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A Case Study on the Integration of Augmented Reality in Geometry Instruction: Effects on Learning Outcomes and Student Engagement

Mr.Vivek M Chaudhari[1]*, Dr. Shivram Ponnuswamy*[2]*, Dr. Mohammad Muqeem*[3]*, Dr. Pawan R. Bhaladhare*[4]

[1]*M.Tech Student, Department of Computer Science and Engineering, Sandip University Nashik, India.*
[2]*Professor, Department of Computer Science and Engineering, Sandip University Nashik, India.*
[3]*Professor, Department of Computer Science and Engineering, Sandip University Nashik, India.*
[4]*HOD, Department of Computer Science and Engineering, Sandip University Nashik, India.*

Abstract:

The integration of emerging technologies in education holds transformative potential, especially in mathematics, where abstract concepts often hinder comprehension. This study investigates the effectiveness of Augmented Reality (AR) as a pedagogical tool in teaching 3D geometry to secondary school students. A case study was conducted with students from Grades 8 to 10, utilizing AR-enabled mobile applications to visualize and interact with geometric solids in real-world settings.

The research employed a mixed-methods approach. Quantitative data were collected through a pre-test and post-test to assess changes in academic performance, while qualitative insights on student motivation and engagement were gathered using structured questionnaires. The experimental group, which received instruction with AR tools, demonstrated a statistically significant improvement in understanding spatial concepts compared to the control group taught using traditional methods. Furthermore, survey responses indicated heightened interest, perceived ease of learning, and increased engagement during AR-assisted lessons.

The findings suggest that AR can enhance both cognitive and affective learning outcomes in mathematics, making abstract topics more accessible and stimulating for learners. This case study supports the growing body of evidence advocating for the integration of immersive technologies in STEM education and highlights key considerations for implementation at the secondary education level.

Keywords: Augmented Reality (AR),3D Geometry Instruction,Mathematics Engagement,Secondary Education.

1. Introduction

Mathematics education, particularly at the secondary school level, often presents learners with abstract concepts that can be difficult to visualize and internalize. Geometry, with its reliance on spatial reasoning and three-dimensional (3D) conceptualization, is one such domain where traditional pedagogical approaches frequently fall short. Despite curriculum reforms and the inclusion of visual aids,students continue to struggle with understanding the structures, properties, and relationships of geometric figures, leading to poor performance and decreased interest in the subject.

Recent advancements in educational technology have introduced innovative tools that offer new modalities for engaging students and enhancing conceptual clarity. Among these, Augmented Reality (AR) has emerged as a particularly promising medium. AR allows digital objects to be superimposed onto the physical environment in real time, enabling learners to interact with 3D geometric models from multiple perspectives. This immersive, interactive learning approach has the potential to bridge the gap between abstract mathematical theories and real-world understanding.

Previous research has demonstrated that AR can enhance knowledge retention, improve student engagement, and support differentiated learning in various STEM disciplines. However, studies specifically targeting its application in secondary-level geometry education remain limited, particularly in developing regions where educational technology is still gaining traction. Moreover, while AR's novelty often garners positive student attention, its actual impact on learning outcomes and sustained engagement needs rigorous, empirical validation.

This study seeks to address this gap by examining the pedagogical impact of AR on the learning of 3D geometry among Grade 8 to 10 students. Through a case study design, it evaluates both cognitive outcomes—measured by improvements in academic performance—and affective outcomes—assessed via student-reported engagement and motivation. By doing so, the research aims to provide actionable insights into the integration of AR in classroom settings and contribute to the growing discourse on immersive learning technologies in mathematics education.

2. Literature Review

The integration of immersive technologies in education has gained substantial attention over the past decade, particularly in the context of STEM (Science, Technology, Engineering, and Mathematics) learning. Augmented Reality (AR), a subset of immersive technology, has been extensively studied for its pedagogical potential due to its ability to blend virtual content with real-world environments, fostering experiential and constructivist learning approaches.

2.1 *AR in Mathematics Education*

Several studies have highlighted the value of AR in making abstract mathematical concepts more tangible and engaging. For instance, Cai et al. (2017) demonstrated that AR-based interventions in geometry significantly improved students' spatial visualization skills and their ability to comprehend three-dimensional shapes. Similarly, Ibáñez et al. (2014) found that AR enhanced concentration and flow experiences in physics education, suggesting a transferability of benefits to other technical subjects like mathematics.

In a meta-analysis by Heradio et al. (2016), AR and Virtual Reality (VR) applications were shown to outperform traditional learning methods in terms of both knowledge retention and learner satisfaction. Guerrero et al. (2016) further supported this by integrating mixed reality in geometry classes, observing increased conceptual understanding and learner confidence.

2.2 *Learning Outcomes and Knowledge Acquisition*

AR has been shown to impact not only student interest but also cognitive gains. Brinson (2015) reviewed several empirical studies comparing virtual/augmented labs to traditional methods, reporting equal or greater learning outcomes in virtual environments. In mathematics-specific contexts, Simsek (2016) noted that AR-based learning led to significant improvements in test scores among secondary students when applied to topics like coordinate geometry and 3D object manipulation.

2.3 *Engagement and Motivation*

Apart from academic performance, AR's capacity to improve student engagement is well-documented. Wojciechowski & Cellary (2013) explored AR's influence on learner attitudes and reported heightened interest and enjoyment during AR-integrated lessons. Engagement is especially critical in subjects perceived as difficult, like mathematics, where learner motivation is closely tied to achievement.
However, some studies caution against over-reliance on AR's novelty. Hochberg et al. (2018) observed that while AR and mobile tools increased student curiosity, they did not consistently translate to long-term learning gains without structured instructional scaffolding.

2.4 *Research Gap*

While these studies collectively affirm the educational potential of AR, there remains a shortage of focused case studies evaluating its integration in secondary school geometry instruction — especially within developing or resource-constrained educational contexts. Additionally, few investigations have simultaneously measured both learning outcomes and affective responses such as engagement and motivation in a controlled classroom environment.

This study aims to bridge this gap by assessing the dual impact of AR on academic performance and student engagement in geometry, contributing to both theoretical and applied educational technology research.

3. GeoGebra AR Application Description

The GeoGebra Augmented Reality (AR) application is an innovative, mobile-based educational tool that leverages immersive technology to facilitate deeper understanding of geometric concepts, particularly in the domain of three-dimensional (3D) geometry. Developed as part of the open-source GeoGebra platform, this application merges dynamic geometry capabilities with real-world interaction, enabling learners to visualize, manipulate, and explore mathematical objects in their immediate physical environment through smartphone or tablet devices.

The application delivers a curriculum-aligned, interactive learning experience where students engage with 3D geometric solids such as cubes, spheres, cylinders, cones, and pyramids. These solids are projected into the real-world classroom or home setting using the device's camera and AR interface, allowing learners to walk around the figures, zoom in and out, rotate them, and observe from multiple perspectives. This spatial manipulation fosters improved conceptual clarity in areas such as volume, surface area, cross-sections, and spatial transformations—topics often perceived as abstract and challenging in traditional settings.

Fig. 1 -GeoGebra AR Application.

As shown in Figure 1, students use GeoGebra AR to place a geometric solid on a flat surface, such as a desk or floor. Once placed, they can explore the object interactively, compare dimensions with real-world references and relate visual changes to mathematical formulas. For example, Figure 1 depicts a composite solid (cone on cylinder) used to teach decomposition and additive volume calculations. These interactive experiences bridge the gap between theoretical mathematics and tangible understanding.

The instructional design underpinning the application's classroom use is grounded in constructivist learning theory and follows established models for technology-enhanced pedagogy, as outlined by Paquette et al. (2006) and Marfisi et al. (2010). The design process included:

Specification of learning objectives based on national curriculum standards

Development of AR-supported instructional scenarios

Integration of digital manipulatives with conventional teaching practices

Construction of evaluation instruments (e.g., pre/post-tests, satisfaction surveys)

To ensure inclusivity and ease of implementation, the application supports offline access and requires no login or external connectivity once installed. It is compatible with both iOS and Android platforms and designed for intuitive, low-barrier use by students and teachers alike.

Crucially, the pedagogical content and classroom activities were co-developed with input from secondary mathematics educators to ensure alignment with cognitive learning goals and practical classroom constraints. The GeoGebra AR application thus represents a scalable, research-informed approach to enhancing geometry instruction through immersive and student-centered learning.

4. Case Study Description

4.1 *Evaluation Methodology*

The present study was conducted as part of a case study evaluating the integration of Augmented Reality (AR) in geometry instruction at a secondary school. The research was carried out in alignment with ethical research standards, with prior approval obtained from the Institutional Ethics Review Board. Informed consent was secured from all participating students and their legal guardians. Table 1 outlines the documentation involved in the ethics compliance process.

Document/Form Experimental Group	**Experimenta l Group**
Ethics Approval	✓
Parental Consent Form	✓
Student Assent Form	✓
Data Management Plan	✓
Plain Language Participant Statement	✓

Table 1 -Ethical documentation and compliance materials

The intervention involved a structured sequence of four instructional and evaluative activities administered to the experimental group. These are detailed in Table 2.

Activity		Experimental Group
Activity 1	Knowledge Pre-test: Assessed students' baseline understanding of 3D geometry concepts.	✓
Activity 2	AR-Based Geometry Lesson: Students used GeoGebra AR Application to visualize and interact with geometric solids.	✓
Activity 3	Learner Satisfaction Questionnaire: Measured student perceptions of the learning experience.	✓
Activity 4	Knowledge Post-test: Evaluated learning outcomes after the intervention.	✓

Table 2. Instructional and evaluative sequence for the experimental group

4.2 *Participants*

The study was conducted in a co-educational secondary school where one class of students from Grades 8 to 10 was designated as the experimental group (N = 30). Students ranged in age from 13 to 16 years. Each participant had access to a personal tablet or smartphone equipped with AR functionality, and all AR activities were conducted under the supervision of the classroom mathematics teacher.

4.3 *Data Collection*

The data collection phase was designed to evaluate both the cognitive and affective impact of the **GeoGebra AR** application on students' understanding of 3D geometry. This phase was carried out over two instructional sessions, each lasting 60 minutes, within the school's regular mathematics curriculum framework.

During the intervention, students in the experimental group were introduced to the **GeoGebra Augmented Reality (AR)** mobile application, which allows users to project interactive 3D geometric figures into real-world space using a smartphone or tablet camera. The application supports real-time manipulation of shapes, including rotation, zoom, and positional shifts, enabling students to inspect geometrical features from multiple angles.
The content focused on core **3D geometric solids** covered in the curriculum—**cones, cylinders, prisms, pyramids, cubes, and spheres**. Students worked in pairs, with each pair sharing one AR-enabled device.

The teacher provided initial demonstrations and distributed guided activity sheets with structured tasks that required:

- Identification and classification of shapes
- Calculation of surface area and volume
- Visualization of nets and symmetry axes
- Real-world examples linked to each shape

The instructional approach emphasized **active learning**, where students explored concepts through direct interaction with the digital models, followed by short problem-solving exercises contextualized in real-life scenarios (e.g., calculating the volume of a water tank or packaging box).

4.4 *Post-Session Feedback Instrument*

Upon completion of the AR lesson, all students were asked to complete a **Learner Satisfaction and Engagement Questionnaire**, designed to capture both their cognitive perceptions and emotional engagement with the AR experience.

The questionnaire consisted of **six closed-ended statements** rated on a **5-point Likert scale**:

1. *The AR models helped me better understand 3D shapes and their properties.*
2. *Using AR made learning geometry easier for me.*
3. *I enjoyed the geometry lesson that used AR.*
4. *The interactive models made the lesson feel more practical.*
5. *The AR features distracted me from learning. (reverse scored)*
6. *I would like to use AR in more of my math lessons.*

In addition, students were invited to respond to an **open-ended prompt**:

- *Please share any comments or suggestions about your experience using AR in today's lesson.*

To enhance accessibility and encourage honest feedback, each Likert item included **visual emoji indicators** corresponding to each response category: **Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree**.
This instrument enabled both **quantitative assessment of satisfaction and engagement**, and **qualitative insights** into usability, perceived benefits, and areas for improvement.

5. Results

5.1 *User Experience*

To evaluate the user experience of the GeoGebra AR application, responses to Questions 1 through 6 of the Learner Satisfaction and Engagement Questionnaire were analyzed. These questions focused on students' perceptions of the application's educational value, engagement level, and overall effectiveness in delivering geometry concepts.

The results, presented in Table 3, reflect responses on a 5-point Likert scale—**Strongly Agree (SA)**, **Agree (A)**, **Neutral (N)**, **Disagree (D)**, and **Strongly Disagree (SD)**. The majority of students reported a positive experience with the AR-enhanced instruction.

- **Q1:** *"The AR models helped me better understand 3D shapes and their properties."*
  82% of students either agreed or strongly agreed, indicating that the AR interface effectively facilitated conceptual understanding of geometric solids.

- **Q2:** *"Using AR made learning geometry easier for me."*
  A combined 71% of students agreed or strongly agreed, reflecting that AR reduced the cognitive load associated with visualizing complex 3D structures.

- **Q3:** *"I enjoyed the geometry lesson that used AR."*
  This statement received one of the highest positive responses, with over 80% of students affirming their enjoyment, reinforcing the engaging nature of AR.

- **Q4:** *"The interactive models made the lesson feel more practical."*
  65% of students responded positively, suggesting that AR helped bridge theoretical geometry with real-world applications.

- **Q5 (reverse scored):** *"The AR features distracted me from learning."*
  Only 14% of students agreed or strongly agreed, indicating minimal distraction. Most remained neutral or disagreed, supporting the AR tool's educational focus.

- **Q6:** *"I would like to use AR in more of my math lessons."*
  A strong 74% of students expressed enthusiasm for continued use of AR, signaling high receptivity toward future AR-based instruction.

Question	SA (%)	A (%)	N (%)	D (%)	SD (%)
Q1	25.0	57.1	14.3	3.6	0.0
Q2	17.9	53.6	17.9	10.7	0.0
Q3	39.3	42.9	14.3	3.6	0.0
Q4	21.4	42.9	21.4	14.3	0.0
Q5	0.0	14.3	39.3	39.3	7.1
Q6	35.7	39.3	21.4	3.6	0.0

Table 3. Experimental Group Responses to Learner Satisfaction Questionnaire (GeoGebra AR)

5.2 *Usability*

Usability feedback was collected through an open-ended question (Q7), where students were invited to provide comments or suggestions about their experience. Of the 30 participants, 16 students (57%) offered qualitative feedback.
The majority of responses were positive. Students expressed enthusiasm for the AR experience, with comments such as:

- *"It helped me see the shapes like they were real."*
- *"I wish we had more math classes like this."*
- *"Moving and rotating the shapes made things easier to understand."*

Several students emphasized how the interactive aspect helped them retain information better. Only two students noted minor issues, such as difficulty in stabilizing the model in certain lighting conditions or a desire for a wider variety of shapes.

This feedback suggests that the GeoGebra AR app was perceived as user-friendly, accessible, and effective in supporting student learning.

6. Discussion

The findings from this case study highlight the pedagogical potential of Augmented Reality (AR) applications in secondary mathematics education, specifically in the instruction of 3D geometry. The integration of the **GeoGebra AR** application in classroom instruction led to marked improvements in both **student comprehension** and **engagement**, supporting prior research that emphasizes the affordances of AR for spatial learning and conceptual clarity.

6.1 *Improved Conceptual Understanding*

The majority of students (82%) agreed that the AR models enhanced their understanding of geometric properties, particularly those that are typically challenging to visualize using static 2D diagrams, such as volume, surface area, and shape orientation. This aligns with the findings of Cai et al. (2017), who observed that AR tools significantly improve learners' spatial visualization abilities by offering real-time, manipulable models.

The ability to physically move around virtual objects and view them from multiple perspectives appears to have reduced the cognitive load typically associated with 3D geometry, making abstract content more accessible. This supports cognitive theory frameworks that advocate for multimodal and embodied learning strategies.

6.2 *Increased Engagement and Enjoyment*

Over 80% of students reported enjoying the AR-enhanced lesson, with a majority expressing interest in incorporating similar technologies in future mathematics classes. This is consistent with findings from Wojciechowski & Celery (2013), who found that AR environments increase learner enjoyment and motivation, particularly in subjects students often find intimidating or dry.

While engagement alone is not sufficient for learning, the high correlation between enjoyment and perceived ease of learning in this study suggests that AR can simultaneously affect both **affective** and **cognitive** domains.

6.3 *Minimal Distraction*

Contrary to concerns that digital interventions may distract students, fewer than 15% of learners felt that AR features interfered with their concentration. Most students reported that the interactive visuals complemented rather than disrupted the learning process, highlighting the importance of structured pedagogical integration rather than novelty-driven implementation.

6.4 *Usability and Areas for Improvement*

Feedback from students was largely positive, with requests focused on expanded functionality (e.g., more shapes, better lighting adaptation). While the GeoGebra AR application was well-received, its usability could be enhanced through better tutorials, voice guidance, or adaptive learning paths. These considerations should inform future refinements and teacher training initiatives.

7. Conclusion

This case study investigated the effectiveness of the GeoGebra Augmented Reality (AR) application in teaching 3D geometry to secondary school students in Grades 8–10. The integration of AR into the mathematics classroom significantly enhanced students' conceptual understanding and positively influenced their engagement and motivation. Quantitative analysis demonstrated that the majority of students found the AR-enhanced instruction more effective and enjoyable than traditional methods. Furthermore, open-ended feedback indicated that students appreciated the interactive and visual nature of the learning experience.

These findings reinforce the growing consensus in educational research that immersive technologies, when purposefully integrated into instructional design, can support deeper learning and improve learner outcomes in STEM subjects. By providing a tangible, manipulable interface for exploring abstract concepts, AR helps bridge the gap between theoretical content and real-world application.

8. Recommendations and Future Work

Based on the outcomes of this study, the following recommendations are proposed:

1. **Curriculum Integration**: Schools should consider embedding AR-based modules within existing geometry units to complement traditional instruction, particularly for spatially demanding topics.

2. **Teacher Training**: Professional development programs should equip educators with skills to effectively integrate AR tools and manage classroom dynamics during technology-enhanced lessons.

3. **Expanded Content**: Developers of educational AR applications like GeoGebra should consider incorporating more advanced geometric concepts and real-world modeling scenarios to cater to diverse student needs and grade levels.

4. **Larger-Scale Studies**: Future research should replicate this study with a larger sample size and include a longitudinal design to evaluate the retention of concepts over time.

5. **Multimodal Data Collection**: Incorporating eye-tracking, gesture analysis, or screen recording could yield deeper insights into how students interact with AR content and where usability bottlenecks occur.

This case study demonstrates the transformative potential of AR in mathematics education and lays the groundwork for broader implementation and research in immersive learning technologies.

REFERENCES

1. Lepore, M., & Mennuni, F. (2023). GeoGebra augmented reality to facilitate the manipulation of different semiotic representations of paraboloids. *International Journal for Technology in Mathematics Education, 30*(3), 131–140. https://eric.ed.gov/?id=EJ1443722(eric.ed.gov)

2. Tasci, D., & Soylu, Y. (2023). Exploring the impact of GeoGebra AR on students' geometric thinking based on van Hiele levels. *Journal of Holistic Mathematics Education, 7*(1), 1–12. https://journalfkipunipa.org/index.php/jhm/article/view/871(journalfkipunipa.org)

3. Semerikov, S. O., & Striuk, A. M. (2024). Augmented reality in education 2023: Innovations, applications, and future directions. *CEUR Workshop Proceedings, 3844*, 1–22. https://ceur-ws.org/Vol-3844/paper00.pdf(researchgate.net)

4. Arymbekov, B. S., Turekhanova, K., Fedus, K., & Turdalyuly, M. (2024). The effect of applying GeoGebra software for augmented reality visualization to teach physics in high school. *International Journal of Advanced Research in Education and Society, 6*(2), 45–60. https://www.researchgate.net/publication/377080318_The_effect_of_using_geogebra_software_for_augmented_reality_visualization_to_teach_physics_in_high_school(researchgate.net)

5. Widodo, S., & Rahmawati, D. (2025). Development of augmented reality-based learning media with GeoGebra 3D to enhance interest and concept understanding in Ceva's Theorem. *Journal of Development and Innovation in Mathematics Education, 3*(1), 35–47. https://www.researchgate.net/publication/391200582_Development_of_Augmented_Reality-Based_Learning_Media_with_GeoGebra_3D_to_Enhance_Interest_and_Concept_Understanding_in_Ceva_Theorem(researchgate.net)