

PAPER

Enhancing Geometry Learning with Mobile Augmented Reality: Evaluating the GeoFormeAR Application in Middle School Education

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ABSTRACT

Augmented reality (AR) has attracted significant attention and has become an important topic for many professionals and researchers. This is due to the capability of AR to offer a multitude of advantages that can enrich various domains of life. In education, AR technology has been increasingly used to create new learning experiences and transform real 3D (three-dimensional) or 2D (two-dimensional) objects into virtual elements, capturing users' interests and motivation while fostering the growth of various human abilities and attitudes. The integration and use of educational games and applications based on AR in mathematics education have historically grown, and their impact has been beneficial for teaching mathematics and creating effective pedagogical scenarios. This paper presents an experiment we will undertake with our educational mobile application, GeoFormeAR, to animate a lesson on "Cylinder and Prism" and then compare it with a similar lesson delivered using the traditional approach in the second class. A post-test was administered to measure the students' understanding and application of geometric concepts. Additionally, a questionnaire was distributed to collect the students' perceptions of usability and engagement. The results of this study indicate a significant difference in performance scores between students using the GeoFormeAR mobile application and those learning geometry using traditional methods. Moreover, the questionnaire results reveal positive student perceptions regarding the usability and engagement of the GeoFormeAR mobile application. In conclusion, this study aims to broaden the scope of future vision on the conceptions and adoption of AR in mathematics teaching and learning.

KEYWORDS

augmented reality (AR), geometry learning, mobile learning, interactive technologies, mathematics education, 3D visualization

Zekeik, H., Mouali, S., Sefian, M. L., Khalfouni, M. (2025). Enhancing Geometry Learning with Mobile Augmented Reality: Evaluating the GeoFormeAR Application in Middle School Education. *International Journal of Interactive Mobile Technologies (IJIM)*, 19(20), pp. 113–131. <https://doi.org/10.3991/ijim.v19i20.56381>

Article submitted 2025-05-02. Revision uploaded 2025-07-29. Final acceptance 2025-08-11.

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1 INTRODUCTION

Augmented reality (AR) can be considered as a new opportunity and innovation that has the potential to enrich real space with fictive 3D and 2D objects [1], [2], [3]. Owing to its benefits, integrating this innovative technology into the educational system is crucial for a successful learning and teaching process. It can renew the teaching of mathematics lessons and provide other advantages to support educational purposes [4], [5].

In recent times, educational systems worldwide have focused on investigating and developing innovative methodologies to enhance students' competencies and capabilities. These approaches encompass adaptations to learning, the individualization of education, and immersive learning, founded upon virtual, augmented, and mixed realities, in addition to the metaverse and artificial intelligence (AI) [6]. Furthermore, the integration of gamification with AR proves a practical pedagogical approach to facilitating the comprehension of complex concepts, such as those encountered in mathematics, while simultaneously enhancing the learning environment [1], [6], [7].

STEM (Science, Technology, Engineering, and Mathematics) education provides a flexible framework for integrating advanced technological fields across various educational levels, preparing students for a diverse range of future careers [8]. Mathematics, as a core STEM discipline, plays a crucial role in this framework. This underscores the importance of innovative educational tools, such as AR applications, that can effectively support mathematics learning, particularly in complex topics like geometry, throughout various stages of schooling.

This study aims to develop and test our mobile application, GeoFormeAR, for the lesson "Cylinder and Prism," which was designed for first-year middle school students in the Moroccan education system. Second, at the end of the course, we will administer a post-test to collect scores on the acquisition of geometric concepts in the two classes, which have completed their sessions using both the AR and classical approaches. Finally, to conclude the global perception of the effect of integrating AR apps for teaching and learning mathematics concepts compared to the traditional method, we applied quantitative statistical analysis to the data obtained from the post-test results of the two groups, and we compared the results using descriptive and T-test statistical methods. The questionnaire responses were also analyzed using descriptive analysis to assess students' perceptions of the application's usability and engagement. The findings provide a comprehensive understanding of AR's potential to enhance student learning, engagement, and motivation in geometry.

2 LITERATURE REVIEW

The adoption of technological tools across various domains has grown significantly over the last few decades. In particular, AR technology has a significant impact on numerous sectors, including healthcare, entertainment, and education [9], [10]. In education, AR technology offers several benefits, including extensive application across various media, usability in real-life scenarios, enhanced interactivity, simplified object modelling due to specialization in rendering limited objects, lower production costs, and ease of use [8]. Moreover, AR in education offers more engagement, experiential learning, personalization, collaboration, creativity, and a bridge between practice and theory, thus revolutionizing traditional modes of teaching [11], [12].

AR seamlessly integrates digital content with the real world, enabling users to interact with physical objects and people while engaging with virtual elements, thereby enhancing their perception of reality [11], [13], [14]. The quality of traditional modes of learning has been questioned, as inappropriate learning methods and the

underutilization of learning media contribute to the decline in education quality [8]. To overcome these challenges and enhance students' learning experience, the effective incorporation of learning media, such as AR technology, is crucial [9], [15]. Integrating AR into learning activities, particularly within academic subjects, holds promise for providing a more comprehensive explanation of the content and for presenting information in a lifelike virtual 3D format [9], [16].

Recent research highlights the critical role of integrating advanced technologies, such as AR, to create smart, accessible, and flexible learning environments that support diverse educational needs, including those in resource-constrained and remote settings [17]. These innovations align with the goals of STEM education to prepare students for future careers across multiple disciplines by providing interactive, technology-enhanced tools tailored to different educational levels.

Mathematics is a curriculum subject at every level of education, from primary school to university. Mathematics learning typically utilizes traditional tools, such as paper, pencils, chalkboards, or whiteboards. However, this traditional method often falls short of effectively visualizing and simulating mathematical concepts. As technology continues to evolve, there is increasing awareness and acknowledgment of AR's potential to improve mathematics learning experiences [18], [19]. AR is proving to be an effective pedagogical tool, offering new ways to engage students and deepen their understanding of abstract mathematical concepts at various educational levels [20], [21], [22].

Recent studies have demonstrated that the use of AR in mathematics teaching has yielded positive results. These include enhancing interactive learning environments and increasing academic performance, engagement, enjoyment, visualization skills, understanding, cooperation, and teamwork [23]. Additionally, the use of AR in mathematics learning has been found to facilitate the abstraction of mathematical concepts, leading to improved spatial ability among students [20].

AR has vast prospects and opportunities for students to engage with 3D models in authentic mathematical environments. Recent research [23] has identified an increasing number of applications of AR technology, particularly in geometry instruction and the study of complex mathematical concepts. According to this study, the integration of AR has been successful, as evidenced by improved learning performance and students' more positive attitudes toward mathematics. AR is especially helpful in enriching the instruction on solid geometry and other geometric abstractions, allowing for more practical and interactive learning experiences for students.

A systematic review [24] was conducted to provide a clear overview of research on AR in mathematics education over the last decade. By analyzing the content of 60 articles published from 2012 to 2021, the authors identified that incorporating AR applications into mathematics instruction has a positive influence on academic performance and teaching processes. In addition, AR applications have a positive impact on students' attitudes toward mathematics, enhance their motivation in mathematics lessons, and improve their three-dimensional thinking skills.

Numerous studies have investigated the effectiveness of AR applications in mathematics education, mostly in geometry teaching. One study [6] explored the impact of AR applications in geometry education on academic achievement, self-regulated learning skills (SRLS), and motivation for secondary school students. Their qualitative findings demonstrated that the AR application is engaging and enjoyable for students, resulting in improved academic performance and increased active participation in the classroom.

Similarly, several mobile AR applications have been designed to enhance students' learning of geometry. An AR Geometry application was developed for sixth-grade students, who received positive user feedback [7]. The AR Geometry Tutorial System (ARGTS) was developed to enhance students' 3D geometric thinking skills [25].

In addition, an AR application was developed to enhance the spatial abilities of junior high school students [26]. The study concluded that the application was practical for learning mathematics, enabling teachers and students to engage with solid geometric concepts in an interactive, real-time manner. They were able to manipulate and measure objects in the AR environment. Another strong example is the GeoGebra tool, which offers dynamic manipulation of geometric shapes and is well suited for advanced exploration [27], [28]. Nevertheless, these tools are often not explicitly designed for guided classroom instruction at the middle school level and may require continuous internet connectivity, which limits their applicability in rural or underserved regions. Additionally, some students, particularly those with limited technological familiarity and expertise, may find these tools less accessible because of their complexity or lack of instructional scaffolding.

In contrast, GeoFormeAR was developed as a mobile AR application specifically designed to support curriculum-aligned geometry instruction in middle schools, focusing on real-time 3D visualization, offline use, and an intuitive interface suited for students with varying levels of digital experience, which ensures broad usability. By addressing these practical and pedagogical gaps, the GeoFormeAR mobile app aims to enhance spatial understanding in well-connected and resource-constrained learning environments. Its ability to function entirely offline ensures accessibility in contexts with limited or no internet infrastructure.

3 PURPOSE OF THE RESEARCH

GeoFormeAR uses AR technology in innovative ways to teach geometry and spatial geometry. Given the limited research on the benefits of AR in mathematics education, particularly in spatial geometry, GeoFormeAR fills this gap as a specialized teaching tool. Abstract Geometry concepts, especially those involving spatial relationships, are traditionally challenging to teach using conventional methods alone. GeoFormeAR enhances student engagement by allowing direct interactions with 3D geometric shapes. Based on a comprehensive literature review of the educational benefits of AR, GeoFormeAR introduces a new pedagogical approach and serves as a practical tool for educators and learners. By leveraging the modern capabilities of AR and user-friendly design principles, this application aims to enhance the understanding and application of geometry in both theoretical and practical contexts, potentially revolutionizing mathematics education.

This study aims to answer several essential questions:

- How is AR integrated into educational settings, particularly in mathematics?
- How does GeoFormeAR improve students' understanding of spatial geometry compared with conventional teaching methods?
- How do the post-test results reflect GeoFormeAR's effectiveness in improving the understanding and application of geometric concepts?
- What are the students' perceptions of the usability and engagement of the GeoFormeAR mobile application?

4 MATERIALS AND METHODS

This section outlines the study model, study group, data collection methods, application processes, and data analysis techniques, providing comprehensive explanations for each component.

4.1 Research model

This study employed a mixed-methods approach that combines quantitative and qualitative methodologies. This study also used the ADDIE model (Analyze, Design, Develop, Implement, and Evaluate) [29]. The ADDIE model provides a structured approach for the design, development, implementation, and evaluation of GeoFormeAR applications.

4.2 ADDIE model implementation

Each phase of the ADDIE model was carefully followed to ensure the development and evaluation of the GeoFormeAR application. Referencing Figure 1 for the detailed phases of the ADDIE model helps to illustrate the systematic approach taken in the development process.

Identifying specific geometric concepts under the needs assessment involved collecting requirements from educators and students during the analytical phase.

The design phase involved the creation of wireframes and mock-ups that visualized the interface and functionalities of the application.

Development was performed in Unity 3D and Vuforia SDK to integrate marker detection and 3D geometry rendering features. Using Tinkercad, 3D models of specific geometric forms were imported into the program. This application was developed for testing and educational purposes.

Finally, an evaluation stage was conducted after the development process using the ADDIE model. The purpose of this stage was to assess the quality of the learning products and processes, both before and after implementation [29]. Evaluation was conducted before implementation during the analysis, design, development, and implementation stages to refine and improve the application based on feedback and testing. Following the implementation, a post-test was conducted to gauge the material’s mastery level and the effectiveness of the application in enhancing learning outcomes.

The diagram in Figure 1 illustrates the ADDIE steps [29].

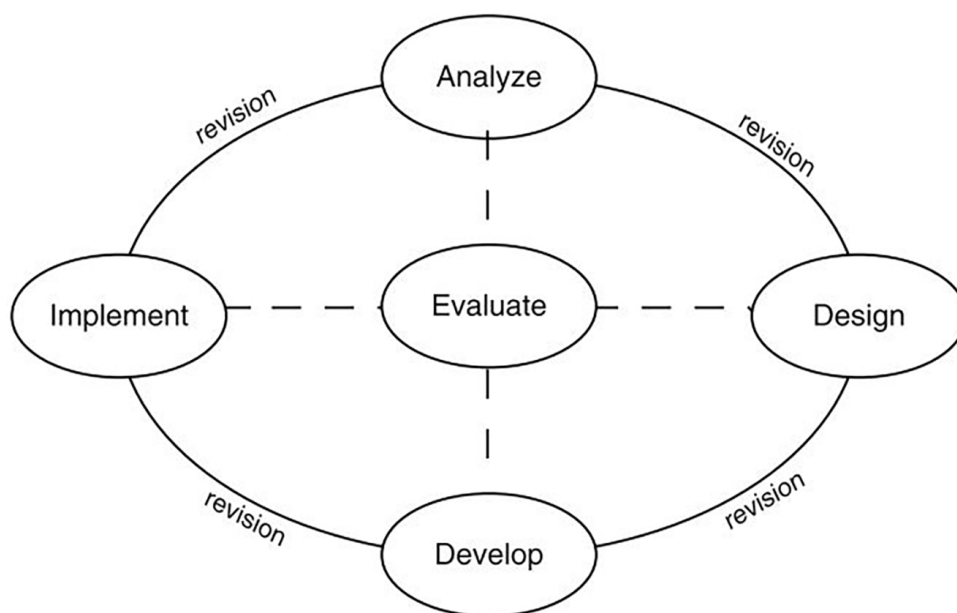


Fig. 1. The ADDIE steps

4.3 System description of GeoFormeAR

GeoFormeAR is a mobile AR application that focuses on geometry, particularly in a 3D space. It offers users the possibility of visualizing 3D shapes interactively and attractively. With GeoFormeAR, students can explore geometric figures in new and engaging ways, interact with them to enhance their understanding, and enjoy an immersive and playful experience. Each marker in the application is associated with a 3D geometry such as a cube, cuboid, cylinder, sphere, pentahedron, or heptahedron. Marker detection involves two methods: the one-marker method and the multiple-marker method [9]. The GeoFormeAR application utilized in this study is based on a one-marker method for marker detection. This method is constrained to the detection and presentation of only one object or image per marker.

Below is a detailed description of the user interface components and their functionalities:

- Main Menu: Upon launching the application, users are greeted with a main menu containing four buttons:
- Start AR (Démarrer): Directs the user to the camera interface to scan the marker and display the 3D shape. This screen also includes a “Back to Main Menu” button.
- How It Works (Comment ça marche): Provides a guide on how to use the application, explaining the steps to scan markers and interact with 3D shapes.
- Print Markers (Imprimer les marqueurs): Allows users to print the markers required for scanning and visualizing the 3D shapes.
- Quit (Quitter): Closing the application.

4.4 Participants

The experiment was conducted with two first-year middle school classes in a public school in Tangier, Morocco. The first group, comprising 50 students, received instructions through an AR application. In contrast, the traditional method (TR) group comprised 31 students.

In the analysis and interpretation paragraphs, “TR” refers to the group that learned through the traditional method, while “AR” refers to the group that learned with the GeoFormeAR application. “Score Tr” and “Score Ar” also represent the score data of the two groups extracted from the post-test.

4.5 Group selection and sampling procedure

The study employed a quasi-experimental design involving two intact middle-school classes from the same school, grade, and teacher. Students were assigned non-randomly to either the AR group, which used the GeoFormeAR application, or the TR group, which received traditional instructions. Classes were selected through convenience sampling based on accessibility and willingness to participate, with efforts to ensure comparable demographic and academic characteristics to reduce instructional and environmental variability. Although random assignment was not feasible, this method offered a practical and realistic context for assessing the educational impact of the GeoFormeAR intervention.

4.6 Group equivalence and pre-learning conditions

Although a formal pretest was not conducted, several steps were taken to guarantee equivalence of the groups before the intervention. Both classes followed the same national mathematics curriculum and demonstrated academic performance comparable to that of the previous semesters. Importantly, none of the groups had prior exposure to geometric concepts through AR or similar technologies. The mathematics teacher who conducted the experiment confirmed the similarities in prior knowledge and engagement levels through classroom observations and performance records. These measures supported the assumption of group homogeneity.

4.7 GeoFormeAR mobile application in use

Using GeoFormeAR unlocks a dynamic experience in geometry education. Clicking on the first button in the main menu of GeoFormeAR activates the AR mode, where the camera is activated to detect markers, as shown in the use case presented in Figure 2. The application's screens are displayed in Figure 3.

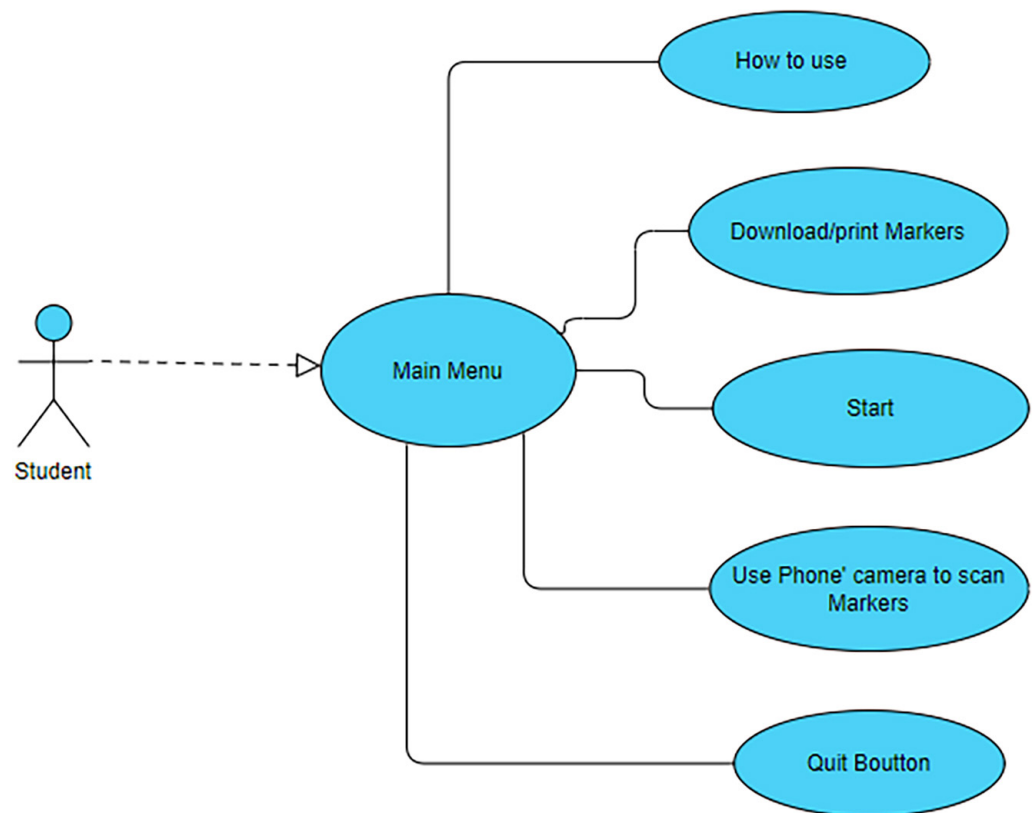


Fig. 2. Use case diagram

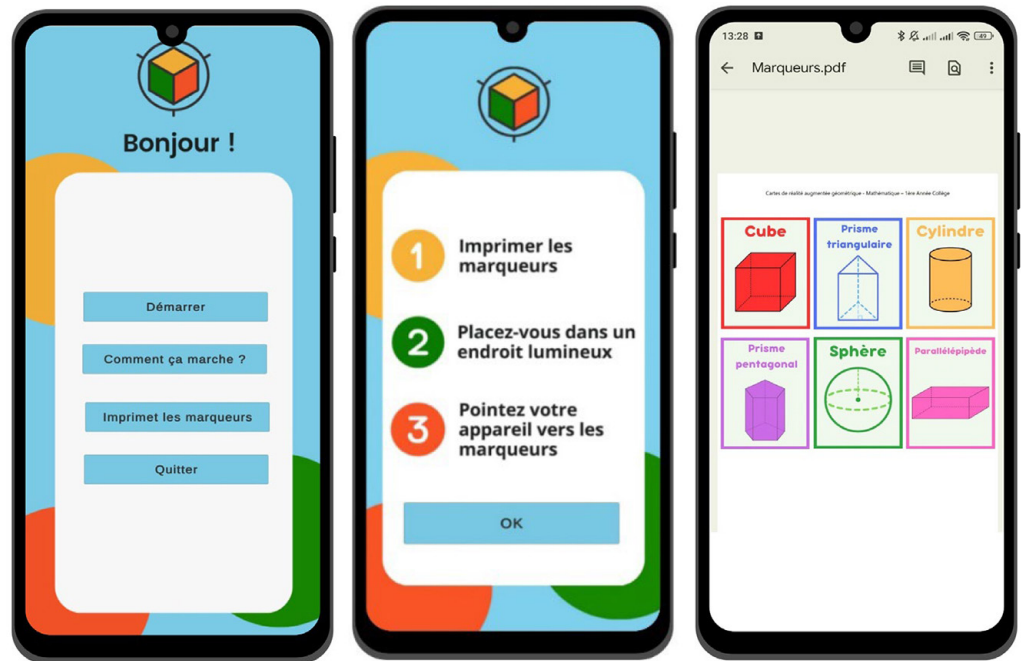


Fig. 3. GeoFormeAR mobile application interfaces for geometry learning: user interaction and features

This mode seamlessly integrates 3D geometric shapes into the user environment, thereby enhancing the visual learning. Each marker is displayed and corresponds to a specific 3D model, such as cubes, cuboids, cylinders, spheres, pentahedra, or heptahedra. When the student scans each marker, the corresponding 3D model appears, allowing them to rotate it, view its pattern, and change the color of each face, as shown in Figure 4. Developed using cutting-edge tools and Unity's latest features, GeoFormeAR is specifically designed to teach geometry in a visually engaging and informative manner to students. Feedback from education professionals and students will guide future enhancements and applications of educational AR technology.



Fig. 4. Display of 3D visualization and interactivity using the GeoFormeAR mobile application

4.8 Data collection

The data were collected from the post-test scores, and the structured questionnaire was distributed to the learners at the end of the lesson.

Quantitative and Qualitative Data. Quantitative data were collected using a post-test to assess the geometric proficiency of students across multiple groups. Each group was assigned to a specific learning method. One group learned geometry through traditional methods (TR), while another utilized the GeoFormeAR application (AR). The test evaluated multiple aspects of geometric understanding:

- Identifying the characteristics of right prisms
- Acquiring information about geometric solids
- Recognizing different types of prisms
- Assessing spatial reasoning by asking students to visualize and manipulate 3D shapes

In addition, a structured questionnaire consisting of 8 Likert-scale items (scored from 1 to 5), one “Yes/No” question, and one open-ended question was administered to 50 middle school students in the AR experimental group after they had used the GeoFormeAR mobile application. Before administration, the questionnaire was reviewed by educational technology experts to ensure content validity and practical applicability.

The questionnaire items were thematically grouped into four main categories: Usability, Learning Effectiveness, Engagement and Satisfaction, and Comparative Evaluation. As shown in Table 1, each category reflects a specific dimension of the learners’ interaction with the GeoFormeAR mobile application, from technical ease to educational value.

Table 1. Categorization of questionnaire items by main category, subcategory, and focus

Main Category	Sub-Category (Item)	Focus
1. Usability	Q1 – Navigation Ease	Ease of navigating through the app interface
	Q2 – Interface Design	Clarity, aesthetics, and usability of the design
	Q3 – Technical Stability	Stability and absence of bugs or interruptions
2. Learning Effectiveness	Q4 – Conceptual Understanding	Improvement in understanding 3D geometric concepts
	Q5 – Information Retention	Ability to remember and apply learned geometric concepts
3. Engagement & Satisfaction	Q6 – Engagement Level	Enjoyment and immersion during learning with the app
	Q7 – Satisfaction Level	Willingness to continue or repeat the learning experience
4. Comparative Evaluation	Q8 – Comparison	Comparison to traditional learning

4.9 Data analysis and interpretation procedure

The data from the post-test and the qualitative questionnaire were analyzed using the IBM SPSS tool (version 26.0), employing descriptive statistics and a

t-test approach. Finally, the findings obtained from all the analysis procedures were interpreted in the subsequent paragraphs to conclude the results and provide an overall perception of the integration in the generalization of AR application use in the mathematics teaching process.

4.10 Ethics considerations

The study targeted minors in an educational setting, and all the respondents voluntarily participated in this study. Before data collection, written informed consent was obtained from the legal guardians of all the participating students. Additionally, assent was obtained from the students themselves.

No identifying information, including name, image, video, or personal data, was collected or disclosed. All responses and data were anonymized and used for research purposes. The anonymity and confidentiality of all participants were preserved throughout the study.

5 RESULTS

The data from the post-test results and questionnaire were analyzed using IBM SPSS software and statistical quantitative methods. The analysis commenced with descriptive statistics, as illustrated in the histograms of Score Tr and Score AR in Figure 5.

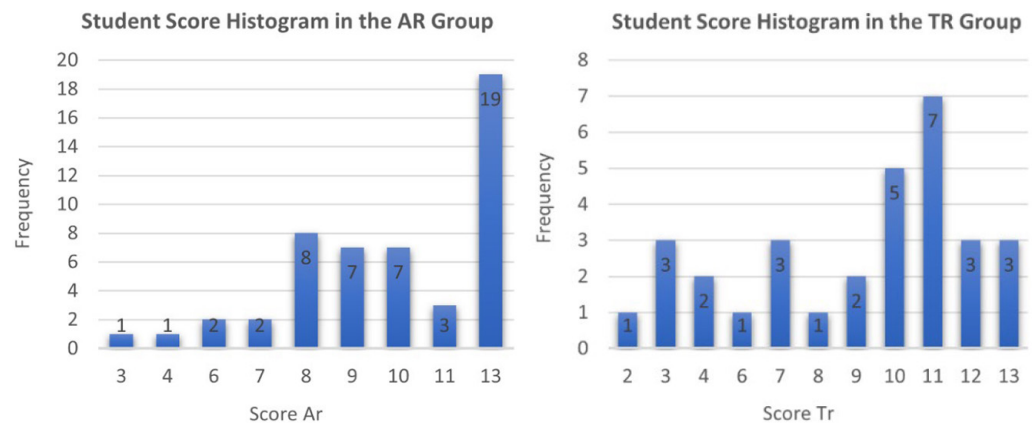


Fig. 5. Comparative analysis of score distributions: Score Ar (left chart) and Score Tr (right chart)

In addition to the study groups, as presented in Table 2.

Table 2. Statistical comparison results between the TR and AR groups

Group Statistics					
	Grp.	N	Mean	Std. Deviation	Std. Error Mean
Score	TR	31	8.84	3.35	0.60
	AR	50	10.20	2.66	0.38

The subsequent interpretations are as follows:

- The mean of the AR group was superior to that of the TR group ($10.20 > 8.84$) because the AR scores were superior to the TR scores.
- The TR group was more dispersed than the AR group because of the difference between the Std. Deviation ($3.35 > 2.66$).
- The mean estimation of the AR group appeared more precise than that of the TR group because of the comparison between their values of the standard error mean ($0.38 < 0.60$).

The descriptive statistical analysis results indicated that the AR group had a higher mean score and lower standard deviation than the TR group. The minor standard error of the mean for the AR group also suggested a more precise estimation of the mean for this group. To gain further insight, performing a significance test (such as a t-test) would be beneficial to determine whether the difference between the means of the two groups is statistically significant.

In the next step, we will apply the t-test to the independent samples, as presented in Table 3, to compare the scores of the two groups, AR and TR.

Table 3. Results of the independent samples t-test for comparison of mean scores between the AR and TR groups

Independent Samples Test										
	Levene's Test for Equality of Variances			t-Test for Equality of Means						
	F	Sig.	t	Df	Sig. (2-Tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference		
								Lower	Upper	
Score	Equal variances assumed	2.49	0.12	-2.03	79	0.04	-1.36	.67	-2.70	-0.02
	Equal variances not assumed			-1.92	53	0.06	-1.36	.71	-2.78	0.06

The results of this t-test indicate the following conclusions:

- The Levene test indicates that the p-value is more significant than 0.05 ($0.12 > 0.05$), thereby rejecting the null hypothesis of equality of variances. Consequently, it can be assumed that the variances of the two groups were equal in the t-test analysis.
- The t-test for equality of means indicated that the p-value was less than 0.05 ($0.04 < 0.05$), thereby rejecting the null hypothesis that the means of the two groups were equal. This indicated a statistically significant difference between the means of the TR and AR groups.

Moreover, we can conclude with the following final interpretations:

- The hypothesis of equality of variance was assumed, and a significant difference was found between the means of the TR and AR groups.
- The data did not support the Equality of Variances Non-Assumption hypothesis, as no significant difference was found between the mean scores of the TR and AR groups.

In the absence of evidence to the contrary (i.e., a significant result from the Levene test), it is reasonable to rely on the initial hypothesis of equal variances, which indicates a statistically significant difference between the two group means.

The 95% confidence interval for the mean difference (-1.36) ranged from -2.70 to -0.02 , indicating a reliable difference under the assumption of equal variances.

Cohen's d was used to assess the practical significance of the observed effect. The resulting value of 0.46 indicates a moderate effect size, which is based on conventional benchmarks ($0.20 = \text{small}$, $0.50 = \text{moderate}$, $0.80 = \text{large}$). This suggests that the AR intervention had a meaningful impact on student learning outcomes.

Following the analysis of the post-test results, this section presents the findings from the student questionnaire, which aimed to capture the learners' overall perceptions of their experience with the GeoFormeAR mobile application.

The analysis of the questionnaire began with descriptive statistics to summarize the user responses. Table 4 presents the descriptive statistics (mean, mode, and standard deviation) for each item in the questionnaire, grouped into four thematic categories: Usability, Learning Effectiveness, Engagement & Satisfaction, and Comparative Evaluation.

Table 4. Descriptive statistics of questionnaire items grouped by four categories

Category	Subcategory	Mean	Mode	Standard Deviation	Category Mean	Category Standard Deviation
Usability	Q1	4.46	5	0.67	4.63	0.70
	Q2	4.66	5	0.47		
	Q3	4.76	5	0.95		
Learning Effectiveness	Q4	4.70	5	0.50	4.67	0.49
	Q5	4.64	5	0.48		
Engagement & Satisfaction	Q6	4.82	5	0.38	4.77	0.42
	Q7	4.72	5	0.45		
Comparative Evaluation	Q8	4.64	5	0.48	–	–

The descriptive analysis of the questionnaire responses, presented in Table 4 and grouped into four main categories, generally showed high levels of satisfaction and effectiveness associated with the GeoFormeAR mobile application. The usability category, which evaluated ease of navigation, interface design, and technical reliability, revealed a high mean score of 4.63 with a standard deviation of 0.70 , indicating that students found the mobile device application intuitive and accessible.

In the learning effectiveness category, which focused on conceptual understanding and information retention, the results were similarly positive, with a mean of 4.67 and a standard deviation of 0.49 , demonstrating the application's strong support for cognitive learning outcomes.

The engagement and satisfaction category yielded the highest overall scores, with a mean of 4.77 and a standard deviation of 0.42 , confirming that learners found the experience highly engaging and satisfying. Finally, the comparison evaluation item assessed how the GeoFormeAR mobile application compared to traditional learning methods, receiving a mean score of 4.64 and a standard deviation of 0.48 , suggesting a strong preference for the interactive and immersive learning environment provided by GeoFormeAR. In general, the low standard deviation values across categories highlight the consistency of positive responses among the participants.

Notably, the mode value for each of the four categories was 5, indicating that the most frequently selected response by students reflected the highest level of agreement, which reinforces the positive perception and consistent satisfaction with the GeoFormeAR mobile application.

Following the analysis of the Likert-scale items, the next section presents the results and interpretation of the “Yes/No” question. Table 5 displays the frequency and percentage distribution of student responses regarding their willingness to recommend the GeoFormeAR application. These results are visually supported by the bar chart shown in Figure 6.

Table 5. Frequency and percentage of students’ responses to the recommendation question

Recommendations					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	No	1	2.0	2.0	2.0
	Yes	49	98.0	98.0	100.0
	Total	50	100.0	100.0	

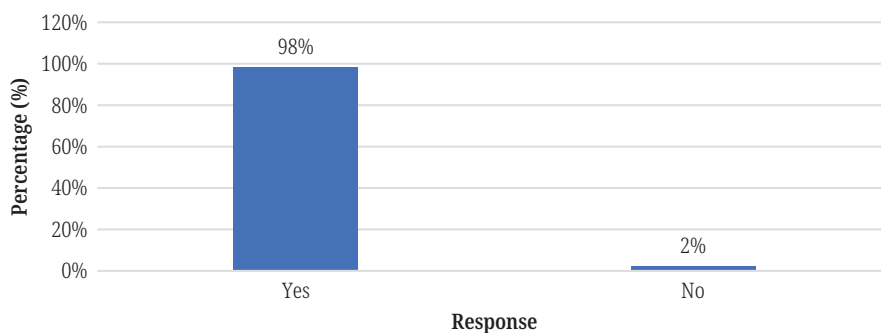


Fig. 6. Bar chart of the percentage of students willing to recommend the GeoFormeAR mobile application

Based on Table 5 and Figure 6, out of 50 students, 98% responded ‘Yes’ to recommending the GeoFormeAR application to others, while only 2% responded negatively. This indicates a high level of user satisfaction and perceived usefulness, which also aligns with the high satisfaction mean of 4.72 on the satisfaction scale, suggesting that the GeoFormeAR app can be effectively generalized for use among similar middle school student populations.

Following the analysis of the “Yes/No” question, open-ended responses were examined to identify additional feature suggestions and user expectations for future versions of the GeoFormeAR mobile application.

The analysis of the open-ended questions revealed that students suggested enhancements, including audio explanations, interactive quizzes, improved customization options, and the inclusion of language support such as Arabic or English. It is important to note that GeoFormeAR already integrates key features, including dynamic explanatory animations for each geometric shape and color customization capabilities. Interestingly, as already mentioned, some students suggested adding support for the Arabic and English languages, which is an excellent recommendation that should be considered for future versions, as it enhances accessibility and promotes inclusivity for diverse learners. These suggestions demonstrate a high level of user engagement and confirm the relevance of existing features while also providing constructive insights for future enhancements that build upon the strong foundation of the current version.

Based on these results, it can be concluded that the GeoFormeAR mobile application successfully met students' expectations by providing an engaging and educational experience, as reflected in the high satisfaction rates and positive feedback. The overwhelming affirmative responses and constructive suggestions confirm its effectiveness and highlight areas for enhancement. These results emphasize the application's strong potential to support inclusive and accessible learning in geometric education.

6 DISCUSSION

The results of this study demonstrate a significant difference in performance between students using the GeoFormeAR application and those learning geometry using traditional methods. Specifically, the AR group utilizing GeoFormeAR achieved a higher mean score of 10.20 than the TR group's mean score of 8.84. The minor standard deviation in the AR group suggested that the scores were more consistent among these students, further indicating the effectiveness of the AR application in providing a uniform learning experience. The lower standard error in the AR group also indicates that the mean estimate was more precise, supporting the reliability of these findings.

The greater performance noted in the AR group can be attributed to several characteristics unique to the GeoFormeAR mobile application. AR interactivity with 3D visualization of geometric concepts can be assumed to contribute to deepening students' understanding and retention of their learning material. An immersive environment enhanced learners' engagement and, in turn, improved their academic outcomes. This study affirms the worldwide trend of integrating AR into the educational system, particularly in mathematics. In general, AR applications in education demonstrate that this technology enables learning and stimulates student interest by integrating educational and entertainment objectives. This combination goes a long way toward classroom management and engendering a more positive and motivated learning environment.

In addition to the post-test results, the questionnaire provided valuable insights into the students' perceptions of the GeoFormeAR mobile application. The high mean scores and low standard deviations across the four categories (usability, learning effectiveness, engagement and satisfaction, and comparison evaluation) demonstrate strong user approval and alignment with pedagogical objectives. Moreover, the 98% positive response rate to the recommendation question further reinforced the acceptability of the application among middle school learners. Open-ended feedback suggests the integration of additional features such as audio explanations and language support, reflecting an important interest in further personalization and accessibility. These findings confirm the educational value of the GeoFormeAR mobile application and suggest pathways for iterative improvement.

The outcomes of this study are consistent with those of earlier investigations of the effectiveness of AR in education. For example, researchers have demonstrated that the use of AR apps in geometry instruction enhances academic performance, self-regulated learning strategies (SRLS), and student motivation in secondary school students [6]. Similarly, AR applications have also had a favorable impact on geometry learning and 3D thinking skills [7], [25]. The findings of this study are supported by additional studies that noted the significant improvement of junior high school students' spatial skills by AR [30], [31].

Additionally, the gamification aspect of AR, which combines learning with fun and interactive experiences, is becoming increasingly recommended for the new

generation of students. In this way, knowledge acquisition is enhanced, and a positive and motivated classroom environment is created. The positive student feedback in this study reinforces the idea that AR is best suited for motivation and engagement.

The findings of this study support key priorities outlined in international digital education frameworks such as the European Framework for the Digital Competence of Educators (DigCompEdu) and the Digital Education Action Plan 2021–2027. These frameworks emphasize the integration of innovative technologies, such as AR, to enhance learning experiences, promote equitable access to digital tools in resource-constrained settings, and foster digital competencies among educators and learners. By demonstrating the effectiveness of the GeoFormeAR mobile application in middle school geometry education, this study provides practical evidence aligned with these policy goals, contributing to scalable and inclusive STEM education strategies worldwide.

Moreover, these insights are particularly valuable for the Global South and low-resource contexts, where scalable, mobile-based AR tools like GeoFormeAR can help bridge gaps in infrastructure and promote equitable access to quality STEM education.

The evidence presented tomorrow from the results of this study will contribute to the growing literature on ARs in education, particularly in supporting geometry learning. The performance of students' academic learning was improved through the GeoFormeAR mobile app. This implies that AR has the potential to modernize and improve mathematics teaching and learning.

Building on these findings, promoting the scalable and sustainable adoption of AR in education requires integrating AR tools within broader curricular frameworks rather than treating them as isolated interventions. Embedding AR activities across multiple subjects and grade levels can create a cohesive learning experience that progressively reinforces key concepts, fostering a deeper understanding of the material. Equally important is providing comprehensive professional development for educators, equipping them to incorporate AR technologies effectively into their teaching practices. Such training should address not only technical proficiency but also pedagogical strategies to engage diverse learners and align AR content with curricular goals. Ongoing support, including coaching and resource sharing, will further enhance the sustainability of AR integration, fostering long-term improvements in teaching and learning.

While this study provides evidence of the GeoFormeAR application's positive impact on middle school students' geometry learning, motivation, and engagement, it focused on short-term outcomes within a classroom context. Long-term retention of knowledge and the transferability of acquired skills to other mathematical domains or real-life problem-solving remain critical areas for further investigation. Future research could adopt longitudinal designs to explore whether the benefits of mobile AR persist over time and extend to broader STEM competencies, thereby informing more sustainable integration of AR technologies into curricula.

7 LIMITATIONS

This study has several limitations. While the results are promising, the modest sample size limits the generalizability of the findings. The lack of a pre-test prevents measurement of learning gains relative to baseline knowledge. Additionally, the quasi-experimental design and non-random sampling may have introduced confounding variables affecting group equivalence.

8 CONCLUSION

The rapid development of technology in domains such as augmented reality, virtual reality, and gamification of learning presents both opportunities and challenges for incorporating these technologies into educational practices. In the current study, we compared two approaches to learning 3D polyhedra: AR and traditional methods. We also examined the recommendation scores of AR games or applications in math lessons. Following the ADDIE model steps, we rolled out our GeoFormeAR learning mobile application for math classes to teach 3D polyhedra in two classes and conducted a test. Our findings indicate that the GeoFormeAR mobile application proved more effective than traditional learning methods, with most students enjoying learning 3D geometry through the app and appreciating the new interaction it brought to their math classes. Moreover, it is crucial to acknowledge the challenges of familiarizing learners with tablets or phones and, consequently, AR tools. These challenges can result in significant time and concentration losses during the learning process. To address this, conducting pre-sessions in collaboration with informatics teachers to cover fundamental informatics concepts and ensure familiarity with the relevant technological tools is recommended.

Looking ahead, integrating AR games or applications into the Moroccan educational system is essential, as it could meet the evolving needs of younger learners, enabling them to learn through innovative methods and fostering creativity. Furthermore, the findings of this study have relevance beyond the Moroccan context, contributing valuable evidence to global discussions on the integration of AR in STEM education.

Future work will focus on developing virtual and mixed-reality educational tools for teaching mathematics and other subjects. Accordingly, the GeoFormeAR mobile application will be refined and tested further in future studies.

9 REFERENCES

- [1] S. Mouali, M. L. Sefian, and I. Bakkali, "Augmented and virtual reality for mathematics education," in *Technological Tools for Innovative Teaching*, Mohamed Khaldi, Ed., IGI Global Scientific Publishing, 2024, pp. 179–198. <https://doi.org/10.4018/979-8-3693-3132-3.ch010>
- [2] D. Rohendi and Y. Wihardi, "Learning three-dimensional shapes in geometry using mobile-based augmented reality," *International Journal of Interactive Mobile Technologies*, vol. 14, no. 9, pp. 48–60, 2020. <https://doi.org/10.3991/ijim.v14i09.13035>
- [3] A. Palancı and Z. Turan, "How does the use of the augmented reality technology in mathematics education affect learning processes? A systematic review," *Uluslararası Eğitim Programları ve Öğretim Çalışmaları Dergisi*, vol. 11, no. 1, pp. 89–110, 2021. <https://doi.org/10.31704/ijocis.2021.005>
- [4] S. Mouali, M. L. Sefian, I. Bakkali, W. El Alem, and A. L. Hemdanou, "Comparing distance assessment to face-to-face approach: Case of LE-Maths in Tetouan's higher normal school," *International Journal of Religion*, vol. 5, no. 11, pp. 2117–2126, 2024. <https://doi.org/10.61707/On1yqp12>
- [5] J. Jibril and H. Çakır, "Students' opinions on the usage of mobile augmented reality application in health education," *Journal of Learning and Teaching in Digital Age*, vol. 8, no. 1, pp. 10–24, 2023. <https://doi.org/10.53850/joltida.1076286>

- [6] G. Cetintav and R. Yilmaz, "The effect of augmented reality technology on middle school students' mathematic academic achievement, self-regulated learning skills, and motivation," *Journal of Educational Computing Research*, vol. 61, no. 7, pp. 1483–1504, 2023. <https://doi.org/10.1177/07356331231176022>
- [7] H. Pradibta, O. D. Triswidrananta, and M. R. Jannah, "The implementation of augmented reality in geometry for primary school students," *Journal of Computing Research and Innovation*, vol. 8, no. 1, pp. 45–57, 2023. <https://doi.org/10.24191/jcrinn.v8i1.341>
- [8] S. Papadakis *et al.*, "Revolutionizing education: Using computer simulation and cloud-based smart technology to facilitate successful open learning," in *Joint Proceedings of the 10th Illia O. Teplytskyi Workshop on Computer Simulation in Education and the Workshop on Cloud-Based Smart Technologies for Open Education (CoSinEi and CSTOE 2022)*, co-located with the *ACNS Conference on Cloud and Immersive Technologies in Education (CITEd 2022)*, S. Papadakis, Ed., Kyiv, Ukraine, vol. 3358, 2022, pp. 1–18. [Online]. Available: <https://ceur-ws.org/Vol-3358/paper00.pdf>
- [9] A. R. Pratama and Sukirman, "Development of augmented reality multiple markers application used for interactive learning media," *Sinkron*, vol. 8, no. 3, pp. 1326–1334, 2023. <https://doi.org/10.33395/sinkron.v8i3.12482>
- [10] M. Tezer, E. P. Yildiz, A. R. Masalimova, A. M. Fatkhutdinova, M. R. Zheltukhina, and E. R. Khairullina, "Trends of augmented reality applications and research throughout the world: Meta-analysis of theses, articles and papers between 2001–2019 years," *International Journal of Emerging Technologies in Learning*, vol. 14, no. 22, pp. 154–174, 2019. <https://doi.org/10.3991/ijet.v14i22.11768>
- [11] S. M. Shaukat, "Exploring the potential of augmented reality (AR) and virtual reality (VR) in education," *International Journal of Advanced Research in Science, Communication and Technology*, vol. 3, no. 2, pp. 52–57, 2023. <https://doi.org/10.48175/IJAR SCT-12108>
- [12] O. Elmira, B. Rauan, B. Dinara, and B. P. Etemi, "The effect of augmented reality technology on the performance of university students," *International Journal of Emerging Technologies in Learning*, vol. 17, no. 19, pp. 33–45, 2022. <https://doi.org/10.3991/ijet.v17i19.32179>
- [13] R. Shi, "Integrating computer vision and AI for interactive augmented reality experiences in new media," *Applied and Computational Engineering*, vol. 102, no. 1, pp. 49–54, 2024. <https://doi.org/10.54254/2755-2721/102/20241002>
- [14] M. B. Ibáñez and C. Delgado-Kloos, "Augmented reality for STEM learning: A systematic review," *Computers & Education*, vol. 123, pp. 109–123, 2018. <https://doi.org/10.1016/j.compedu.2018.05.002>
- [15] W. Deng, L. Wang, and X. Deng, "Exploring interactive learning environments based on augmented reality technology," *International Journal of Interactive Mobile Technologies*, vol. 18, no. 12, pp. 15–29, 2024. <https://doi.org/10.3991/ijim.v18i12.49911>
- [16] J. Guncaga, L. Korenova, and E. Severini, "Enhancing STEAM education with AR: A primary education teacher training study," *Proceedings of the 23rd European Conference on e-Learning – (ECEL 2024)*, vol. 23, no. 1, pp. 114–121, 2024. <https://doi.org/10.34190/ecel.23.1.2692>
- [17] S. Papadakis *et al.*, "Unlocking the power of synergy: The joint force of cloud technologies and augmented reality in education," in *Joint Proceedings of the 10th Workshop on Cloud Technologies in Education (CTE 2021) and 5th International Workshop on Augmented Reality in Education (AREdu 2022)*, Kryvyi Rih, Ukraine, 2022. *CEUR Workshop Proceedings*, vol. 3364, 2022, pp. 1–23. <https://ceur-ws.org/Vol-3364/paper00.pdf>
- [18] M. F. A. Hanid, M. N. H. Mohamad Said, N. Yahaya, and Z. Abdullah, "The elements of computational thinking in learning geometry by using augmented reality application," *International Journal of Interactive Mobile Technologies*, vol. 16, no. 2, pp. 28–41, 2022. <https://doi.org/10.3991/ijim.v16i02.27295>

- [19] Z. Mengmeng, H. Xiao, L. Xiangwei, and L. Linying, "Effects of augmented reality-based digital mobile game-based learning on the engagement of students," *International Journal of Interactive Mobile Technologies*, vol. 19, no. 6, pp. 90–102, 2025. <https://doi.org/10.3991/ijim.v19i06.53809>
- [20] S. Pahmi, A. Hendriyanto, S. Sahara, L. H. Muhaimin, K. S. Kuncoro, and B. Usodo, "Assessing the influence of augmented reality in mathematics education: A systematic literature review," *International Journal of Learning, Teaching and Educational Research*, vol. 22, no. 5, pp. 1–25, 2023. <https://doi.org/10.26803/ijlter.22.5.1>
- [21] K. S. Kuncoro, Y. S. Kusumah, D. Suryadi, D. Juandi, and A. Jupri, "Augmented reality for supporting student's engagement in mathematics education: A systematic literature review," *Eurasia Proceedings of Educational & Social Sciences (EPESS)*, vol. 35, pp. 19–29, 2024. <https://doi.org/10.55549/epess.797>
- [22] L. M. Angraini and Rahmawati, "The existence of augmented reality in mathematics learning: A systematic literature review," *Rangkiang Mathematics Journal*, vol. 3, no. 2, pp. 1–13, 2024. <https://doi.org/10.24036/rmj.v3i2.54>
- [23] M. Bulut and R. B. Ferri, "A systematic literature review on augmented reality in Mathematics education," *European Journal of Science and Mathematics Education*, vol. 11, no. 3, pp. 556–572, 2023. <https://doi.org/10.30935/scimath/13124>
- [24] Z. B. Erşen and Y. Alp, "A systematic review of augmented reality in mathematics education in the last decade," *Malaysian Online Journal of Educational Technology*, vol. 12, no. 1, pp. 15–31, 2024. <https://doi.org/10.52380/mojet.2024.12.1.476>
- [25] E. İbili, M. Çat, D. Resnyansky, S. Şahin, and M. Billinghamurst, "An assessment of geometry teaching supported with augmented reality teaching materials to enhance students' 3D geometry thinking skills," *International Journal of Mathematical Education in Science and Technology*, vol. 51, no. 2, pp. 224–246, 2020. <https://doi.org/10.1080/0020739X.2019.1583382>
- [26] M. H. Pambudi, A. Suyitno, and Z. Mastur, "Development of application based on augmented reality to improve student's spatial ability," *Jurnal Didaktik Matematika*, vol. 9, no. 2, pp. 314–327, 2022. <https://doi.org/10.24815/jdm.v9i2.25936>
- [27] A. Buchori, J. Sulianto, and S. Osman, "Interactive learning media with augmented reality (AR) GeoGebra for teaching geometry in elementary school," *Profesi Pendidikan Dasar*, vol. 10, no. 3, pp. 17–30, 2023. <https://doi.org/10.23917/ppd.v10i3.4469>
- [28] O. Iparraguirre-Villanueva, C. Paulino-Moreno, H. Chero-Valdivieso, K. Espinola-Linares, and M. Cabanillas-Carbonell, "Integration of GeoGebra calculator 3D with augmented reality in mathematics education for an immersive learning experience," *International Journal of Engineering Pedagogy*, vol. 14, no. 3, pp. 92–107, 2024. <https://doi.org/10.3991/ijep.v14i3.47323>
- [29] R. M. Branch, *Instructional Design: The ADDIE Approach*. Boston, MA: Springer-Verlag US, 2009. <https://doi.org/10.1007/978-0-387-09506-6>
- [30] M. H. Pambudi, A. Suyitno, and Z. Mastur, "Development of application based on augmented reality to improve student's spatial ability," *Jurnal Didaktik Matematika*, vol. 9, no. 2, pp. 314–327, 2022. <https://doi.org/10.24815/jdm.v9i2.25936>
- [31] W. N. Yanuarto and A. M. Iqbal, "The augmented reality learning media to improve mathematical spatial ability in geometry concept," *Edumatica: Jurnal Pendidikan Matematika*, vol. 12, no. 1, pp. 30–40, 2022. <https://doi.org/10.22437/edumatica.v12i01.17615>

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