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Augmented reality in the teaching of geometric solids for elementary school: Experience report in a public school

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Abstract

Background: Augmented Reality (AR) integrates virtual objects with the real world on smartphone screens, creating a seemingly seamless blend of both.
Aim: This research aimed to explore the use of AR in teaching geometric solids to final-year elementary school students. An interactive tool, RA Solids, was employed, originating from a 2023 research experience in a 6th-grade class.
Method: The study was conducted in a public school with students mostly classified as digital immigrants. The Didactic Engineering methodology was utilized for research.
Result: The outcomes were positive, showing that the school environment was conducive to implementing the teaching and learning process of geometric solids using digital technology.
Conclusion: The use of AR in education, specifically in teaching mathematics, demonstrates promising results in enhancing student engagement and understanding, particularly in the context of geometric solids.

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INTRODUCTION

Technological resources have become increasingly relevant in education, offering new perspectives and possibilities for teaching in the most diverse areas of knowledge. Our approach uses a digital application - AR Solids - explicitly designed for teachers with students of any age group. The readers may wonder about the developmental appropriateness and pedagogical basis for using technology in this way (Darling-Hammond et al., 2020; Haleem et al., 2022; Lewis Presser et al., 2023).

Even though there is a wide variety of digital technological devices, such as computers, internet, and tablets, which have been introduced in Brazilian schools since 1980, it is evident that these tools have not yet been fully used to promote significant changes in pedagogical practices (Otterborn et al., 2019). Although they are considered didactic resources, they are not yet exploited to their capacity by teachers to encourage practical improvements in the teaching and learning process (Azevedo & Duarte, 2018). In this scenario, we believe that Augmented Reality (AR) is a good choice, capable of increasing the understanding of complex concepts, such as geometric solids.

The report was applied in a municipal school in Fortaleza - CE, with two classes of students from the 6th year of Elementary School (EM) final years, totalling sixty participants. The methodology chosen was a case study with a qualitative approach based on ED. Using technological tools and the AR application - Sólidos RA - students were subjected to interactive and immersive activities (Huang et al., 2021; Küçük et al., 2016; Nam & Lee, 2020). In the meantime, it is suggested that AR helps to improve mathematics teaching, especially concerning the study of geometric solids. It is believed that the inclusion of AR in the educational process can encourage greater student involvement, arousing interest and curiosity and facilitating the assimilation of abstract and complex concepts to raise hypotheses from issues related to spatial geometry.

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Based on these premises, as a problem, we seek to know which learning of geometric solids is evidenced through AR technology mediated by the Didactic Engineering (DE) methodology. This study aims to describe an experience using AR in teaching geometric solids through the AR Solids application to favour the spatial perception of students mediated by the ED research methodology. Present concepts of quantification and establishment of relationships between vertices, faces, and edges in the visualization and learning of geometric concepts.

Numerous studies on Augmented Reality (AR) have been conducted, revealing that AR notably aids students by enhancing conceptual understanding (Putra et al., 2022), enriching learning experiences (Özdamlı & Hürsen, 2017; Yu-peng & Yu, 2023), and fostering motivation and engagement across various subjects, particularly in mathematics and science education (Huang et al., 2021). This research comprehensively synthesizes existing studies on augmented reality (AR) in education, with its novelty anchored in providing an experiential report on the implementation of AR in a public-school setting. In addition, it is essential to present evidence and reflections on the efficiency of using AR in teaching geometric solids, which contributes to improving pedagogical practices and provides subsidies for using this technology as an innovative and efficient educational strategy.

Literature Review

1. Augmented reality for educational report

Researchers have used the AR tool since the early 90s. Its definition is based on different realities, where real and virtual objects connect on a single visualization screen, where the user has a virtual vision composed of real and virtual (Milgram et al., 1995). Havlíková, (2020) reports that AR is not only limited to virtual and real images linked to other technologies but also has other characteristics, such as the union of real and virtual, real-time interaction, and 3D records (three dimensions). AR technology is multidisciplinary and is present in "at least six classes of potential applications [...]" and "[...] have been explored: medical visualization, maintenance and repair, annotation, robot path planning, entertainment, and navigation and target selection of military aircraft" (Azuma, 1997).

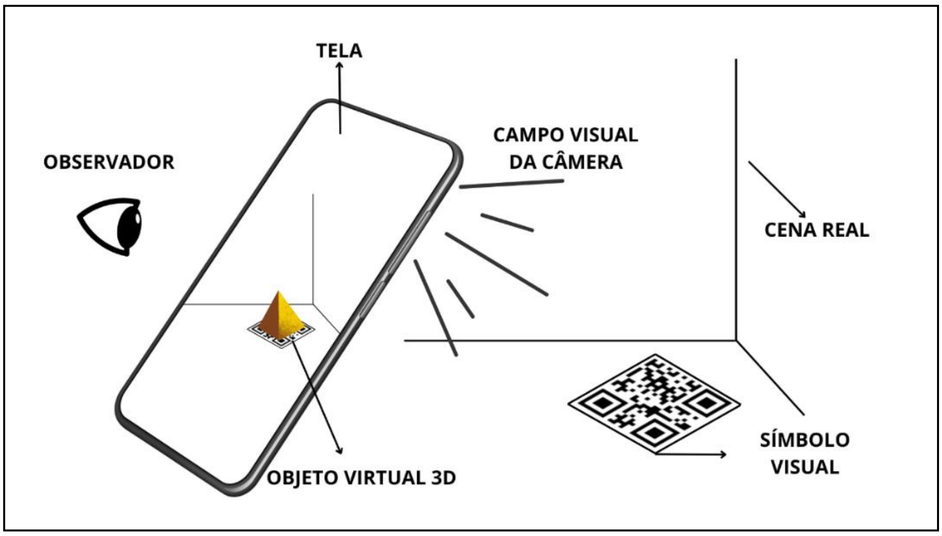

Figure 1. Use of augmented reality on mobile devices

AR, for educational support, uses some elements of the real and virtual world (Figure 1). This results in printing a visual symbol (a marker that serves as a reference for the projection of the 3D virtual object) in the visual field of the camera, tablet, or any mobile device, which can be the Android or IoS operating system. Then, through the cell phone camera, it is possible to identify or detect the visual symbol. Some technological devices need to install programs with marker recognition. In this way, we can see the 3D virtual objects on the mobile screen, which can contain movements, animations, and insertions made by the user (observer). The interactive animation between the user and AR provides a real scenario of teaching and learning, turning the traditional object drawn on paper and pencil into a virtual object in real time, containing various functions and dimensions for visualization from different points of view. Thus, AR aims to portray and insert imaginary situations, using several definitions, according to (Tori et al., 2006):

> a) is a particularization of mixed reality, when the main environment is real, or there is a predominance of real; b) it is the enrichment of the real environment with virtual objects, using some technological device, functioning in real time; c) it is an enhancement of the real world with texts, images and virtual objects, generated by computer; d) it is the mixture of real and virtual worlds at some point of the reality/virtuality continuum that connects completely real environments to completely virtual environments; e) it is a system that supplements the real world with virtual objects generated by the computer, appearing to coexist in the same space and presenting the following properties: combines real and virtual objects in the real environment; executes interactively in real time; aligns real and virtual objects with each other; applies to all senses, including hearing, touch and force and smell.

Reis & Kirner (2012) AR applications offer constructivist approaches to teaching and learning, according to which students are active participants and can be directed by the teacher. This makes it better known for the explorations that these real and virtual scenarios provide in investigating artefacts. There is a wide variety of interaction platforms for educational purposes. It is notorious that AR is still developing in the knowledge of some teachers, which makes them traditional in the academic environment since they could include applications of interest to students and facilitate the understanding of concepts in any teaching area through direct representation with their virtual objects. In this way, several works on this theme have been published in Brazil, explicitly using AR digital technology in conjunction with mathematics teaching. We highlight two of them that will be described about their applications in the educational scenario. Soares et al. (2022) inserted AR in the teaching of Spatial Geometry, presenting the challenges in students' learning based on the Fedathi Sequence (SF) with the GeoGebra software. The authors present an analysis of digital technologies in the teaching of Spatial Geometry, highlighting relevant evidence for readers that the use of GeoGebra Dynamic Geometry can provide the dynamism of traditional education in an interactive, creative environment that encourages the construction of new knowledge related to the teaching of Mathematics.

Some demonstrations are carried out in the educational field with the cell phone and the GeoGebra application, aiming at the 3D construction applied to a class of the Federal University of Ceará (UFC) of the degree course in Pedagogy, composed of 20 students through the Google Meet platform. The results and conclusions show that the experience lived by the subjects was validated with the SF and RA in teaching and learning Spatial Geometry, favoring geometric thinking and mathematical concepts for teacher training. Recently, Santiago & Alves (2023) published an article that shows how using Olympic Problems (OP) can help improve the teaching of the circumscribed circumference content in the equilateral triangle. To this end, the authors created a didactic proposal using AR, with a problem from the Brazilian Mathematical Olympiad for Public Schools (OBMEP), based on the premise of (Alves, 2019; Sousa et al., 2023), describes the Olympic Didactic Situations in any interactive environment using GeoGebra technology. Throughout the text, the authors present images of each step that can be used and then provide links to the constructions in 2D (two dimensions), 3D, and included in AR. This work records that the AR function can be restricted on some mobile devices but can be included in others to give a didactic sequence with any math content.

2. The RA Solids app

The first software model of Sólidos RA was created in 2020 due to a work requested in the discipline of Special Topics in Mathematics Education of the Mathematics Degree course at the Federal Institute of Espírito Santo (IFES). At the end of 2020, Sólidos RA was made free for mobile and tablet users in the Google Play Store. It was initially launched with two modules: Visualization and Creation. Over the following months, updates were made with general improvements in the use of the application and the inclusion of three other modules. In addition to Portuguese, the application was translated into other languages, such as English, Spanish, German, and Malay (Amorim and Freitas, 2023).

The Sólidos RA app is an AR tool specially developed to assist in the study and visualization of geometric solids. AR, in turn, is a technology that combines virtual elements with the real environment, providing an interactive and immersive experience. Solids AR uses the cell phone's camera, such as a smartphone or tablet, to superimpose virtual elements on physical objects. In this app, students can explore 3D geometric solids more practically and dynamically.

Using the app, students can visualize geometric solids in their real environments, moving around and observing them from different angles. This makes for a deeper understanding of the characteristics of these three-dimensional figures, such as vertices, faces, and edges. The tool also offers planning features so students visualize the flat shapes corresponding to geometric solids. This helps students to make connections between the two- and three-dimensional representations of these figures, which helps in developing spatial thinking and understanding the properties of geometric solids.

Figure 2. RA Solids app menu

Sólidos RA app offers an experience of visualization and manipulation of geometric solids through QR code scanning using an Android smartphone or tablet. By accessing the information menu, it is possible to download the available modules, each with specific QR codes used by Sólidos RA. The app offers five modules: Visualization, Planning, Creation, Modeling, and Geoplane.

Users can explore geometric solids with the Visualization module, allowing rotation, magnification, and detailed observation of their three-dimensional characteristics. The Planification module, in turn, enables the visualization of the flat shapes that correspond to the solids, which helps understand the relationships between two-dimensional and three-dimensional representations. The other modules were not studied in this research.

The RA Solids application is an educational tool that uses AR technology to make the study of geometric solids more engaging, interactive, and visually stimulating—enabling greater learning of geometric solids by offering a practical, fun, and refreshing approach to exploring the properties and relationships of three-dimensional figures.

METHOD

The research was conducted in a municipal school in Fortaleza-CE, with two classes of students in the 6th year of elementary school, identified as Class A and Class B. In all, 60 students participated in the research, divided into five classes, each lasting 55 minutes. The research work, a case study, was conducted by the mathematics teacher of the classes, one of the authors of this article. Both types were interested in the research.

This research is a case study, and we adopted ED as a methodology. For Yin (2016), the case study is an empirical research approach that aims to investigate a contemporary phenomenon in its natural context. It is beneficial when the boundaries between the context and the phenomenon are invisible. This type of study seeks to gain a deeper understanding of the phenomenon in question by using multiple sources of evidence. The qualitative approach values subjectivity, variety of perspectives, and contextualization of data, allowing for a deeper understanding of social and human phenomena. Moreover, qualitative research is also concerned with the research process itself, recognizing the relevance of the interaction between the researcher and the subjects, as well as the active role of the researcher in the construction of knowledge (Yin, 2016).

The ED methodology is based on an experimental scheme of didactic actions in a school environment (Almouloud & Coutinho, 2008). ED includes several demands in elaborating products for teaching and conducting applied research in the classroom. According to Almouloud & Coutinho (2008), this research methodology presents four stages of the investigative procedure, namely: previous analyzes, which is based on the structuring of the theoretical foundation, the formulation of hypotheses, the literature review, the analysis of the student's profile and previous knowledge about the content to be taught.

The second stage is conceptions and a priori analysis (Almouloud, 2007). This phase aims to designate the relevant variables to control students' behaviors and describe their senses. The research variables were defined and executed in this stage, the data collection instruments (questionnaires) were elaborated, and each student's analysis was developed. As a research instrument, a questionnaire of hits and errors of classes A and B was elaborated and applied in different situations for the students. The purpose of the questionnaire was to identify the percentage of hits in geometry questions and errors to validate and answer the main objective of the research.

In the penultimate experimentation stage, it was time to expose every device built throughout the application. The students used the RA Solids application, answered the questionnaire and the researcher teacher recorded the observations made during the experimentation, as described (Almouloud, 2007). Finally, the final stage consisted of a posteriori analysis and validation. According to Almouloud (2007), this analysis portrays data selected during the application, such as student writings, photographic records, and audio records.

The investigative process was conducted through a set of activities programmed and applied in three meetings with the students of each class. The activities in the first two classes were carefully planned, including a didactic sequence, which involved conceptual exposition and conversation, and practical training centered on geometric design. During this activity, students were encouraged to develop their imagination and represent geometric solids in their notebooks while identifying the number of vertices, faces, and edges of each figure. In addition, the teacher asked the students to draw the plan of eight geometric solids, such as the cube, the parallelepiped, the cylinder, the tetrahedron, the triangular and pentagonal prisms, and the square and hexagonal pyramids.

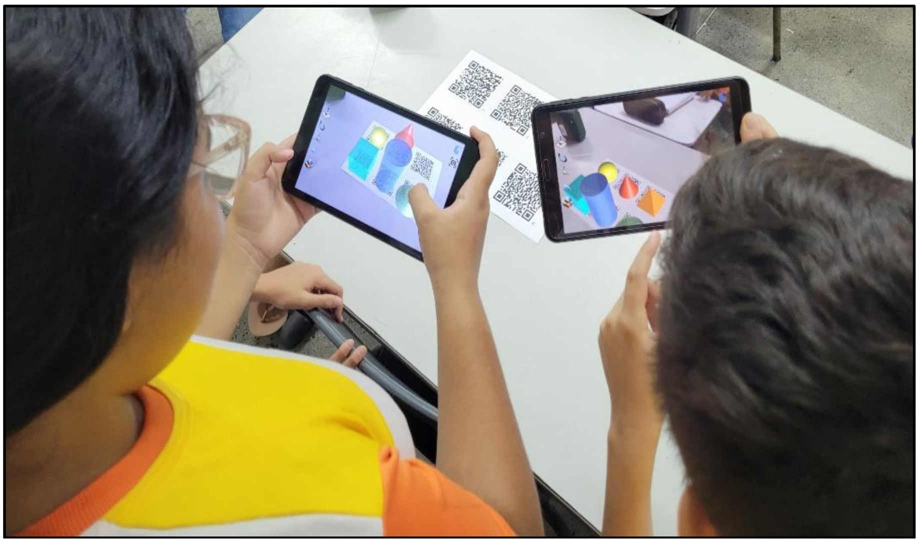

Figure 3. Students visualize geometric solids.

In the second moment, corresponding to the third and fourth classes, we explored the study of geometric solids using the RA Solids application. The modules covered were Visualization and Planning.

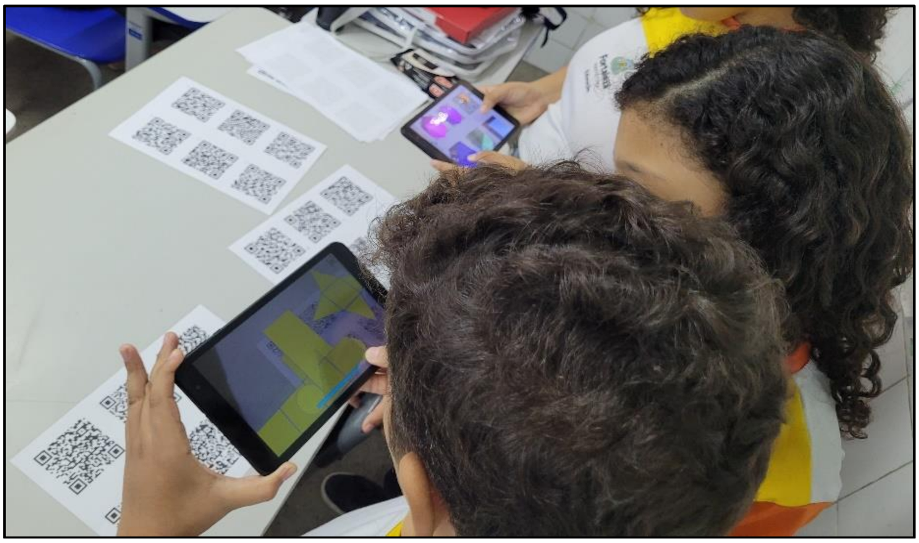

Figure 4. Students work on planning solids.

Students interacted with the app and made observations to establish relationships between vertices, faces, and edges and understand the ideal planning for each solid. It was an opportunity for students to explore the characteristics of these figures more visually and interactively. In the last class, students were evaluated to verify their understanding of the concepts. They answered a questionnaire of experimentation and validation of the readings made by the RA Solids application.

RESULTS AND DISCUSSION

The first question of the written assessment focused on John's intention to bring innovation to his math artifacts store, where he decided to offer geometric objects with varied shapes. The question was about a square-based pyramid and asked for the values of this object's edges, vertices, and faces. The information regarding this question is presented in the following three tables. Table 1 shows the number of hits and errors concerning counting faces.

Table 1. Number of Faces

Room	Settlement	Error
Class A	30	02
Class B	21	07

The result was entirely satisfactory, with 94% of the students in Class A and 75% in Class B getting the question right. Table 2 shows the data regarding the number of correct answers and errors concerning the number of edges.

Table 2. Number of edges

Room	Settlement	Error
Class A	24	08
Class B	21	07

The results show a hit rate of 75% in both Class A and Class B, demonstrating a significant hit result. Table 3 presents the data regarding the number of hits and errors concerning the number of vertices.

Table 3. Number of Vertices

Room	Settlement	Error
Class A	26	06
Class B	23	05

Class A's percentage of students who got the question right was 81%, while in Class B, this figure was 82%. This percentage is statistically significant, indicating an excellent performance in both groups. The second question of the written assessment dealt with geometric objects that require flat-form visualization during manufacture. To illustrate this, a cylinder-shaped cooling tank was presented and asked to identify the shape of the planification shown in the figure. The results of the number of students who correctly correlated the planification with the geometric solid are presented in Table 4.

Table 4. Planning

Room	Settlement	Error
Class A	30	02
Class B	21	07

It was found that Class A had a 94% success rate in the proposed question, while Class B had a 75% success rate. These results show a satisfactory performance of the students. The third question of the written assessment was about the characteristics of a polyhedron, including its base, height, and length. The question specifically presented a prism with a triangular base and asked about the shape of the geometric object. Table 5 shows the data relating the number of students who associated the geometric solid with its corresponding name.

Table 5. Polyhedron

Room	Settlement	Error
Class A	30	02
Class B	21	07

The results indicate a satisfactory performance in classes A and B, with 75% and 71% of students getting the question right. The first question of the questionnaire asked about the experience of using the AR Solids application to study geometric solids. Table 6 shows the data reflecting the students' perception of the use of this AR application.

Table 6. Students' perceptions

Did you enjoy using the augmented reality app to study geometric solids?	Yes	No
Class A	32	00
Class B	28	00

The use of the RA Solids app in the classroom received overwhelmingly positive feedback from the students of both Classes A and B. The sense of satisfaction was evident as they engaged with the app's features, suggesting that the interactive element of Augmented Reality significantly enhanced their learning experience. The ease of visualizing geometric shapes in a three-dimensional space allowed them to grasp complex concepts more naturally. This positive response highlights the potential of technology-assisted learning tools in modern education, especially in subjects that benefit from visual aids.

To gauge the app's effectiveness, the second question on the questionnaire specifically addressed the contribution of RA Solids to the students' understanding of geometric solids. The responses, as presented in Table 7, clearly show that the students felt their comprehension of the subject matter improved with the use of the app. The data points to a correlation between the use of innovative educational technology and the level of understanding that students achieve. Such insights are invaluable, confirming the critical role that educational applications can play in enhancing the learning process and supporting students in achieving their educational goals.

Table 7. Student data

Do you think the augmented reality app helped understand the content of geometric solids?	Yes	No
Class A	32	00
Class B	27	01

The feedback from the students regarding the use of the Augmented Reality app was overwhelmingly positive. In Class A, every single student reported that the app had a beneficial impact on their understanding of geometric solids. This unanimous response highlights the app's effectiveness in conveying complex concepts in a manner that resonates with young learners. The technology seems to have bridged the gap between abstract geometric theory and tangible comprehension, allowing students to visualize and manipulate shapes in a virtual space, thereby solidifying their grasp of the subject matter.

In Class B, the sentiment was nearly as unanimous, with 96% of the students acknowledging the advantages of the app in aiding their conceptual understanding. This slightly lower percentage, while still remarkably high, suggests that while most students find such technological tools helpful, there may be a small subset that either prefers traditional learning methods or requires additional support to benefit from digital learning tools. It underscores the need for educators to maintain a flexible approach to pedagogy, one that encompasses a variety of teaching methods to cater to the diverse learning needs of all students.

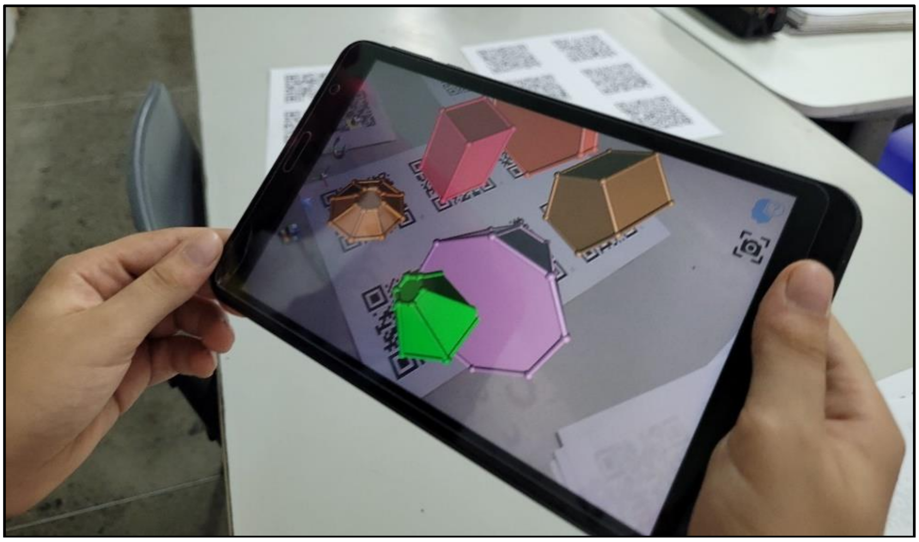

Figure 5. Student work with AR

The data analysis in this research provided favorable evidence for using AR Solids in the study of Geometric Solids. The integration of Augmented Reality (AR) in educational contexts, particularly in the realm of mathematics, has been a subject of growing interest in recent academic discourse. In this study, the application of AR for teaching geometric solids in an elementary school setting has yielded remarkably positive outcomes. According to a recent study by Verkhova et al., (2019), the use of interactive technology in classrooms, especially AR, has significantly enhanced student engagement and understanding of complex concepts. The data collected through a complementary questionnaire within this study echoes these findings, demonstrating the AR Solids application's effectiveness. All students participating in the study expressed notable satisfaction with the AR-based learning experience, underscoring its potential as a transformative educational tool.

The students' enthusiastic reception of the AR Solids application aligns with contemporary pedagogical theories emphasizing interactive and immersive learning experiences. As explored by Πέλλας et al. (2018) and Li et al. (2016), immersive technology like AR creates a dynamic learning environment that fosters deeper conceptual understanding, particularly in subjects such as geometry, where visual and spatial awareness are crucial. In this study, the positive perception of students not only highlights the quality of the AR experience but also suggests a broader implication for pedagogical practices. The students' heightened interest and engagement are indicative of the significant role that AR can play in enhancing traditional teaching methodologies, supporting the notion posited by Li (2014) that technology integration is key to modernizing education and catering to the needs of digital-native learners.

Furthermore, the data synthesized from multiple academic sources underscore the relevance of AR as a critical pedagogical tool in contemporary education. The unanimous satisfaction among students using the AR Solids application in this study is a testament to the efficacy of AR in creating an interactive and stimulating educational experience. This aligns with the findings of Amores-Valencia et al. (2022), who note that AR's ability to provide hands-on, experiential learning opportunities significantly enhances student comprehension and retention of abstract concepts. The positive student feedback not only reinforces the quality of the experience provided by AR in this context but also sets a precedent for future research and development in educational technology. This study, therefore, contributes to the ongoing dialogue in the field of educational technology, advocating for the thoughtful integration of AR to revolutionize teaching methods and enhance learning outcomes in mathematics education.

This finding reinforces the relevance and potential of using AR as an educational tool to promote a deeper and more engaged understanding of students in this specific knowledge area. By offering an interactive and immersive experience, AR has proven to be an effective strategy to facilitate learning and arouse students' interest, creating perspectives and enriching the teaching-learning process of geometric solids.

CONCLUSION

The study revealed that the teacher-researcher's active approach, from lesson planning to activity execution, significantly enhanced the students' grasp of geometric solid planning. Augmented Reality proved to be a valuable innovation, enriching the learning experience. Improved student performance highlighted the flexibility and importance of applying non-linear Didactic Engineering stages. The AR Solids app was well-received by the students, who acknowledged its effectiveness in understanding geometric concepts. In summary, incorporating this technology into mathematics education offers an engaging and effective method, supporting improved student comprehension of Geometric Solids.

AUTHOR CONTRIBUTION STATEMENT

PVSS : Idea, desain, conceptualizon, analysis, and editing
EZ : Drafting the manuscript, correction, directing, and final approval
RD : Editing, reviewing, and proofreading

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