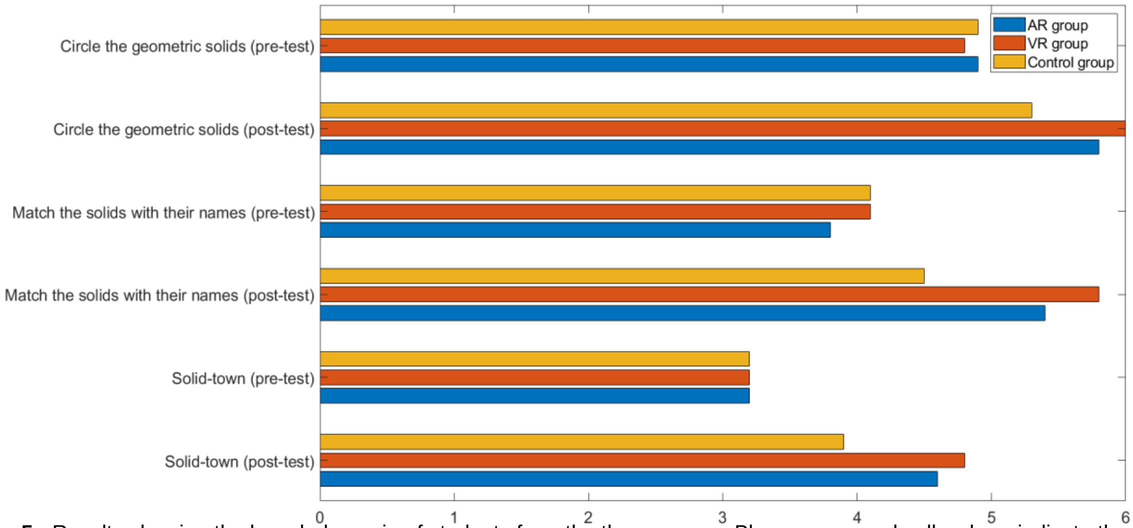

Fig. 5 Results showing the knowledge gain of students from the three groups. Blue, orange and yellow bars indicate the mean values for the exercises regarding their knowledge of mathematical solids before and after the experiment.

4 CONCLUSIONS

We presented the development and implementation of AR and VR applications in the field of Mathematics. Preliminary results of the research indicated that the use of AR and VR applications had a higher impact on student's learning and understanding of mathematical concepts compared to traditional teaching approaches. Furthermore, the results revealed that these technologies are more interactive and interesting for the students than the use of printed material. Regarding the comparison of the two technologies and their effectiveness as teaching tools, AR and VR technologies seem to have a similar impact. In the future we plan further analyze the results of the experiment. Also, in the future we plan to investigate the use of AR and VR technologies in teaching mathematics, as well as ways to integrate them into the teaching practice as part of in-class and/or extra curriculum activities.

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REFERENCES

[1] Chen, P., Liu, X., Cheng, W., & Huang, R., "A review of using Augmented Reality in Education from 2011 to 2016", *Innovations in smart learning*, pp.13-18, 2017.

[2] Dimmel, J., & Bock, C., " HANDWAVER: A GESTURE-BASED VIRTUAL MATHEMATICAL MAKING ENVIRONMENT.", *Technology in Mathematics Teaching ICTMT 13 Ecole Normale Supérieure de Lyon/Université Claude Bernard Lyon 1 3 to 6 July*, pp.323, 2017.

[3] González, N.A.A., "How to include augmented reality in descriptive geometry teaching", *Procedia Computer Science*, vol. 75, pp. 250–256, 2015.

[4] GU, W., "The Application of Virtual Reality in Education.", *DEStech Transactions on Computer Science and Engineering*, 2017.

[5] Huang, K. T., Ball, C., Francis, J., Ratan, R., Boumis, J., & Fordham, J., "Augmented Versus Virtual Reality in Education: An Exploratory Study Examining Science Knowledge Retention When Using Augmented Reality/Virtual Reality Mobile Applications." *Cyberpsychology, Behavior, and Social Networking*, vol. *22,* no.2, pp. 105-110,2019.

[6] Ibáñez, M. B., Di Serio, Á., Villarán, D., & Kloos, C. D. “Experimenting with electromagnetism using augmented reality: Impact on flow student experience and educational effectiveness”, *Computers & Education*, vol.71, pp. 1-13 , 2014.

[7] Kaufmann, H., & Schmalstieg, D., “Mathematics and geometry education with collaborative augmented reality,” *ACM SIGGRAPH conference abstracts and applications*, pp. 37-41, 2002.

[8] Kaufmann, H., Schmalstieg, D., Wagner, M., “Construct3d: a virtual reality application for mathematics and geometry education”, *Education and information technologies*, vol. 5**,** no. 4, pp. 263–276, 2000.

[9] Krichenbauer, M., Yamamoto, G., Taketom, T., Sandor, C., & Kato, H., “Augmented reality versus virtual reality for 3d object manipulation,” *IEEE transactions on visualization and computer graphics*, vol.24, no.2, pp.1038-1048, 2018.

[10] Martin Gutierrez, J., Meneses Fernandez, M.D., “Applying augmented reality in engineering education to improve academic performance & student motivation”. *International Journal of Engineering Education* Vol.30, no.3, pp. 625–635, 2014.

[11] Martín-Gutiérrez, J., Mora, C. E., Añorbe-Díaz, B., & González-Marrero, A., “Virtual technologies trends in education.”, *EURASIA Journal of Mathematics Science and Technology Education*, vol 13, no.2, pp. 469-486, 2017.

[12] Radu, I., “Augmented reality in education: a meta-review and cross-media analysis.”, *Personal and Ubiquitous Computing*, vol 18, no.6, pp.1533-1543, 2014.

[13] Sotiriou, S., & Bogner, F. X.,. “Visualizing the invisible: augmented reality as an innovative science education scheme.”, *Advanced Science Letters*, vol 1, no.1, pp.114-122, 2008.

[14] Stavroulia, K.E., Baka, E., Lanitis, A., Magnenat-Thalmann, N., “Designing a virtual environment for teacher training: enhancing presence and empathy.” *Proceedings of ACM Computer Graphics International*., pp. 273-282, 2018.