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POLIEDROS REGULARES MEDIANTE REALIDAD AUMENTADA: INNOVACIÓN EDUCATIVA EN EL AULA

REGULAR POLYHEDRA THROUGH AUGMENTED REALITY: EDUCATIONAL INNOVATION IN THE CLASSROOM

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Resumen

Se sabe que la implementación de la tecnología en la educación tiene resultados positivos en los procesos de enseñanza-aprendizaje. En la última década, la implementación de la realidad aumentada (RA) en la enseñanza de las matemáticas ha adquirido gran importancia, ya que permite al estudiante visualizar e interiorizar conceptos matemáticos abstractos. En este estudio, se desarrollaron recursos basados en RA para enseñar poliedros regulares a estudiantes de octavo grado de educación general básica (EGB) en una institución educativa de Ecuador, analizando el impacto de la aplicación ARLOON GEOMETRY en el proceso de aprendizaje de los estudiantes. La investigación, con un enfoque cuasiexperimental y un diseño pre-test y post-test, se llevó a cabo con dos grupos: 8.º "A" (grupo control), que utilizó métodos tradicionales en el ciclo de aprendizaje con la ayuda de una guía didáctica para este tema, y 8.º "B" (grupo experimental), que incorporó la RA a su aprendizaje mediante el uso de secuencias didácticas. El análisis estadístico y la prueba t de Student no mostraron diferencias significativas en el rendimiento académico entre los dos grupos en la prueba previa (valor $p = 0{,}5743$), pero sí se observó una diferencia significativa en la prueba posterior (valor $p = 0{,}0005424$), lo que indica que el uso de la RA mejoró el aprendizaje de poliedros regulares en

el grupo experimental en comparación con el grupo de control. Este estudio demostró que la RA es una herramienta innovadora en el ámbito educativo.
Palabras clave: Tecnología educativa, Matemáticas, Realidad aumentada, Rendimiento académico, Innovación pedagógica.

Abstract

It is known that the implementation of technology in education has positive results in teaching and learning processes. In the last decade, the implementation of augmented reality (AR) in mathematics teaching has gained significant importance, as it allows students to visualize and internalize abstract mathematical concepts. In this study, AR-based resources were developed to teach regular polyhedra to eighth-grade students in a school in Ecuador, analyzing the impact of the ARLOON GEOMETRY application on the students' learning process. The research, with a quasi-experimental approach and a pre-test/post-test design, was conducted with two groups: 8th grade "A" (control group), which used traditional methods in the learning cycle with the help of a teaching guide for this topic, and 8th grade "B" (experimental group), which incorporated AR into its learning through the use of didactic sequences. Statistical analysis and Student's t-test showed no significant differences in academic performance between the two groups in the pre-test (p-value = 0.5743), but a significant difference was observed in the post-test (p-value = 0.0005424), indicating that the use of AR improved the learning of regular polyhedra in the experimental group compared to the control group. This study demonstrated that AR is an innovative tool in education.
Keywords: Educational technology, Mathematics, Augmented reality, Academic performance, Pedagogical innovation.

Sumário

Sabe-se que a implementação de tecnologia na educação tem resultados positivos nos processos de ensino e aprendizagem. Na última década, a implementação da realidade aumentada (RA) no ensino da matemática ganhou significativa importância, pois permite aos alunos visualizar e internalizar conceitos matemáticos abstratos. Neste estudo, recursos baseados em RA foram desenvolvidos para o ensino de poliedros regulares a alunos do oitavo ano de uma escola no Equador, analisando o impacto do aplicativo ARLOON GEOMETRY no processo de aprendizagem dos alunos. A pesquisa, com abordagem quase-experimental e delineamento pré-teste/pós-teste, foi conduzida com dois grupos: o grupo "A" (grupo controle), que utilizou métodos tradicionais no ciclo de aprendizagem com o auxílio de um guia didático para o tema, e o grupo "B" (grupo experimental), que incorporou a RA em sua aprendizagem por meio do uso de sequências didáticas. A análise estatística e o teste t de Student não mostraram diferenças significativas no desempenho acadêmico entre os dois grupos no pré-teste (valor p = 0,5743), mas uma diferença significativa foi observada no pós-teste (valor p = 0,0005424), indicando que o uso da RA melhorou o aprendizado de poliedros regulares no grupo experimental em comparação com o grupo de controle. Este estudo demonstrou que a RA é uma ferramenta inovadora na educação.
Palavras-chave: Tecnologia educacional, Matemática, Realidade aumentada, Desempenho acadêmico, Inovação pedagógica.

Introduction

Over time, educational institutions have faced significant challenges in developing effective strategies for teaching mathematics. Despite ongoing efforts, the quest for innovative methodologies that make the teaching and learning process more accessible persists (León, 2021). Specifically, within the domain of mathematics, and more precisely in the field of geometry, noChart limitations arise when teaching concepts that require the manipulation or visualization of three-dimensional objects, such as solids. A cognitive conflict emerges when attempting to teach three-dimensional topics using two-dimensional representations. Various scholars, such as Aragón (2020), have identified one of the root causes of this issue: many educators continue to rely on outdated approaches that predate the digital era. This underscores the need to examine the impact of implementing Augmented Reality (AR) in teaching basic geometry at primary and secondary education levels to enhance learning outcomes (Céspedes et al., 2012).

Lledó et al. (2022) describe AR as a convergence of elements perceivable through our senses with those that are not visible to the naked eye but nonetheless form part of our everyday environment. This technology enables users to interact with intangible yet real aspects of their surroundings, enriching their understanding of reality. Similarly, Marín and Sampedro-Requena (2020) emphasize that AR must integrate three key components: the representation of reality through virtual elements, direct and instantaneous interaction with objects, and the ability to experience these objects in three-dimensional, tangible ways. The emergence of new educational technologies in recent years has significantly transformed the paradigm of teaching and learning. Numerous studies, including that of Céspedes et al. (2012), have highlighted the importance and implementation of Augmented Reality (AR) in primary education settings. The author references three distinct cases to substantiate this assertion. First, initiatives such as those conducted in New Zealand by the active HIT group involved the creation of instructional materials in the form of three-dimensional images viewable through a handheld lens. Second, interactive video games developed by Harvard and Massachusetts universities allowed students to engage virtually with their environment using mobile devices equipped with AR software. The third and arguably most noChart example took place in Peru, at the Jesús Nazareno School, where AR technologies were employed to convey knowledge and advancements in the country's archaeological heritage. Additionally, a study conducted by Wu et al. (2012) revealed that students who used an AR application to explore geometric figures demonstrated better concept retention and higher motivation to learn compared to those who relied on traditional methods. This evidence underscores AR's potential to foster a more active and participatory approach to learning.

Other findings, such as those reported by Naranjo et al. (2021), highlight the application of this learning strategy in a study involving a group of 105 students from a school in Taiwan. These students attended classes utilizing Augmented Reality (AR), where both their motivation and academic performance showed significant improvement following the use of this technology. Furthermore, the approach introduced by Kaufmann and Schmalstieg (2006) underscores the use of AR in teaching and learning processes through the "Construct3D" interface model. This method enhances student learning by addressing the challenge of representing three-dimensional objects within two-dimensional spaces. The innovation of this approach lies in the incorporation of a head-mounted display (HMD), which creates an immersive experience by seamlessly integrating virtual objects with reality. This technology allows students to interact with virtual objects as if they were tangible, providing a more engaging and effective learning experience. All of this underscores the extensive use and applicability of Information and Communication Technologies (ICT) in educational environments, a trend that was further accelerated by the onset of the SARS-CoV-2 (COVID-19) pandemic. These technologies facilitated interaction between students and educational institutions during a period of unprecedented disruption. At the national level, research by Naranjo et al. (2021) demonstrated that the use of Augmented Reality (AR) contributed to improved academic performance. Specifically, students who learned about round geometric figures through AR mediation achieved higher grades compared to their peers who followed traditional learning methodologies.

Similar findings were reported by Ladino and Hernández (2022), who implemented AR using tools such as Geogebra and Photomath to teach equations and systems of equations to students in an educational institution located in the province of Chimborazo. The ability to observe and manipulate geometric figures within a realistic virtual environment offers students an exceptional learning experience. According to Ovalle and Vásquez (2020), visualizing figures and solids in an AR environment enables children to learn through immediate visual stimuli, fostering a dynamic and agile development of spatial understanding in geometric concepts. Therefore, building on this evidence, the present study aims to develop instructional resources utilizing AR for teaching regular polyhedra to eighth-grade students in a public educational institution in Ecuador.

Additionally, it seeks to evaluate the impact of AR on academic performance through structured baseline assessments and ultimately compare the academic outcomes of students who utilize AR with those who follow traditional educational methods. In this context, the following hypothesis is proposed: the incorporation of the Augmented Reality application *Arloon Geometry* into instructional planning and delivery has a positive impact on learning regular polyhedral in the 8th grade "B" class, compared to the 8th grade "A" class, which received traditional instruction.

Materials and methods

This study employed a quasi-experimental approach for its quantitative component, utilizing a pre-test and post-test design (Suwono et al., 2022; Noroozi et al., 2023). Two research groups were established: the control group (CG) and the experimental group (EG). The dependent variable was academic performance, while the independent variables were the proposed AR-supported didactic sequences and the instructional guide. The primary objective of this study was to measure the effect of the independent variable on the dependent variable, specifically to evaluate the impact of AR on academic performance. This approach aimed to determine whether the proposed methodology positively influences the learning cycle of students, thereby validating its effectiveness.

The sample consisted of eighth-grade students from the General Basic Education (GBE) system in an Ecuadorian educational institution. The control group (CG) comprised 25 students from class "A," while the experimental group (EG) consisted of an equal number of students from class "B." For the CG, a didactic guide was employed to address the limited content available in the Ministry of Education textbooks regarding polyhedra. This guide was structured into five subtopics, each dedicated to a specific type of regular polyhedron. It included the following components: an exploratory section, the definition of the regular polyhedron, its graphical representation, its elements and properties, formulas for calculating its area and volume, and a set of activities designed to apply the acquired skills. For the EG, didactic sequences were implemented over five class sessions, one dedicated to each type of regular polyhedron. These sequences were carefully designed to align with specific objectives, performance-based skills, learning activities, teaching resources, and relevant indicators, criteria, techniques, and evaluation tools tailored to the subject matter. Importantly, AR technology was integrated into these sequences through the ARLOON GEOMETRY platform.

The research instruments used were two assessments on polyhedra, corresponding to the unit "Geometric Blocks and Plane Figures," with identical content for both classes. The first evaluation (Pre-Test) was conducted at the outset to diagnose students' prior knowledge of polyhedral, while the second evaluation (post-test) was administered at the end of the topic to measure the level of learning achieved on regular polyhedral. The Pre-Test and Post-Test evaluations were designed to include a programming matrix, detailing key aspects such as objectives, target skills, and allocated time. These instruments were reviewed and approved by the subject area coordinator and the vice principal prior to implementation. For Class "A," both tests were administered in written format, while for Class "B," the evaluations were conducted online using the Quizizz educational platform, employing the same assessment tools. Notably, both classes were evaluated using identical questions in their respective tests, which were validated by subject-matter experts. Data analysis was carried out using RStudio version 2024.09.0+375, with statistical measures such as mean, mode, variance, and standard deviation calculated. To compare the study groups, the Student's t-test was employed, ensuring the fulfillment of normality and homoscedasticity assumptions.

Results and Discussion

This section presents the evaluation of the dependent variable across both phases, namely the Pre-Test and Post-Test, in accordance with the qualitative and quantitative scale established in Article 194 of the General Regulations of the Organic Law of Intercultural Education (LOEI) (Chart 1).

Table 1. *Quantitative and Qualitative Scale of Academic Performance.*

Learning Achievements Attained			
9.00 – 10.00	**7.00 – 8.99**	**4.01 – 6.99**	**≤4**
Masters the required learning outcomes	Achieves the required learning outcomes	Is close to achieving the required learning outcomes	Does not achieve the required learning outcomes

Source: Own elaboration based on MINEDUC-LOEI (2014)

Pre-Test Results for GC and GE: After administering the pre-test to both the control group (GC) and the experimental group (GE), the detailed scores obtained are presented in Table 2.

Table 2. *Results pre test del GC and GE.*

Result/10	$f_{i\ Control}$ Group (GC)	f_i Experimental Group (GE)
0	0	1
1	3	1
2	5	5
3	4	3
4	5	7
5	3	1
6	3	4
7	2	2
8	0	1
TOTAL	**25**	**25**

Source: Own elaboration. fi refers to the number of students who obtained the specified grade.

It was observed that, for both the control group (GC) and the experimental group (GE), 68% of the students did not achieve the required learning outcomes according to the quantitative and qualitative scale of the general regulations of the LOEI (Figure 1).

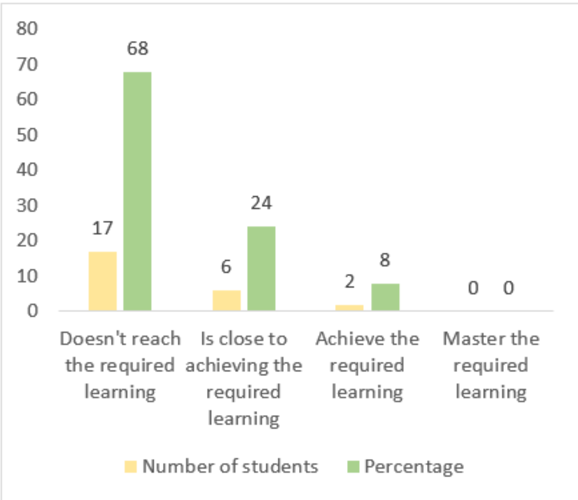

***Fig 1**. Percentage and number of students in the GC grades according to the scale in Chart 1.*

Source: Own elaboration

These results were concerning, as they indicated that the majority of students had not adequately acquired the fundamental knowledge about polyhedra. Similarly, statistical calculations were performed for both the control group (GC) and the experimental group (GE) based on the pre-test results, which yielded the following outcomes (Chart 3):

Table. 1 *Statistics of the pre-test for the CG and EG.*

Statistician	GC	GE
Mean	3.68	3.96
Mode	2,4	2,4
Standard deviation	1.84	2.03
Variance	3.39	4.12

Source: Own elaboration based on the output from RStudio v2024.09.0+375.

Therefore, it was evident that neither the GC nor the GE met the required learning outcomes necessary to grasp the units or topics presented. **Post-Test Results for GC and GE:** After implementing the intervention, as discussed in the previous chapter, the following scores were obtained, as reflected in Chart 4:

Table 2. *Post-test scores of the GC and GE.*

Result/10	f_i Control Group (GC)	f_i Experimental Group (GE)
1	1	0
2	2	0
3	2	3
4	6	1
5	4	0
6	3	4
7	2	8
8	5	2
9	0	1
10	0	6
TOTAL	25	25

Source: Own elaboration. fi refers to the number of students who obtained the specified grade.

It was evident that, for both the control group (GC) and the experimental group (GE), 44% and 16% of students, respectively, did not achieve the required learning outcomes according to the quantitative and qualitative scale of the general regulations of the LOEI. Similarly, it was found that 28% (GC) and 40% (GE) achieved the required learning outcomes, meaning these students obtained scores ranging from 7.00 to 8.99 out of 10 points (Figures 3 and 4).

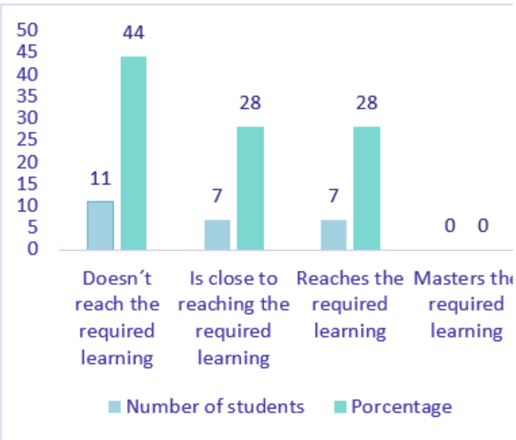

Fig. 3: *Percentage and number of students in the GC based on the grading scale from Chart 1.*

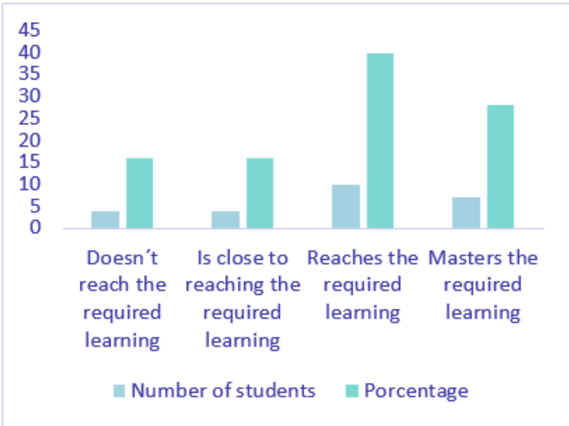

Fig 4: *Percentage and number of students in the EG grades according to the scale in Chart 1.*

Source: Own elaboration

Additionally, statistical measures for both groups based on the post-test results were calculated, and these are reflected in Chart 5.

Table 5. *Statistics of the post-test for the CG and EG.*

Statistic	GC	GE
Mean	5.08	7.12
Mode	4	7
Standard Deviation	2.08	2.24
Variance	4.33	5.02

Source: Own elaboration based on the output from RStudio v2024.09.0+375.

To demonstrate that the intervention implemented with the experimental group (GE) was significantly more effective than that of the control group (GC), a T-Student test was applied to both groups, both for the pre-test and post-test. According to Sampieri and Fernández (2018), the "t" test, or T-Student test, is a statistical method used to determine whether there are significant differences between the means of two groups. Before conducting this test, it is crucial to verify certain assumptions: normality of the data and homogeneity of variances. The purpose of applying this test to the pre-test was to confirm that both groups were at an equal starting point at the beginning of the intervention, meaning there were no significant differences in their prior knowledge. For the pre-test, before carrying out the analysis, it was verified whether the data met the aforementioned assumptions. To do this, the Shapiro-Wilk test and Levene's statistic were applied, with the results presented in table 6.

Table 6. *Results of the Levene and Shapiro-Wilk tests.*

Test	P-Result
Shapiro-Wilk normality test A	0.1412
Shapiro-Wilk normality test B	0.4125
Levene's Test for Homogeneity of Variance A, B	0.7373

Source: Own elaboration based on the output from RStudio v2024.09.0+375.

The results showed that the Shapiro-Wilk tests for the control group (GC) and the experimental group (GE) yielded p-values of 0.1412 and 0.4125, respectively, indicating that the data follows a normal distribution (p-value > 0.05). Similarly, the Levene's test showed a p-value of 0.7373, suggesting that there were no significant differences in variances between the two groups. The results from the T-Student test calculations yielded the following outcomes (Chart 7):

Table 7. *T-Student Test for the Pre-Test.*

Test	P-Result
T-Student	0.5743

Source: Own elaboration based on the output from RStudio v2024.09.0+375.

Taking a 95% confidence interval, the test yielded a p-value of 0.5743 (p-value > 0.05), indicating that no significant difference could be concluded between the two study groups. This means that both groups started under similar conditions at the beginning of the study, and no significant difference in academic performance was found between the control group (GC) and the experimental group (GE). Similarly, following the same methodology used for the pre-test results, it was verified whether the post-test scores for both the GC and GE passed the normality tests before performing the T-Student test. The results indicated that the data passed the respective tests (p-value > 0.05), confirming that the scores followed a normal distribution and did not show significant differences in variances between the two study groups.

Table 8: *Results of the Levene and Shapiro-Wilk tests for the post-test.*

Test	P-Result
Shapiro-Wilk normality test A	0.1187
Shapiro-Wilk normality test B	0.1147
Levene's Test for Homogeneity of Variance A, B	0.2409

Source: Own elaboration based on the output from RStudio v2024.09.0+375.

The T-Student test, used to verify whether the intervention had a positive impact on students' academic performance, is reflected in Chart 9, where the p-value was 0.0005424 (p-value < 0.05) within a 95% confidence interval. It was concluded that the application of instructional sequences mediated by virtual reality using the Arloon Geometry app had a positive impact on the learning of regular polyhedra in the experimental group (GE), compared to the control group (GC), which was taught using a traditional teaching methodology.

Table 9. *T-Student test for the post-test.*

Test	P-Result
T-Student	0.0005424

Source: Own elaboration based on the output from RStudio v2024.09.0+375**.**

Similar results were obtained by Yakir (2019), where the sample size was the same for both the experimental and control groups. Likewise, prior to the intervention, it was determined that there were no significant differences between the two groups, which, from a statistical perspective, indicates that both research groups were at a comparable academic level at the outset of the study. The implementation of Augmented Reality (AR) enhanced learning about regular polyhedra from three primary dimensions: physical, cognitive, and contextual. According to Bujak et al. (2013), in the physical dimension, AR facilitates more natural interactions, which supports the creation of tangible representations of educational concepts. In the cognitive aspect, the spatial-temporal alignment of information is observed to contribute to a better symbolic understanding, allowing students to grasp abstract concepts with greater ease. Finally, in the contextual dimension, AR promotes collaborative learning by integrating virtual content into educational environments. Additionally, several studies, such as those by Bujak et al. (2013), Salinas et al. (2013), Bacca et al. (2015), Gazcón et al. (2018), Fidan and Tuncel (2019), Chang et al. (2022), and De Lima et al. (2022), have shown that, like the present study, the use of AR technology significantly aids students in retaining concepts in the long term. Specifically, Fidan and Tuncel (2019) conducted interviews with the students in their study, who emphasized that AR applications were more useful, realistic, and engaging for their learning, helping them to better understand and analyze the scenarios presented. This aligns with Coimbra et al. (2015), who argue that AR fosters motivation, facilitates a better comprehension of the subject being studied, and strengthens students' connection to the learning content.

Finally, as stated by De Lima et al. (2022), the success of implementing technologies such as AR largely depends on how educators perceive these tools and their ability to integrate them effectively into their educational objectives, teaching strategies, and expectations. AR provides students with the opportunity to examine three-dimensional objects or educational materials from various perspectives, significantly enhancing their understanding of concepts, as noted by Chen et al. (2011). Future lines of research could focus on investigating how AR influences variables such as motivation, as well as utilizing larger research groups with broader samples.

Conclusions

The use of Augmented Reality (AR) as a teaching tool has proven to be more effective than traditional methods, generating a positive impact on student learning. This is due to its ability to stimulate motivation, facilitate a better understanding of concepts, and promote greater engagement with educational content, thereby enhancing the overall learning experience compared to conventional teaching techniques. Before the intervention, students from the "A" and "B" parallel classes in 8th grade did not show significant differences in their average grades, indicating that both groups started with a similar academic level. However, after the intervention, the "B" group, which was taught using instructional sequences mediated by the Arloon Geometry app, showed significant progress and achieved the expected learning outcomes.

The results from the T-Student test reveal a significant difference between the "A" and "B" groups post-intervention, highlighting the effectiveness of the Arloon Geometry app in teaching regular polyhedra. AR contributed to learning by facilitating natural interactions and, from a cognitive perspective, enhancing students' symbolic understanding. Furthermore, from a contextual standpoint, it promoted collaborative learning. Nonetheless, the success of these technologies largely depends on how educators perceive and adapt them to their teaching objectives and strategies.

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Declaraciones éticas y editoriales del artículo
Contribución de los autores (Taxonomía CRediT). Juan Andrés González Cantos: conceptualización de la investigación, diseño metodológico, desarrollo del proceso investigativo, análisis formal de los datos, redacción del borrador original del manuscrito, revisión crítica del contenido científico y supervisión general del estudio. Tatiana Gabriela Quezada Matute: curación y organización de los datos, participación en la recolección de información, validación de los resultados obtenidos y elaboración de representaciones gráficas y visualización de los datos. Johnny Castillo Berrezueta: provisión de recursos académicos y materiales para el desarrollo del estudio, apoyo en la administración del proyecto investigativo y revisión editorial del manuscrito antes de su publicación. Juan Carlos Bernal Reino: conceptualización de la investigación, diseño metodológico, desarrollo del proceso investigativo, análisis formal de los datos, redacción del borrador original del manuscrito, revisión crítica del contenido científico y supervisión general del estudio.
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