Augmented Reality for Exploring Solids: A Study on Improving Pre-Service Teachers

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Abstract: Applications of augmented reality are gradually being integrated into teaching at various levels and types of schools. Augmented reality has the potential to transform the training of future teachers in the context of developing their mathematical knowledge, digital skills, and teaching competencies. The paper focuses on researching the impact of augmented reality on the learning of future primary teachers. The aim was to investigate the impact of AR applications on the development of cognitive and psychomotor skills and on students' motivation to learn. The study had a mixed research design. Using a pedagogical experiment, we investigated the effectiveness of an educational intervention based on the use of applications Augmented Reality in combination with hands on activities in the training of future teachers. The educational intervention was a set of activities that were carried out in a mixed reality environment using the 3D solids construction kit, the Polyedres augmentes and GeoGebra applications. The content of the educational intervention was the exploration of significant elements and properties of solids. We tested students' knowledge and abilities in the following areas: identification of simple solids from a picture; identification of significant elements of solids (vertices, edges and faces); identification of the shapes of faces of solids; nets of solids; simple metric tasks with solids. The study was conducted in 2024 with 152 primary education students as part of geometry courses. In line with the results of previous research in this area, we found that AR has the potential to improve understanding of geometric concepts, increase interactivity and student motivation. Augmented reality opens up new possibilities for exploring solids and their properties, as it allows for transfer between planar and spatial representation of solids and helps to develop spatial imagination.

Keywords: Augmented reality in education, app AR Polyedres Augmentes, app AR GeoGebra, Solids in geometry education, Primary education, Primary education, Teacher training

1. Introduction

1.1 Background and Context

Augmented Reality (AR) has emerged as a transformative tool in educational settings, capable of enhancing the learning experience by integrating digital information with the physical world. AR applications provide interactive and immersive learning environments that make abstract concepts more tangible and understandable. This capability is particularly beneficial in the field of mathematics education, where spatial reasoning and the visualization of geometric solids are critical skills.

Recent advancements in AR technology have led to its gradual integration into various levels of education, from primary schools to higher education institutions. The potential of AR to revolutionize teaching and learning processes is supported by numerous studies that demonstrate significant improvements in student engagement, motivation, and academic performance. For pre-service teachers, AR offers unique opportunities to develop their pedagogical skills, digital literacy, and content knowledge in innovative ways.

1.2 Importance of AR in Education

The importance of AR in education cannot be overstated. AR provides a dynamic and interactive platform that bridges the gap between theoretical knowledge and practical application. By overlaying digital content onto real-world environments, AR enables students to interact with learning materials in new and meaningful ways. This interaction enhances cognitive processes and supports the development of critical thinking and problem-solving skills.

In the context of teacher training, AR is particularly valuable. It allows pre-service teachers to experience realistic classroom scenarios and practice their teaching strategies in a controlled environment. This hands-on approach helps future educators to refine their skills and become more confident in their teaching abilities. Moreover, AR tools can simulate diverse classroom settings, including the management of student behavior and the adaptation of lessons for different learning styles.

Studies have shown that AR can significantly improve students' understanding of complex subjects. For example, research by Moro et al. (2017) demonstrated that AR-enhanced lessons in medical education improved students' spatial understanding and retention of complex anatomical structures. Similarly, in mathematics education, AR applications have been found to enhance students' spatial reasoning and comprehension of geometric properties (Lin et al., 2015).

1.3 Objectives of the Study

The primary objective of this study was to investigate the impact of AR applications on the cognitive and psychomotor skills of pre-service teachers, as well as their motivation to learn. Specifically, the study aimed to:

- Evaluate the effectiveness of AR-based educational interventions in improving pre-service teachers' understanding of geometric solids.
- Assess the development of spatial reasoning and geometric visualization skills through the use of AR tools.
- Explore the potential of AR applications to enhance student engagement and motivation in learning mathematics.
- Determine the applicability of AR tools in primary education settings, particularly in teaching geometry.

To achieve these objectives, a mixed-methods research design was employed, combining quantitative assessments (pretests and posttests) with evaluative feedback from participants. The study focused on a set of AR activities involving the 3D Solids Construction Kit, the Polyedres Augmentes application, and the GeoGebra application. Through these activities, pre-service teachers were provided with opportunities to explore and manipulate 3D geometric shapes, thereby enhancing their understanding and teaching competencies.

By examining the impact of AR on pre-service teachers, this study aims to contribute to the growing body of research on the use of AR in education and provide insights into the potential benefits and challenges of integrating AR into teacher training programs.

2. Literature review and theoretical background

2.1 Augmented Reality in Educational Settings

Augmented Reality (AR) is emerging as a powerful tool in educational environments, demonstrating its potential to significantly increase student motivation and engagement. AR's capacity to create dynamic and interactive learning experiences bridges the gap between theoretical knowledge and practical application, making abstract concepts more tangible and understandable.

AR applications are increasingly being utilized in higher education to create immersive learning environments that engage students and enhance their understanding. Prodromou (2020) discusses the transformative impact of AR on higher education, emphasizing how AR can make learning more interactive and personalized. According to Prodromou, AR can support diverse learning styles by offering multimodal content that includes visual, auditory, and kinesthetic elements. For instance, the chapter by Ferko, Berger-Haladová, and Bohdal (2020) highlights the use of AR in enhancing collaborative learning experiences in STEM education, noting improvements in student engagement and knowledge retention.

One notable application of AR in higher education is its use in medical training. AR simulations provide medical students with realistic, hands-on experience without the risks associated with real-life procedures. A study by Moro et al. (2017) demonstrated that AR-enhanced anatomy lessons significantly improved students' spatial understanding and retention of complex anatomical structures. The immersive nature of AR allowed students to visualize and manipulate 3D models of the human body, leading to better comprehension and skill acquisition.

The use of AR in teaching mathematics and geometry has garnered considerable attention due to its ability to make abstract concepts tangible. AR tools enable students to interact with geometric shapes in a 3D space, thereby enhancing their spatial reasoning and understanding of geometric properties. Research by Lin et al. (2015) explored the effectiveness of AR in improving the geometric thinking of undergraduate students. Their study found that students who used AR applications to study geometric transformations and spatial relationships performed better in assessments compared to those who relied solely on traditional teaching methods. The interactive and visual nature of AR helped students grasp complex geometric concepts more effectively.

AR not only supports cognitive development but also enhances psychomotor skills by providing interactive, hands-on learning experiences. Dünser et al. (2012) conducted a study that showed how AR applications could improve students' ability to visualize and manipulate 3D objects. This is particularly beneficial in fields such as engineering and architecture, where spatial awareness and the ability to understand and create 3D models are crucial. In the context of teacher training, AR has been shown to enhance both digital literacy and teaching competencies. Bower et al. (2014) highlighted that pre-service teachers who engaged with AR technologies during their training developed a better understanding of how to integrate digital tools into their teaching practices. This is critical in preparing future educators to use innovative technologies to improve student learning outcomes.

Several case studies have demonstrated the practical benefits of AR in educational settings. For example, a study by Garzón and Acevedo (2019) investigated the use of AR in a university-level geometry course. The study found that AR applications significantly improved students' motivation and engagement, leading to better academic performance. Students reported that the ability to interact with 3D geometric shapes in real-time helped them understand complex concepts and retain information more effectively. Moreover, a study by Fuchsová, Adamková, and Lapšanská (2020) examined the use of AR in biology education, finding that it significantly enhanced students' understanding of biological processes and structures. Additionally, the work of Dillingerová, Babinská, and Koreňová (2020) on AR and future mathematics teachers showed that AR tools effectively prepared students for teaching complex mathematical concepts.

Despite the numerous benefits of AR, its implementation in educational settings is not without challenges. Technical issues, such as the need for advanced hardware and reliable software, can hinder the widespread adoption of AR technologies. Professional development and training are essential to ensure that teachers can effectively integrate AR into their teaching practices. Future research should focus on addressing these challenges and exploring new ways to leverage AR's potential in education. This includes developing cost-effective AR solutions, creating comprehensive training programs for educators, and conducting longitudinal studies to assess the long-term impact of AR on student learning outcomes.

2.2 AR and Teacher Training

AR is not only transforming student learning but also revolutionizing teacher training by enhancing pre-service teachers' skills and competencies. AR tools provide an immersive and interactive environment where future educators can develop their teaching strategies, digital literacy, and classroom management skills. This innovative approach shows significant potential for increasing student motivation and engagement in learning.

The integration of AR into teacher training programs has been shown to significantly improve the preparedness of pre-service teachers. According to Prodromou (2020), AR-based training allows teachers to experience realistic classroom scenarios in a controlled environment. This hands-on approach helps them practice and refine their teaching methods without the pressures of a real classroom. For example, AR can simulate diverse classroom settings, including managing student behavior, adapting lessons for different learning styles, and integrating technology into teaching practices.

Ferko, Berger Haladová, and Bohdal (2020) discuss how AR applications can enhance collaborative learning among pre-service teachers. By working together in an AR environment, future teachers can develop their communication and teamwork skills. These collaborative experiences are crucial for fostering a supportive professional community and preparing teachers for the collaborative nature of modern educational environments.

Furthermore, AR in teacher training supports the development of digital competencies, which are essential for integrating technology into education effectively. Bower et al. (2014) highlighted that pre-service teachers who engaged with AR technologies during their training developed a better understanding of how to use digital tools in their teaching practices. This includes creating interactive lessons, using AR to visualize complex concepts, and enhancing student engagement through technology.

The work of Kaufmann and Schmalstieg (2003) demonstrated how AR applications in educational training could significantly enhance spatial abilities and problem-solving skills. Their research focused on the use of AR for geometry education, where pre-service teachers could interact with 3D models, improving their understanding and ability to teach these concepts.

Several studies have demonstrated the positive impact of AR on teacher training. For instance, Garzón and Acevedo (2019) found that AR applications in teacher education programs increased pre-service teachers' motivation and engagement. The study reported that the interactive nature of AR made learning more enjoyable and meaningful, which in turn enhanced the overall training experience. Additionally, research by Dillingerová, Babinská, and Koreňová (2020) on AR and future mathematics teachers showed that AR tools effectively prepared students for teaching complex mathematical concepts, thereby increasing their confidence and competence in the subject.

Despite the evident benefits, implementing AR in teacher training also presents challenges. These include the need for advanced hardware and reliable software, as well as the necessity for professional development to ensure that educators can effectively use AR technologies. Addressing these challenges requires a strategic approach, including investing in infrastructure, providing continuous training, and developing a supportive community of practice among educators.

Future research should focus on exploring new ways to leverage AR's potential in teacher training. This includes developing cost-effective AR solutions, creating comprehensive training programs that incorporate AR, and conducting longitudinal studies to assess the long-term impact of AR on teacher effectiveness and student outcomes. By doing so, we can better understand how AR can be used to prepare future educators to meet the demands of 21st-century classrooms.

2.3 Previous Studies on AR in Mathematics Education and Research Gaps

The application of Augmented Reality (AR) in mathematics education has been a growing field of study, demonstrating significant potential in enhancing students' understanding of complex mathematical concepts. Various studies have explored how AR can improve learning outcomes, spatial abilities, and engagement in mathematics.

One of the seminal works in this area is by Kaufmann and Schmalstieg (2003), who investigated the use of collaborative AR in teaching geometry. Their study demonstrated that AR could significantly enhance students' spatial visualization skills and their ability to comprehend geometric concepts through interactive 3D models. The immersive environment provided by AR allowed students to manipulate geometric shapes, which led to a deeper understanding of the subject matter.

Lin et al. (2015) further explored the effectiveness of AR in improving the geometric thinking of undergraduate students. Their research found that students who used AR applications to study geometric transformations and spatial relationships performed better in assessments compared to those who relied on traditional teaching methods. The interactive and visual nature of AR helped students grasp complex geometric concepts more effectively, highlighting the benefits of incorporating AR into the mathematics curriculum.

In a study focused on pre-service teachers, Ferko, Berger Haladová, and Bohdal (2020) examined how AR applications could be used to enhance collaborative learning in STEM education. They found that AR tools not only improved the pre-service teachers' understanding of mathematical concepts but also fostered a collaborative learning environment that encouraged communication and teamwork.

Moreover, Bower et al. (2014) highlighted the role of AR in making abstract mathematical concepts more concrete. By visualizing and interacting with mathematical models, students were able to develop a better conceptual understanding, which is often challenging to achieve through traditional methods. This study emphasized the importance of integrating AR into mathematics education to make learning more engaging and effective.

Despite these positive findings, several research gaps remain in the field of AR in mathematics education. One major gap is the need for longitudinal studies that examine the long-term effects of AR on students' learning outcomes and retention of mathematical concepts. Most existing studies have focused on short-term interventions, and there is limited understanding of how sustained use of AR impacts students' mathematical abilities over time.

Another gap is the lack of comprehensive studies that explore the integration of AR in diverse educational settings. Much of the existing research has been conducted in controlled environments, such as university labs or specific classroom settings. There is a need for more studies that investigate the practical implementation of AR in a variety of educational contexts, including under-resourced schools and different cultural settings.

3. Research Methodology

3.1 Research Design

The research design employed in this study was a mixed-methods approach, integrating both quantitative and qualitative (evaluative) methodologies to comprehensively investigate the impact of augmented reality (AR) applications on pre-service teachers' knowledge and skills in geometry. Mixed-methods research combines elements of qualitative and quantitative research approaches for the broad purposes of breadth and depth of understanding and corroboration (Creswell & Plano Clark, 2011).

The quantitative component consisted of a pretest-posttest design, which is effective in measuring the changes in participants' knowledge or skills before and after an intervention (Campbell & Stanley, 1963). The pretest assessed students' initial understanding of geometric solids, while the posttest, administered after the AR intervention, measured the same parameters to determine any cognitive gains.

The evaluative component involved the use of semi-structured questionnaires with open-ended questions. This method is beneficial for exploring participants' attitudes, experiences, and perceptions in depth (Patton, 2002). The evaluative data provided insights into students' experiences with AR and their views on its applicability in primary school teaching.

3.2 Participants

The study involved 152 primary education students from Comenius University in Bratislava, Faculty of Education. These students were enrolled in one of seven courses focusing on mathematics, geometry, and the teaching of geometry. The participants were selected to evaluate the effectiveness of AR tools in their professional preparation, as future primary school teachers need a strong foundation in these areas to effectively teach young learners.

3.3 Instruments and Tools

The quantitative instruments included pretest and posttest designed to evaluate students' knowledge of geometric solids. The pretest consisted of six questions, each requiring students to identify a geometric solid based on an image and describe at least five properties. The geometric solids included a cuboid, a triangular prism positioned on its side, a regular square pyramid, a regular hexagonal prism, and a non-traditionally oriented cylinder. Additionally, students were asked to identify solids from their nets, including the nets of a cube, a cuboid, a regular square pyramid with equilateral triangle faces, another variant of a regular square pyramid, and a regular hexagonal prism.

For the evaulative component, semi-structured questionnaires were used. These questionnaires included open-ended questions designed to capture students' opinions on the AR intervention and their views on the use of AR applications (Augmented Polyhedrons - Mirage, AR GeoGebra) in primary school teaching. This method is effective in collecting detailed and nuanced data, as it allows participants to express their thoughts in their own words (Silverman, 2000).

3.4 Data Collection Procedures

The quantitative data were collected in two phases. The pretest was administered at the beginning of the activity to establish a baseline of students' knowledge of geometric solids. After the educational intervention, which involved the use of AR applications and hands-on activities, the posttest was administered. The posttest was identical to the pretest to ensure comparability of results.

In our research, we conducted an evaluative approach based on students' opinion surveys.

This data collection method is effective in understanding the subjective experiences and attitudes of participants (Bryman, 2016; Kostrub et al., 2017).

3.5 Data Analysis Techniques

The quantitative data from the pretests and posttests were analyzed using descriptive and inferential statistics. Descriptive statistics, including mean scores and standard deviations, were used to summarize the data. A paired sample t-test was conducted to compare the pretest and posttest scores, assessing the cognitive gains made by the students (Field, 2013). The analysis focused on three key areas: the initial level of knowledge about geometric solids, the level of knowledge after the intervention, and the cognitive gain achieved through the AR-based learning activities.

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In our research, we conducted an evaluative approach based on students' opinion surveys. The feedback collected from these questionnaires was analyzed to assess students' perceptions regarding the effectiveness of AR in their learning process and its potential application in primary education. This evaluative approach provided a structured method for interpreting students' opinions and drawing conclusions about their experiences with AR in educational settings.

4. Educational Intervention

4.1 Description of AR Applications Used

The educational intervention aimed to enhance the understanding of geometric solids among pre-service teachers by incorporating various augmented reality (AR) applications. These applications provided an interactive and immersive learning experience, enabling students to visualize and manipulate 3D shapes effectively. The primary AR tools used in this study were the 3D Solids Construction Kit, the Polyedres Augmentes application, and the GeoGebra application. Each tool offered unique features and capabilities that contributed to the overall learning objectives of the intervention.

4.2 The 3D Solids Construction Kit

The 3D Solids Construction Kit, also known as the 4D Frame Educational Kit, allowed students to physically construct geometric shapes. This hands-on approach helped students understand the properties and structures of various solids by building and manipulating physical models. The kit included various components such as rods and connectors, which could be assembled to form different geometric shapes, including cubes, pyramids, prisms, and more. By constructing these models, students could explore the number of faces, edges, and vertices, enhancing their spatial reasoning and comprehension of geometric properties.

4.3 Polyedres Augmentes Application

The Polyedres Augmentes application, developed by Mirage, provided an AR environment where students could visualize and interact with 3D geometric solids. Using a set of 12 markers (QR codes), each corresponding to a different solid, students could view the augmented models on their smartphones or tablets. The application allowed students to rotate and manipulate the solids in real-time, providing a comprehensive understanding of each shape's properties. The activity involved identifying and documenting the name and characteristics of each solid, such as the number of faces, edges, and vertices.

4.4 GeoGebra Application

The GeoGebra 3D Calculator application was another crucial tool in the intervention. GeoGebra is a versatile mathematical software that enables the visualization and exploration of geometric concepts in a dynamic environment. Students used the GeoGebra 3D Calculator to view and compare virtual models of geometric solids with their physical counterparts constructed using the 3D Solids Construction Kit. The application also allowed students to sketch the nets of the solids and explore their properties interactively.

4.5 Structure of the Augmented Reality Activities

The educational intervention was structured around a series of mixed reality activities that integrated the use of AR applications and physical construction kits. Students worked in groups of 4 to 6 to complete the following tasks:

1. Installation and Setup:

- Students installed the Polyedres Augmentes application on their smartphones or tablets.

- They used the application to view and interact with 12 geometric solids, each associated with a specific AR marker.

- Students documented the name and properties of each solid, filling out a provided table.

2. Physical Modeling:

- Using the 4D Frame Educational Kit, students constructed at least four geometric solids from the list provided.

- They took photos of their constructed models alongside the AR images from the Polyedres Augmentes application for comparison.

- Students also sketched the nets of the constructed solids.

3. GeoGebra Activities:

- Students installed the GeoGebra 3D Calculator application and opened specific 3D models using provided search codes.

- They compared the virtual models in GeoGebra with their physical constructions.

- The AR feature in GeoGebra was used to overlay virtual models onto physical ones for detailed comparison.

4. Project Creation:

- Students summarized their findings and learning experiences in a project report or presentation.

- The project included photos, sketches, and descriptions of the methods and results.

- Students submitted their projects via MS Teams or Moodle as per the instructor's guidelines.

These activities were designed to provide a comprehensive learning experience, combining theoretical understanding with practical application through the use of AR technologies and hands-on construction. The intervention aimed to enhance students' spatial reasoning, understanding of geometric properties, and ability to integrate technology into their future teaching practices.

5. Findings and Results

5.1 Evaluative Findings

The quantitative analysis was conducted to measure the cognitive gains in understanding geometric solids among pre-service teachers before and after the intervention using augmented reality (AR) applications. The analysis was based on pretest and posttest scores obtained from 185 participants.

5.1.1 Pretest and posttest scores

The pretest and posttest consisted of six tasks where students identified geometric solids and described their properties. The total possible score for each test was 20 points. The following results summarize the findings:

1. Mean Pretest Score:

- The average pretest score was 10.95 points.

2. Mean Posttest Score:

- The average posttest score was 13.84 points.

3. Score Improvement:

- The mean difference between posttest and pretest scores was 2.89 points, indicating a significant improvement.

5.1.2 Statistical analysis

A paired sample t-test was conducted to determine whether the improvement in scores was statistically significant.

- *t-Statistic: 14.23*

- *p-Value: < 0.001*

The p-value of less than 0.001 indicates that the improvement in scores is statistically significant, suggesting that the AR intervention had a positive impact on students' understanding of geometric solids.

5.2 Evaluative Findings

The evaluative data were gathered through semi-structured questionnaires, which captured students' feedback on the AR intervention. The responses were analyzed using thematic coding to identify recurring themes and patterns.

5.2.1 Increased engagement and motivation

Many students reported that the AR applications made the learning process more engaging and interactive. The ability to visualize and manipulate 3D models helped them better understand the geometric concepts.

> *"The application was interesting and easy to use, and it was colorfully well-designed."*

> *"We enjoyed it very much, but we missed having the names of the solids."*

5.2.2 Improved understanding

Students expressed that the AR tools facilitated a deeper understanding of geometric properties and relationships. The interactive nature of the applications allowed them to explore the shapes and their characteristics more thoroughly.

> *"Yes, it enhanced my understanding because visual aids help me the most in learning."*

> *"The application simplified spatial orientation."*

5.2.3 Future application in teaching

Several students highlighted the potential of using AR applications in their future teaching careers. They believed that these tools could significantly enhance the learning experience for primary school students by making abstract concepts more concrete and accessible.

> *"As a group, we think the application could be a motivating element in the educational process for children."*

> *"This application also provided inspiration that we can use in the educational process."*

5.2.4 Connection between theory and practice

Students appreciated that the AR activities connected theoretical knowledge with practical application, enhancing their spatial awareness and understanding.

> *"As future teachers, we need to have a better understanding of solids; this activity connected theory with practice within visual awareness."*

> *"Thanks to teamwork and the use of digital technologies, the application increased our motivation to learn geometry due to the interaction with the application and among us."*

5.3 Discussion

The findings from both the quantitative and evaluative analyses indicate that the AR intervention was effective in improving pre-service teachers' knowledge of geometric solids. The significant increase in posttest scores demonstrates the cognitive benefits of using AR in geometry education. Additionally, the positive feedback from students suggests that AR applications can enhance engagement and understanding, making them valuable tools for teaching complex concepts.

6. Conclusion

This study demonstrates the potential of augmented reality to transform the teaching and learning of geometry. By providing an interactive and immersive learning experience, AR can help pre-service teachers develop a stronger understanding of geometric solids and prepare them to use innovative teaching methods in their future classrooms. The positive impact on both cognitive gains and student motivation underscores the value of integrating AR applications into teacher education programs.

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