APPLICATION OF AUGMENTED REALITY FOR WORKING MEMORY IMPROVEMENT TO DEVELOP EXECUTIVE FUNCTIONS: A CASE STUDY

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Abstract

Working memory, a fundamental component of executive functions, plays a key role in regulating behaviour, decision-making and learning. In the last decade, Augmented Reality (AR) has emerged as a promising technology for education, due to its ability to provide interactive environments that enhance learning and concentration. In this context, the present pilot study aims to examine the efficacy of an AR-based intervention to improve the executive ability of working memory in a primary school student. To achieve this general objective, a methodology based on a quantitative approach with a single-case quasi-experimental design, using pretest and posttest, has been implemented. For this design, the sample was purposively selected in a non-probabilistic manner and consists of a 7-year-old female student. Specifically, the BRIEF2® (Behaviour Rating Inventory of Executive Function-2) was used as an instrument to measure working memory skills. The intervention was carried out in a school in Alicante, Spain. As for the procedure, it consisted of five individual sessions of 30 minutes each, where tasks designed to increase cognitive load were performed in a gradual and controlled manner based on the common thread 'Let's go to the zoo'. During the sessions, the student was asked to perform specific working memory exercises, adapted using AR software that incorporates interactive visual and auditory stimuli. These stimuli are adjusted in real time to the user's responses, allowing for a high level of personalisation and encouraging participant engagement. The results were obtained from the assessment test applied before and after the intervention. Preliminary findings indicate a significant improvement in working memory measures and suggest that Augmented Reality can be a viable and engaging tool for training executive functions. In addition, teacher feedback highlights the potential of AR to provide an immersive experience that fosters motivation and active learning, making it a valid alternative to traditional cognitive training methods. In conclusion, this pilot study not only demonstrates the potential of AR to positively impact working memory, but also provides a methodological basis for future research with larger samples.

Keywords: Augmented reality, working memory, executive functions, primary education.

1. Introduction

Since the end of the twentieth century, emerging technologies have transformed education, with Augmented Reality (AR) standing out for its ability to integrate digital information with the physical environment in real time, creating interactive and immersive experiences (Tarafdar et al., 2024). Through devices such as smartphones and viewers, AR stimulates student attention and participation (Cabero-Almenara & García-Jiménez, 2015). In addition to being motivating, it strengthens essential cognitive skills, such as working memory, improving information processing and retention (Martínez-Pérez et al., 2021). It also promotes personalized and student-centred learning, encouraging their participation and curiosity (Zhang et al., 2022).

On the other hand, working memory is the ability to temporarily retain and manipulate information for complex cognitive tasks such as language, learning, and reasoning (Christoff, 1992). It is key in planning, problem-solving and decision-making (Baddeley, 2000), as well as being essential for executive functions, allowing information to be updated, adapting to changes and resisting distractions (Nee et al., 2013).

In this sense, it should be remembered that executive functions (EF) are cognitive processes that allow behaviour to be managed to achieve goals, especially in complex situations (Kontostavlou & Drigas, 2022). They are key in the academic, professional and everyday spheres, facilitating adaptation, decision-making and problem solving (Diamond, 2013). Their development depends on internal and external factors, which has driven the search for pedagogical strategies to strengthen them from childhood.

Integrating AR into education improves working memory and executive functions (Squires, 2017). Their immersive experiences increase attention and concentration (Lim et al., 2019), adapting to different learning styles (Papanastasiou et al., 2018). Furthermore, by combining real and virtual elements, it reduces cognitive load and optimizes information processing and retention (Thees et al., 2020). For their part, Bacca et al., (2014) highlight that AR facilitates visual and experimental learning, promoting the consolidation of knowledge and cognitive development. Their interaction with digital content in real environments motivates students, improving their performance and solving complex tasks (Poupard et al., 2024). Additionally, its interactive nature increases engagement, favouring the retention and recall of information (Basumatary & Maity, 2023).

2. Objectives

The main objective of this project is to examine the effectiveness of an intervention based on Augmented Reality to improve the executive skill of working memory in a Primary Education student. The following research questions have been extracted from the general objective that supports this intervention:

1. Are there any changes in the scores obtained in the items associated with working memory after the implementation of the intervention?

2. Are there significant differences in working memory before and after developing the intervention?

3. Method

This study employs a quantitative approach with a quasi-experimental single-case design, due to its flexibility and customizability (Krasny-Pacini & Evans, 2017). The sample, selected in a non-probabilistic manner (Etikan et al., 2016), consists of a 7-year-old student. To create the AR environments, the tutor and the family were interviewed. After the intervention and data collection, the analysis was performed with SPSS 29.0.

3.1. Description of the context and participant

This study addresses the case of a 7-year-old girl who is in the second year of Primary Education in a state-subsidised school in Alicante. Without academic or socio-emotional difficulties, they show performance in line with their development, actively participate in class and interact positively. Their family environment is structured and promotes healthy habits. The case is part of a broader study on the use of AR to improve executive functioning in Primary, complying with ethical and data protection regulations.

3.2. Study variable and instrument

This research analyses working memory through an AR intervention through a tablet. For its evaluation, the BRIEF2® scale was used, applied as a pre-test and post-test in a 7-year-old student. The teacher answered a questionnaire of 63 items on a three-point Likert scale, read aloud by the researcher and digitally recorded in *TEACorrige*. Particularly, 17 items of the BRIEF2® assess difficulties in retaining information during a task. Unlike its previous version, this scale integrates working memory and its maintenance into a single domain due to its high correlation.

3.3. Procedure

The educational intervention consisted of a series of activities to assess and strengthen working memory using AR. Visual learning allowed the system to reinforce correct answers and guide in case of errors. The stages were:

1. Initial contact: The educational team was met; the study was explained, and family consent was obtained.
2. Preparation: Activities were designed, and the tutor was interviewed to create the AR environments.
3. Pretest: BRIEF2® was applied, with the tutor responding on a Likert scale while the researchers recorded the data in *TEACorrige*.
4. Intervention: Five individual sessions of 30 minutes were held in three weeks, with AR activities on the theme Let's go to the Zoo to develop working memory.
5. Post-test: The evaluation was repeated with BRIEF2® to measure the student's evolution.

3.4. Data analysis

After planning and implementing the intervention, as well as collecting the data, the analysis of the results was carried out. To do this, version 29.0 of the statistical software SPSS for Windows (Statistical

Package for Social Sciences) was used. In this context, a descriptive analysis was first performed to calculate the mean, standard deviation and median of the data obtained in the participant's pre-test and post-test. Subsequently, Wilcoxon's non-parametric signed range test, designed for related samples, was applied in order to detect possible significant differences between the student's pre-test and post-test results.

4. Results

As for the results, after analysing the data collected, they have been shown in different graphs and tables. These representations illustrate the answers linked to the X research questions formulated according to the central variable of the study.

4.1. Descriptive analysis of the participant

In particular, the first figure shows the participant's scores on the items related to working memory in BRIEF2®. Specifically, it presents the results corresponding to the pre-test and the post-test. The vertical axis of the graph shows the values 0, 1, and 2, corresponding to the Likert scale: 0 (never), 1 (sometimes) and 2 (frequently).

Figure 1. Scores of the participant's working memory.
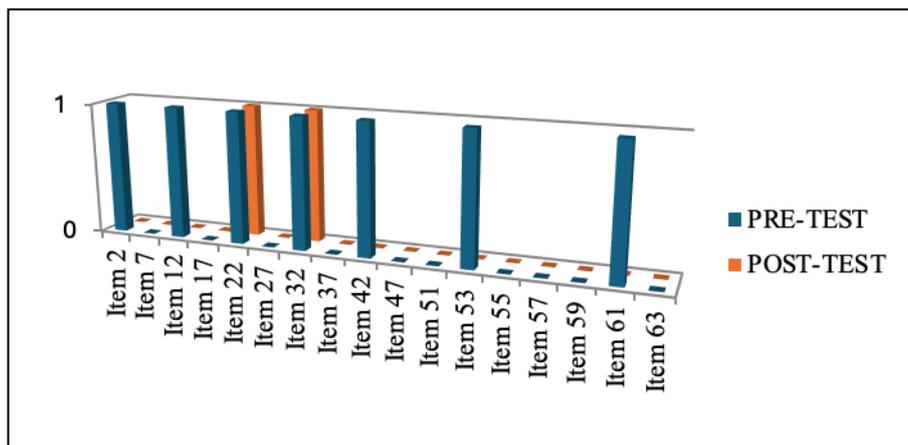
In relation to the data obtained in the pre-test and post-test on working memory, reflected in Figure 1, a decrease of 29.41% was observed in the items evaluated. Specifically, a reduction of one point was recorded on the Likert scale in the following aspects: difficulty remembering and carrying out two consecutive tasks (item 2), difficulty maintaining concentration on recreational activities (item 12), difficulty completing initiated tasks (item 42), lack of persistence or effort in carrying out activities (item 53), and difficulty maintaining attention (item 61). It should be noted that, according to the BRIEF2®, higher scores indicate a greater presence of difficulties in this executive function. However, in the remaining 70.59% of the items, the participant obtained the same scores in both the pre-test and the post-test. It should be noted that 10 of the 17 items that make up the working memory were already obtained in the pre-test.

Similarly, Table 1 shows the results of the descriptive analysis.

Table 1. Descriptive statistics of the participant's working memory.

	N	Stocking	Desv. standard	Medium
Pre-test	1	0,41	0,507	0
Post-test	1	0,12	0,332	0

4.2. Possible significant differences in working memory between the results of the participant's pre-test and post-test

After analyzing the data using the nonparametric Wilcoxon signed range test for two related samples, the results are summarized in Table 2. To interpret the data, the following conditions are considered: (a) Post < Pre; (b) Post > Pre; (c) Post = Pre.

Table 2. Statistical testing of Wilcoxon's signed ranges for dependent samples in working memory for the participant.

	Ranges	*N*	*Average Range*	*Sum of ranks*
Post-test – Pre-test	Negative Range	5[a]	3	15
	Positive Range	0[b]	0	0
	Draws	12[c]		
	Total	17		

The statistical results of the Wilcoxon signed range test are shown below in Table 3.

Table 3. Wilcoxon signed-rank test statistics for the participant.

Z	*Sig. asin. (bilateral)*
-2,236	0,025

As shown in Table 3, the results corresponding to the participant indicate a significance of $p < .05$.

5. Discussion and conclusions

Based on the results obtained in this study and on the research questions formulated, the conclusions derived from the data analysis are presented. Specifically, there was evidence of a decrease in difficulty in remembering and executing two consecutive tasks. This result coincides with the findings of Makhataeva et al., (2023), who highlight that AR systems can increase mental representations of objects, leading to reduced cognitive load and greater accuracy of performance in tasks that involve memory, such as remembering positions of objects in a space. This suggests that AR can help execute consecutive tasks by relieving the mental load. In addition, a decrease in scores was detected in aspects such as difficulty in maintaining concentration in recreational activities. These results are consistent with those of Buchner et al., (2021), who argue that AR appears to be less cognitively demanding and leads to higher performance in learning environments.

Likewise, the immediate visual feedback offered by AR could help reduce the difficulty in completing initiated tasks by improving the user's performance and attention. According to Othman et al., (2020), this factor can make learning experiences more enjoyable and less monotonous, which can help reduce boredom and therefore finish the activity. Similarly, there was a decrease in the lack of persistence or effort in carrying out activities. In this context, the AR system can provide different levels of instructional support, which can reduce the complexity of perceived tasks and physical exertion, especially in assembly tasks. This adaptability is particularly beneficial for students with lower cognitive abilities (Vanneste et al., 2023). Finally, there was a reduction in difficulty in maintaining attention, and along these lines, several studies explore AR as a tool to help reduce difficulties in maintaining attention, mainly among people with attention-related disorders (Ghasemi et al., 2024).

In conclusion, the results obtained in this study suggest that AR can be an effective tool to improve working memory and attention in learning environments. Although the effects were not homogeneous in all the items evaluated, the improvements observed in certain areas suggest that this technology has great potential in the educational field. In particular, there was evidence of progress in aspects such as the ability to remember, concentration and the ability to complete tasks. Visual feedback and AR interactivity appear to have been key factors in these changes. Therefore, it would be relevant to continue exploring its impact on different executive functions and to evaluate its effectiveness in a larger sample of participants. In addition, future research could focus on the permanence of these long-term effects and on the adaptation of the intervention to different learning styles and cognitive levels.

References

Bacca, J., Baldiris, S., Fabregat, R., Graf, S., & Kinshuk. (2014). Augmented reality trends in education: A systematic review of research and applications. *Educational Technology & Society, 17*(4), 133-149.

Baddeley, A. D. (2000). The episodic buffer: A new component of working memory? *Trends in Cognitive Sciences, 4*(11), 417-423.

Basumatary, D., & Maity, R. (2023). Effects of Augmented Reality in Primary Education: A Literature Review. *Human Behavior and Emerging Technologies*. https://doi.org/10.1155/2023/4695759

Buchner, J., Buntins, K., & Kerres, M. (2021). The impact of augmented reality on cognitive load and performance: A systematic review. *Journal of Computer Assisted Learning, 38*, 285-303. https://doi.org/10.1111/jcal.12617

Cabero-Almenara, J., & García-Jiménez, E. (2015). Augmented Reality in Education: An Overview. *Virtual Campuses, 4*(2), 25-40.

Christoff, K. (1992). Working memory. *Science, 255*(5044), 556-559. https://doi.org/10.1016/s0079-7421(08)60452-1.

Diamond, A. (2013). Executive functions. *Annual Review of Psychology, 64,* 135-168.

Etikan, I., Musa, S., & Alkassim, R. (2016). Comparison of Convenience Sampling and Purposive Sampling. *American Journal of Theoretical and Applied Statistics, 5*(1). https://doi.org/10.11648/J.AJTAS.20160501.11

Ghasemi, S., Behravan, M., Uber, S., & Gračanin, D. (2024). Attention and Sensory Processing in Augmented Reality: Empowering ADHD population. *ArXiv,* abs/2405.01218. https://doi.org/10.48550/arXiv.2405.01218

Kontostavlou, E. Z., & Drigas, A. S. (2022). Executive functions training and giftedness. *Challenges: New Trends in Physical Education, Sport and Recreation, 43*, 1005-1014.

Krasny-Pacini, A., & Evans, J. (2017). Single-case experimental designs to assess intervention effectiveness in rehabilitation: A practical guide. *Annals of physical and rehabilitation medicine, 61*(3), 164-179. https://doi.org/10.1016/j.rehab.2017.12.002

Lim, T., Nonis, J., & Hedberg, J. (2019). Immersive learning: Using augmented reality to enhance learning experiences. *Journal of Educational Computing Research, 56*(4), 502-527.

Nee, D., Brown, J., Askren, M., Berman, M., Demiralp, E., Krawitz, A., & Jonides, J. (2013). A meta-analysis of executive components of working memory. *Cerebral cortex, 23*(2), 264-282. https://doi.org/10.1093/cercor/bhs007

Martínez-Pérez, S., González-González, C. S., & Navarro-Adelantado, V. (2021). Augmented reality for learning: Systematic review of applications in educational settings. *Educational Research Review, 34,* 100396.

Makhataeva, Z., Akhmetov, T., & Varol, H. (2023). Augmented-Reality-Based Human Memory Enhancement Using Artificial Intelligence. *IEEE Transactions on Human-Machine Systems*, *53*, 1048-1060. https://doi.org/10.1109/THMS.2023.3307397

Othman, F., Adnan, W., & Nasruddin, Z. (2020). Augmented Reality Storytelling Teachers and Preschool Children Experience. In X. S. Yang, R. S. Sherratt, N. Dey, & A. Joshi (Eds.), *Proceedings of Fifth International Congress on Information and Communication Technology* (pp. 155-164). https://doi.org/10.1007/978-981-15-5856-6_15

Papanastasiou, G., Drigas, A., Skianis, C., Lytras, M., & Papanastasiou, E. (2018). Virtual and augmented reality effects on K-12, higher and tertiary education students' twenty-first century skills. *Virtual Reality, 23*, 425-436. https://doi.org/10.1007/s10055-018-0363-2

Poupard, M., Larrue, F., Sauzéon, H., & Tricot, A. (2024). A systematic review of immersive technologies for education: Learning performance, cognitive load and intrinsic motivation. *British Journal of Educational Technology, 56*(1), 5-41. https://doi.org/10.1111/bjet.13503

Squires, D. (2017). Working Memory & Augmented Reality's Trajectory: A Literature Review of AR in Education, Online Learning, Workforce Training, and Working Memory Research. *Journal on Educational Technology, 14*, 55-63. https://doi.org/10.26634/JET.14.3.13860

Tarafdar, P., Leung, A. C. M., Yue, W. T., & Bose, I. (2024). Understanding the impact of augmented reality product presentation on diagnosticity, cognitive load, and product sales. *International Journal of Information Management, 75*, 102744. https://doi.org/10.1016/j.ijinfomgt.2023.102744

Thees, M., Kapp, S., Strzys, M., Beil, F., Lukowicz, P., & Kuhn, J. (2020). Effects of augmented reality on learning and cognitive load in university physics laboratory courses. *Computers in Human Behavior*, *108*, 106316. https://doi.org/10.1016/j.chb.2020.106316

Vanneste, P., Dekeyser, K., Ullauri, L., Debeer, D., Cornillie, F., Depaepe, F., Raes, A., Noortgate, W., & Said-Metwaly, S. (2023). Towards tailored cognitive support in augmented reality assembly work instructions. *Journal of Computer Assisted Learning, 40*, 797-811. https://doi.org/10.1111/jcal.12916

Zhang, J., Li, G., Huang, Q., Feng, Q., & Luo, H. (2022). Augmented Reality in K–12 Education: A Systematic Review and Meta-Analysis of the Literature from 2000 to 2020. *Sustainability, 14*(15), 9725. https://doi.org/10.3390/su14159725