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Exploring the Potential of Augmented Reality in the Teaching and Learning of Geometry

Jesús Jacinto-Perez[1], Yerico Sanchez-Vasquez[2], Karina Espinola-Linares[3], Orlando Iparraguirre-Villanueva[4]
[1,2,3,4]Facultad de Ingeniería, Universidad Tecnológica del Perú, Chimbote, Perú,
u21202983@utp.edu.pe, *u21230122@utp.edu.pe, c24051@utp.edu.pe, c27399@utp.edu.pe*

***Abstract*— The systematic review aimed to investigate the influence of augmented reality on the learning and teaching process of geometry between 2017 and 2024. For this purpose, five main databases were used: Scopus, Science Direct, Springer, IOPScience and EBSCO, as well as additional databases. The PRISMA methodology was used in the search and information gathering process, executing its four phases and applying the eligibility criteria of the papers. In total, 44 articles, 4 conferences and 2 book sections were collected. The years 2020, 2022 and 2023 stood out for having the highest number of articles, with 9 each, representing 54% of the total. The United Kingdom and Turkey were the countries with the highest scientific production, contributing 20% of the articles. In addition, the predominant methodology was quantitative, with a total of 29 studies. Finally, the systematic review concludes that augmented reality offers great opportunities for education, providing a significant advantage in the geometry teaching process compared to traditional methods.**

Keywords*— Augmented Reality; Geometry; education; teaching methods; learning; technology

I. INTRODUCTION

At present, there are still certain pending aspects related to changes in learning methods, due to the constant technological progress, therefore, new technologies will be the main element in the training of future professionals, being necessary to rethink traditional teaching methods [1]. The practice must be carried out in an interactive way motivating an active role of students, where teachers must opt for learning media that capture the interest of learning [2].

One of the technologies that has been gaining momentum in recent years is augmented reality, which has had a great impact on different sectors, such as education, where the use of augmented reality applications can be used effectively in the classroom as an experimental tool to encourage student participation in different classroom activities[3].

Augmented Reality is a technology that is based on superimposing or adding virtual elements in the user's sensory field, giving the sensation that these virtual elements are as real as the elements in their environment. This technology is often confused with Virtual Reality, however, they are different terms, since AR does not replace reality with an artificial environment, but combines the environment surrounding the user, influencing their perception of reality [4].

With this in mind we will see how AR works, this digital tool works through the AR Core library, created by Google that offers an environment for the creation of Augmented Reality applications, it calculates the location and dimensions of the three-dimensional object. In smartphones, it works by evaluating luminosity and tracking movements to understand its position in relation to the real environment, enabling interaction with virtual objects [5].

Based on this, the importance of this article lies in highlighting the impact and growing relevance of the application of augmented reality in education, where these applications enrich learning experiences, since active and participatory teaching is encouraged.

The integration of Augmented Reality in education is becoming an extremely important tool due to the growing technological progress and increasing availability of devices in which this technology can be applied, such as mobile devices, with which children interact from an early age. As a result, it is essential to understand how this digital tool can be used effectively to enhance the teaching and learning processes of Geometry.

Students can effectively develop Descriptive Geometry problems using Augmented Reality, developed on the Vuforia platform, thanks to which they are able to generate 3D objects of geometric figures in SketchUp [6]. In this way we see that AR can enrich learning experiences by providing visual and interactive representations of geometric figures, thus converting traditional teaching into a more dynamic and meaningful one for students, since it allows them to explore and manipulate virtual objects in a three-dimensional environment, increasing the understanding and retention of geometric concepts. Therefore, this research seeks to harness the potential of AR to improve the quality and effectiveness of geometry education.

The aim of this article is to conduct a comprehensive investigation into how augmented reality influences the teaching and learning process of geometry. From this, it will analyze how the inclusion of augmented reality in the classroom can improve the understanding of geometry, increase student engagement, as well as foster more interactive and meaningful learning. In addition, the different augmented reality applications and tools available for teaching geometry will be explored and best practices and strategies for their effective implementation in the educational system will be discussed.

II. Literature Review

The work [7] focused on testing the performance of augmented reality in learning. The study involved 96 students from the faculties of Gardening and Landscape Architecture, separated into 2 groups, the experimental group using augmented reality technology and the control group using visual methods and traditional teaching technologies. The results showed that the experimental group's progress increased the "excellent" ratings by 13%, the satisfactory ratings decreased by 10% and the unsatisfactory ratings decreased by 4%. Concluding that the use of augmented reality boosts student performance.

The work [8] focused on the teaching of the solar system through the use of Virtual Reality and Augmented Reality. In which 24 students participated, they were given a pre-test, then alternated between AR and VR, answered a questionnaire and evaluated their experience. It was found that the VR module had more notable results with 61.67% correct answers in the post-test compared to 48.33% for AR. In conclusion, VR and AR technology do have an impact on teaching, with VR being slightly more efficient.

The work [9] focused on how the game kit "Pengembara", using augmented reality, impacts on the learning of primary school students. The kit was implemented in 7 checkpoints, in which AR was used in 4 of them, at each point students completed quizzes and were guided to completion. It was evident that AR helped students to better understand the topics, which was reflected in their learning outcomes. In conclusion, the use of AR software improved students' engagement in learning by making it more meaningful and enjoyable.

The article [10] highlights the impact of augmented reality through the toolKit "AR-DEHAES" on the learning of the Descriptive Geometry course of university students. The project was divided into 2 groups, one group used the toolkit with AR and the other simply used traditional learning methods. The results revealed a remarkable improvement by using AR compared to traditional methods, which was reflected in the tests. In addition, the use of the toolkit made it easier for students to understand the course, making the learning process a more interactive experience.

The work [11] sought to assess how students interact and learn with augmented reality mobile applications in the understanding of 3D geometry. The study selected 26 students from 3 schools. Three phases were conducted: initial training, use of an AR geometry app and a final evaluation. According to the results of the final interview, the use of AR motivates students to learn and helps them to understand geometry. In conclusion, AR can be used effectively as a teaching and learning tool.

The study [12] focuses on exploring the current challenges and opportunities for integrating AR effectively in school settings. The work involved online questionnaires, two-day group sessions, and in-depth interviews with primary school teachers in the UK. The results revealed that many teachers are effectively disposed of AR and that it has the potential to motivate students and enrich their practical learning, but the lack of budgets in schools is a major barrier to its implementation, as well as the complexity of its applications and the need for them to be intuitive. In conclusion, AR can be very useful in the learning process of students, but adequate investment is needed for the devices.

The article [13] examines the integration of augmented reality (AR) into pedagogical practices in Indonesian schools, highlighting its opportunities and challenges. Using a synthesis research approach, existing literature on AR in education was analyzed. The results indicate that AR is a promising tool that makes learning environments more authentic and engaging, providing meaningful experiences for students. However, technical challenges were identified that negatively affect the educational experience. In conclusion, AR technology can be used in various learning environments due to its versatility, but its limitations should be carefully considered. Table 1 presents the main results and limitations of the related work.

TABLE I. Conclusions and limitations of related work

Ref.	Main results	Challenges/Limitations
[7]	+13% in excellent ratings, higher motivation in the RA group	Requires smartphones and familiarization with the app.
[8]	RA had positive impact (48.33%), but less than VR (61.67%); valued experience	Less effective compared to VR, possible hardware dependency.
[9]	Improved student engagement through game mechanics: clear goals, immediate feedback	May require constant technological support and teacher training to take advantage of its pedagogical potential.
[10]	Significant improvement of skill 2 towards the subject matter, more understandable and engaging 3D tasks.	Financial resources limit its expansion; requires investment for greater reach.
[11]	Improved understanding and motivation in geometry, encouraging autonomous learning.	Difficulties arise due to learning styles, prior knowledge and lack of technical or cognitive preparation.

III. Methodology

The systematic literature review (SLR) method is used in this study because it organizes the review appropriately, ensuring its structure and accuracy. In addition, the PRISMA method is used, which is an effective tool that facilitates systematic reviews in an orderly and accurate manner. Its use ensures a complete and transparent presentation of methods and results, allowing for assessment of the applicability of findings, replication of reviews, and reduction of research waste [14].

These approaches are fundamental to an accurate assessment of the impact of augmented reality on the teaching and learning of geometry. The section is organized as follows: 1) purpose and questions, 2) search strategies, 3) inclusion and exclusion criteria.

A. Purpose and questions:

Based on the literature review, this study will investigate the impact of the use of augmented reality in geometry education and teaching, The research questions are as follows:

- What are the main challenges and opportunities presented by augmented reality in teaching?
- How does Augmented Reality affect students' performance, motivation and participation?
- How effective has the application of AR in the teaching and learning of geometry been in comparison to traditional teaching?

B. *Research Strategies*

The data collection method was based on the search for reliable sources, through an exhaustive review of articles, with special attention to databases such as Scopus, ScienceDirect, Springer, IOPScience, Ebsco, among others. At the beginning, a total of 427 articles were identified, of which only 50 were relevant after applying the inclusion and exclusion criteria, as shown in Fig. 1.

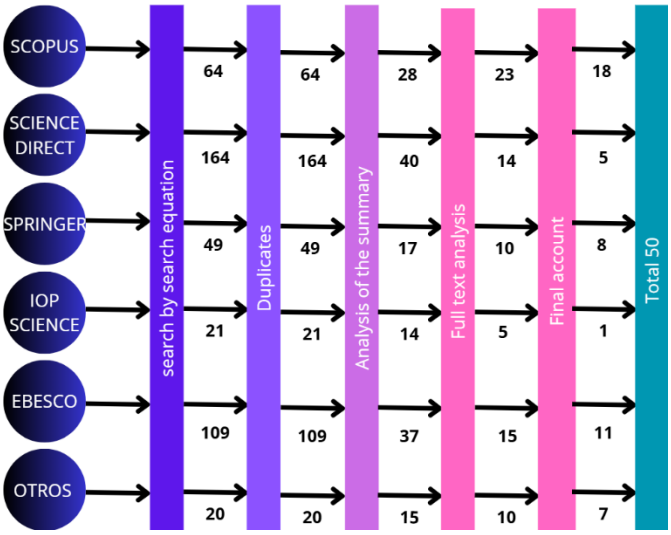

Fig. 1 Article selection process

C. *Inclusion and Exclusion Criteria*

For the present study, the following inclusion and exclusion criteria were applied:

TABLE II. INCLUSION AND EXCLUSION CRITERIA

Criteria	
cl us .	Studies should use robust and transparent methodologies in their research on augmented reality in education.
	Studies published from 2017 to 2024 are preferred to ensure that they reflect recent developments in the use of augmented reality in education.
	Studies should focus on identifying and analysing the main challenges and opportunities presented by augmented reality in the educational context.
	Studies should directly address the use of augmented reality in education.
	Studies directly addressing the impact of Augmented Reality on student motivation.
	Research examining the influence of Augmented Reality on student engagement in the learning process.
	Research specifically evaluating the use of Augmented Reality as a tool for teaching geometry.
	Studies directly comparing the effectiveness of Augmented Reality with traditional teaching methods in the context of geometry.
Exclusion	Studies that are not directly related to the use of augmented reality in education are excluded.
	Studies published before 2017 are excluded in order to maintain the relevance and timeliness of the research.
	Studies are excluded if they lack details about their methodology or do not provide sufficient information to assess the validity of their findings.
	Studies that do not make a direct comparison of the effectiveness of Augmented Reality with traditional teaching methods.
	Studies that do not specifically address student performance, motivation and engagement as a result of using Augmented Reality.

When applying the search to all information related to the research topic, the following keywords were taken into consideration: "challenges AND opportunities," "augmented AND reality AND in AND teaching," "augmented reality, motivation and participation, geometry," "augmented reality, teaching geometry, improves understanding, traditional teaching methods, and "augmented reality AND geometry education AND traditional teaching methods AND efficiency".

The studies collected from the 6 databases were then evaluated and selected using four phases. After the first phase, the 427 articles continued with the 427 articles as no duplicates were found, in the second phase the abstracts of the articles were analysed leaving 151, in the third phase after the complete analysis, 77 articles remained. Finally, the sources were reviewed according to the PICO questions, leaving only 50 articles in the systematic review. The application of the prism method can be seen in fig.2.

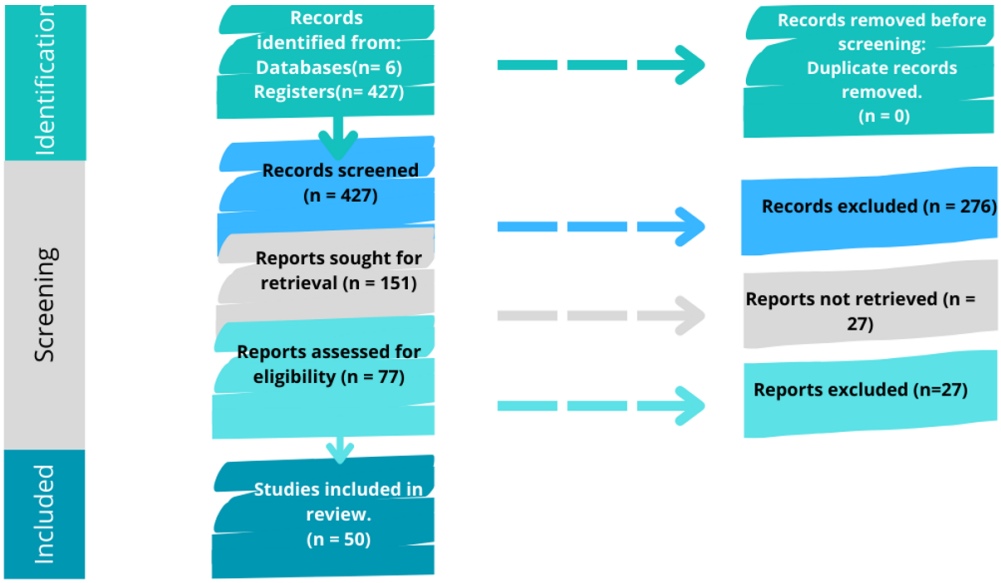

Fig. 2 PRISMA diagram

IV. RESULTS

In this section, we present various graphs illustrating the findings obtained from our systematic literature review. These graphs provide us with a more detailed overview of all the articles considered, covering different key aspects, such as the number of articles found per year in each database, a geographical overview of the articles, a co-occurrence diagram to identify our keywords and finally a bar chart to observe the methodology of the articles.

Fig. 3 shows the number of articles found in the six academic databases for the years 2017 to 2024. Visualizing the evolution and increase of interest in research on Augmented Reality (AR) in education over these years, showing the growth and acceptance of this technology in the educational field.

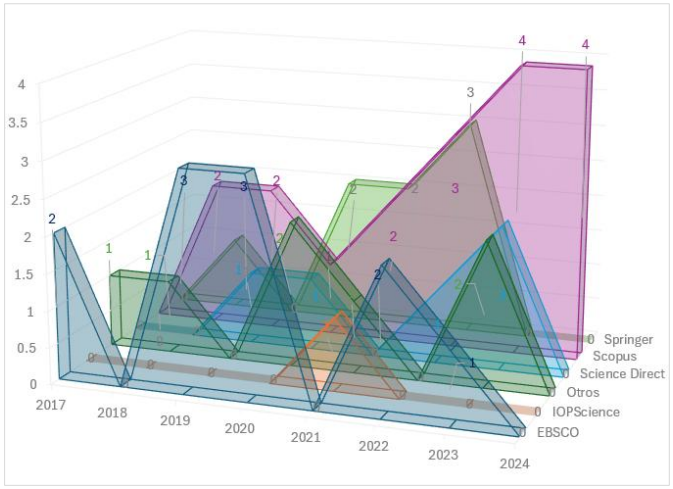

Fig. 3 Articles by year and database

In 2024, 4 articles were found in Scopus. In 2020, 9 articles were found, of which 3 were in EBSCO, 2022 likewise 9 articles were found, of which the largest number were in Scopus and Springer with 3 articles each. In 2023, 9 articles were found in the same way, of which 4 were found in Scopus. On the other hand, in 2021, 6 articles were found with a greater presence in Scopus and Springer, 2 each. In EBSCO 3 of the 6 articles were found in 2019. In 2018, 4 articles were found in Springer, Scopus and Others. Furthermore, in 2017 only 3 articles were found, of which 2 are in EBSCO and 1 in Others. Finally, IOPScience shows that only 1 article was found in 2021.

Fig. 4 illustrates how the analyzed articles are distributed geographically, showing the number of publications per country. This visual representation clearly highlights the prevalence of the research topic in different parts of the world, it can be clearly identified which countries or geographical regions have a higher concentration of articles on Augmented Reality in education.

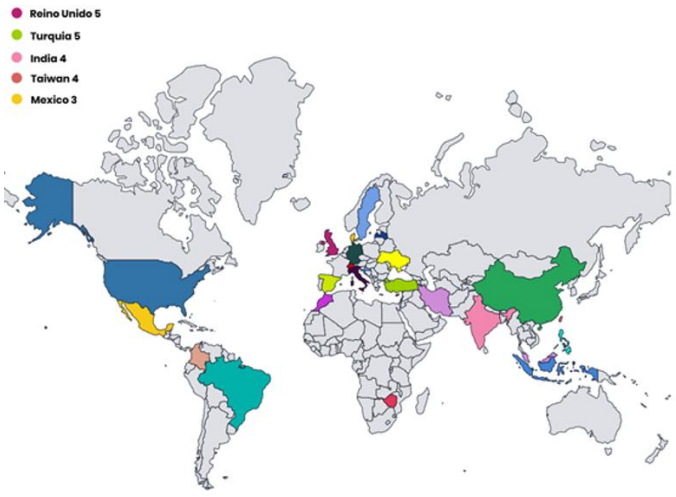

Fig. 4 Articles analyzed by country

Fig. 4 shows that the UK and Turkey top the list with 5 articles each on the application of augmented reality in education and teaching. In addition, India and Taiwan follow with 4 articles each, while Mexico has a lower number of articles with only 3, and 7 countries are present in this list with 2 articles and 15 countries with 1 article.

It is also important to note that the articles were reviewed by year from 2017 to 2024, providing a detailed analysis of how interest in the research topic has evolved over these years. This representation allows us to observe how academic production on the topic has varied over time, providing a clear perspective of its development and relevance over the years analyzed. The years 2020, 2022 and 2023 saw the highest number of articles 27, equivalent to 54% of the total. On the other hand, 2017 was the year in which the fewest articles were considered with only 3, 2019 and 2021 had 12 articles with 6 each, and finally in the years 2024 and 2018 a total of 8 articles were found.

In Fig. 5, a bibliometric analysis is presented, using the VoSviewer tool, using a level 2 concurrence, a total of 36 relevant keywords were identified that make up this figure.

Fig. 5 not only shows the interactions and co-occurrences between terms but also highlights significant relationships and patterns of connection within the analysed dataset. The keywords are organised in clusters, each represented by a different colour, allowing for the identification of thematic groups and interrelated areas of research.

For example, the central term ‘augmented reality’ acts as a main node, connecting to various research areas, such as ‘virtual reality,’ ‘education technology,’ and ‘geometry.’ These connections indicate that augmented reality is an integrating hub within the field studied, linking to both technological applications and specific educational approaches.

The network design facilitates a deeper understanding of how keywords interact with each other and how thematic relationships are structured in the domain studied. This is very important for identifying trends, emerging areas and possible gaps in the literature analysed, thus providing a conceptual map of the subject matter addressed.

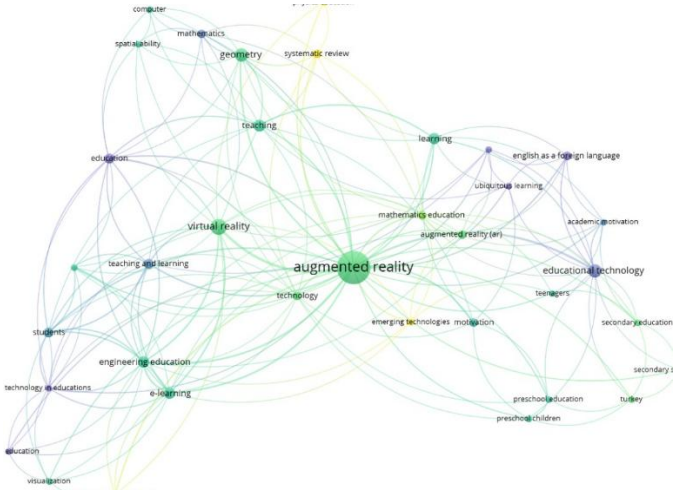

Fig. 5 Visualization of the bibliometric analysis

V. DISCUSSIONS

In the following section the discussions of the systematic review article will be carried out. In this context, the research questions formulated using the PICOC method will be taken into account. These questions will be answered comprehensively and supported with arguments both for and against, as appropriate. In addition, the results obtained in previous research, which were reviewed in the background, will be compared with the results of the current research that was used for the methodology and results of this study.

A. *RQ1: What are the main challenges and opportunities presented by augmented reality in education?*

The main challenges of implementing AR in education indicate that, as an emerging technology, it requires more rigorous testing to evaluate its effectiveness.In addition, its implementation needs to be managed responsibly, considering factors such as budget.In this regard, free AR application resources are actively sought, which correlates with the results of the paper [12], which indicates that lack of budget in schools is a significant barrier to implementation.

On the other hand, technical issues and challenges in creating materials represent a major obstacle to implementing AR. These findings align with work [13] that points out that technical challenges such as internet connection failures and the instability of AR applications directly influence the educational experience.

On the other hand, AR in teaching presents significant opportunities for the improvement of education, such as the ability to improve the understanding of geometry in subjects like three-dimensional composition and volume calculation due to the fact that it offers an immersive environment that stimulates all the senses, this being altogether a significant added value in the learning process in the classroom which correlates with the work [13] that states that the use of AR in the classroom provides meaningful experiences due to the fact that there is a more authentic and engaging environment for the students. Table 2 shows the challenges and opportunities.

TABLE III. CHALLENGES AND OPPORTUNITIES

Category	Considerations	References
Challenges	– Need for larger scale testing to assess effectiveness. – Technical drawbacks and difficulties in developing materials. – Workload involved in preparing practical experiences and managing course time. – Need for teachers to have technological knowledge of VR and AR to achieve the intended objectives. – Need for responsible innovation and implementation considerations. – Search for free resources of AR applications.	[15], [16], [17], [18], [19], [20], [21], [22], [23], [24], [25], [26], [27], [28]

Opportunities	– Ability to improve understanding of three-dimensional composition and volume calculation. – Added value of immersive technologies in the learning process of students. – Ability to offer immersive simulations involving all senses. – Evolution towards more accessible and less expensive solutions. – Opportunity to use mobile devices to organize and personalize the learning process.	[17], [20], [21], [22], [25], [29], [30], [31], [32], [33]

B. RQ2: How does Augmented Reality affect student performance, motivation and participation?

Firstly, AR influences students' performance in the following way, it helps them to take a more active and conscious role in how they are learning in the classroom by improving their ability to use more complex educational methods or strategies. In addition, the use of AR reinforces knowledge retention which leads to higher student scores, this correlates with the results of the paper [9] which indicates that by using AR students had a better understanding of the topics and an improvement in their scores. On the other hand, focusing on geometry, the use of AR favours the recognition of three-dimensional shapes, which coincides with the findings of the paper [11] which mentions that the integration of AR as an educational resource can improve both the understanding of geometric concepts, as well as the way students engage in the learning process. Secondly, AR also influences students' motivation in the following way, being a new teaching strategy it motivates students in a better way than traditional methods since it boosts their internal motivation involving factors such as curiosity and personal satisfaction, which drives them to explore more similar applications.

Furthermore, in Geometry, the use of AR motivates students by reducing fear and anxiety towards this course, stimulating their interest which contrasts with the results of the work [11] that indicates that the use of AR motivates learning and helps them to understand geometry topics making them feel excited and not bored when reading or listening to the lecture. Finally, the use of AR directly influences student engagement, supporting interactivity and connectivity by influencing their willingness to actively participate. In addition, it influences the strengthening of the ability to collaborate effectively in a group, which involves a favourable emotional connection between the student and the teacher. Table 3 shows the organisation of the benefits by category.

TABLE IV. PERFORMANCE, MOTIVATION AND PARTICIPATION

Category	Benefits	References
Performance	– -Reduce task completion time. – -Actively manage their learning strategies. – -Higher scores. – -Retention of knowledge – -Proportional reasoning – -Apply more advanced strategies when learning. – -Improved recognition of geometric shapes.	[17], [21], [23],[24], [28], [31], [34], [35], [36], [37], [38], [39], [40], [41], [42], [43], [44], [45], [46], [47], [48], [49], [50], [51], [52], [53], [54]
motivation	– -Motivation of students compared to traditional methods. – -Satisfaction and desire to explore more similar applications. – -Internal motivation – -Attention to higher level concepts. – -Prompting curiosity. – -Students' interest in the subjects. [16] – -Intrinsic motivation [33]. – -Reduction of fear and anxiety towards geometry classes [45].	[17], [21], [22], [23], [28], [30], [32], [36], [38], [39], [40], [42], [45], [52], [53], [54], [55], [56], [57]
participation	– -Supports interactivity and connectivity. – -Development of teamwork skills [15]. – -Influences interactivity of learners. [27] – -Improves socio-affective relationships [38]. – -Positive emotional interaction between student and teacher [45].	[15], [17], [21], [23], [30], [32], [34], [40], [55], [56], [58]

C. RQ3: How effective has the application of AR been in teaching and learning geometry compared to traditional teaching?

The application of AR in the teaching and learning of geometry has proved to be more effective than traditional teaching, due to the following considerations. The use of AR increases both the stimulus and the effectiveness of the learning process of students, in addition, compared to the traditional method, when using AR, better scores were obtained and there was an improvement in the retention of information, which correlates with the results of the work [7] in which the group that used AR obtained an improvement in their grades, showing that the use of this technology boosts performance. Furthermore, in the teaching of geometry thanks to the use of AR there were significant differences in terms of understanding and classification of geometric figures and improvement in spatial skills of students, compared to conventional practical materials, coinciding with the results of the work [10] which mentions that there was a marked improvement in the understanding of the descriptive geometry course, due to the fact that there was a more interactive learning experience. Table 4 shows some considerations for the effectiveness of AR.

TABLE V. EFFECTIVENESS OF AR

Category	Considerations	References
Effectiveness of AR	– AR improves both motivation and effectiveness of students [3]. – Compared to the traditional method, using AR resulted in higher scores and better retention of information [22]. – Statistically significant differences in geometric shape classification and improvements in spatial skills [47]. – AR is more effective in improving understanding of geometric shapes compared to traditional physical manipulatives [35]. – AR allows students to manipulate physical equipment with real-time visual feedback [42]. – Significant advantage in improving memory retention, problem-solving skills and overall student performance [49].	[30], [31], [34], [45], [49], [52], [53], [54], [56], [59], [60], [61], [62], [63], [64]
AR tools	– Tools – AR App with QR cards, "aura" layers, audio, video and mobile interaction – AR mobile app with 3D models of the solar system, animations and touch interaction – Pengembara kit with game-based learning integration – AR-DEHAES – AR + mobile augmented reality textbooks	[7] [8] [9] [10] [11]

VI. CONCLUSIONS

It was concluded that the SLR examined and analyzed articles related to the topic of augmented reality in the teaching and learning of geometry from 2017 to 2024, using the PRISMA method, inclusion and exclusion criteria were applied, resulting in 50 articles, of which 18 (36%) were articles found in the Scopus database, 11 (22%) articles from Ebsco, 5 (10%) in Science Direct, 8 (16%) articles from Springer, 1 (2%) in IOPScience and 7 (14%) articles from other databases were used. Furthermore, geographically the UK and Turkey top the list of countries with 5 articles each, followed by India and Taiwan with 4 respectively highlighting the prevalence of the research topic in these areas. Quantitative methodology also prevailed with 29 articles out of 50.

In these studies, the authors agree and highlight that Augmented Reality in education offers significant opportunities to improve education, such as the ability to improve understanding of geometry and volume calculation through an immersive environment that stimulates the senses. In addition, the authors highlight that AR in geometry teaching is more effective than traditional methods, improving learning and information retention. They also highlight that AR improves performance and knowledge retention, especially in geometry, by facilitating the understanding of three-dimensional shapes. They also claim that it motivates students by arousing their curiosity and reducing their anxiety, encouraging participation and collaboration in class.

On the other hand, it is worth mentioning the main limitations encountered in carrying out this SLR. Firstly, a high percentage of paid articles were identified, especially in databases such as IEEE. Secondly, multiple articles on AR were found, but not directly related to the topic of education. Also, a low number of articles relating to AR to geometry were observed.

Finally, this review highlights the need for further exploration of Augmented Reality for teaching geometry, as well as the potential of this technology given that there are some significant challenges for its implementation and use in education.

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