Journal of Information Technology Education: Research

An Official Publication of the Informing Science Institute
InformingScience.org

JITEResearch.org

Volume 23, 2024

EVALUATING THE IMPACT OF AN AUGMENTED REALITY APP ON GEOMETRY LEARNING IN KAZAKH SECONDARY SCHOOLS

Galiya K. Beisenbayeva*	Sh. Ualikhanov Kokshetau University, Kokshetau, Republic of Kazakhstan	galiya.beisenbayeva@yahoo.com
Akan M. Mubarakov	L.N. Gumilyov Eurasian National University, Astana, Republic of Kazakhstan	mubarakov.a.m@proton.me
Zoya T. Seylova	S. Seifullin Kazakh Agrotechnical University, Astana, Republic of Kazakhstan	z_seylova80@outlook.com
Larissa U. Zhadrayeva	Abai Kazakh National Pedagogical University, Almaty, Republic of Kazakhstan	zhadrayevalarissa@protonmail.com
Botagoz N. Artymbayeva	Nazarbayev Intellectual School of Chemistry and Biology in Petropavlovsk, Petropavlovsk, Republic of Kazakhstan	b.n.artymbayeva@hotmail.com

* Corresponding author

ABSTRACT

Aim/Purpose	This paper aims to evaluate the influence of an augmented reality mobile application on improving secondary students' visualization and comprehension of geometric concepts.
Background	The study involved developing an AR app named Geometria to enhance geometry education.

Accepting Editor Aaron M. Glassman │Received: October 3, 2023│ Revised: May 21, July 22, 2024 │ Accepted: August 8, 2024.
Cite as: Beisenbayeva, G. K., Mubarakov, A. M., Seylova, Z. T., Zhadrayeva, L. U., & Artymbayeva, B. N. (2024). Evaluating the Impact of an Augmented Reality App on Geometry Learning in Kazakh Secondary Schools. *Journal of Information Technology Education: Research, 23,* Article 22. https://doi.org/10.28945/5355

Methodology	In a specialized boarding school in Kokshetau, Kazakhstan, 82 tenth-graders were randomly split into control (n=42) and experimental groups (n=40), underwent either traditional instruction or lessons incorporating the AR Geometria app, and were subsequently assessed using a 20-question test spanning spatial relationships, 3D visualization, and advanced geometry concepts, complemented by a feedback questionnaire on the app's impact and usability, all under consistent teacher supervision.
Contribution	The research serves as an exploration into the realm of AR in education, offering a detailed assessment of how the Geometria application can revolutionize traditional teaching methodologies in secondary geometry education.
Findings	Upon analysis, the experimental group demonstrated significant advancement in their geometry proficiency, especially in competencies like 3D visualization, suggesting that augmented reality tools like Geometria can substantially bridge the conceptual gaps often encountered in conventional teaching settings.
Recommendations for Practitioners	Teacher training on augmented reality should be provided, equitable student access should be ensured, and ongoing feedback should be gathered.
Recommendations for Researchers	Larger, longer-term studies across diverse educational settings and technologies should be conducted.
Impact on Society	Geometry instruction can be strengthened through the effective use of augmented reality to improve STEM outcomes.
Future Research	Future studies should focus on best practices for augmented reality implementation and comparisons to other technologies.

Keywords	stereometry, education system, geometry, visualisation, augmented reality, digital technologies

INTRODUCTION

Today, the informatization of education is aimed at shifting the paradigm from conventional teaching methods with the use of chalk and blackboard to the digitalization of the pedagogical process using technical means (Gloria & Benjamin, 2018; Shyshenko et al., 2024). The active introduction of e-learning and the digitalization of education dictate new requirements for approaches and technologies, which is confirmed by official documents. For example, within the framework of the state program "Digital Kazakhstan," which was launched in 2017, Kazakhstan's education is waiting for online training, a cloud-based distance learning system, a digital ID passport for each student, interactive educational content (Government of the Republic of Kazakhstan, 2017). Currently, "Digital Kazakhstan" is not just a project on paper but already a reality. Educational platforms have been launched, digital educational resources are being developed, personalized and adaptive learning is being developed for each student, active teacher training is being conducted, and explanatory work is being conducted with parents.

By 2020, the volume of investment in educational technologies in the world has exceeded USD250 billion, with most of it coming from the introduction of novel technologies in the domain of primary and secondary education. Admittedly, even before the pandemic, the global EdTech market showed active growth. According to some forecasts, the volume of investments in online education was expected to reach USD350 billion by 2025. According to Deborah Quazzo, an investor and an ardent supporter of EdTech (GSV Ventures), taking into account the new reality, the forecasts should be adjusted. In 5 years, the market volume may reach USD 1 trillion (Forbes Education, 2020).

Hattie (2017) notes: "The use of modern technologies increases the degree of involvement of a child in the educational process and contributes to the development of a positive attitude to learning and school." Contemporary students are actively incorporating diverse electronic devices into their educational pursuits, thereby embracing the potential of digital learning to customize their educational pathways and enhance the scope of educational materials. This trend within the education system has resulted in a substantial proliferation of mobile learning applications catering to the diverse educational and cognitive requirements of students.

Augmented Reality (AR) is a rapidly developing technology that aims to expand the real space with virtual objects (augmented components). AR opens up wide opportunities in teaching any discipline (C. H. Chen et al., 2015). The use of this technology does not require expensive and complex equipment, such as displays on head-mounted devices; a mobile device is sufficient for its use. The volume of research on the integration of augmented reality in educational settings is expanding annually, which indicates that there is an increased interest in this topic (Fernandez, 2017). Most studies report that the use of augmented reality technology leads to an increase in academic performance in educational institutions. For example, the studies by Akçayır and Akçayır (2017) and Ibáñez et al. (2020) note that the use of this technology during classes improved students' academic performance and understanding of the material, the level of motivation and interest in studying the subject increased. Furthermore, there has been an increase in student engagement and participation in the educational process, accompanied by enhanced social interaction and communication among students.

The utilization of augmented reality in pedagogy would allow students to study a variety of information in an interactive form, namely, to work with animated 3D models using only a mobile device (Medina Herrera et al., 2019; Ye et al., 2024). In addition, such a solution would allow distance learning to be conducted without spending money on proper equipment. Through direct interaction with interactive shapes, students will improve spatial visualization. By employing this application, students are able to manipulate augmented reality objects, exerting control over their movement, rotation, scaling, and perspective, thereby fostering the enhancement of spatial cognition.

In recent years, there has been a notable shift towards the dominance of mobile devices over desktop computers, reflecting a broader trend in technology consumption. This transition is accompanied by the widespread adoption of mobile internet, emphasizing the growing importance of on-the-go connectivity and accessibility. Additionally, the development of AR and virtual reality (VR) technologies has surged, marking significant advancements in immersive experiences and their integration into various industries and everyday life. These trends collectively signify a dynamic evolution in technology usage, with mobile devices, mobile internet, and AR/VR technologies playing pivotal roles in shaping the contemporary digital landscape.

Geometry education in Kazakh schools typically comprises two main sections: planimetry and stereometry, with two-dimensional objects being the focus in Grades 7-9. While the planimetry curriculum imparts foundational knowledge relevant to disciplines like physics, chemistry, and geography, its simplified content often fails to sufficiently engage students with spatial thinking or the understanding of geometric relationships. Consequently, when students progress to studying stereometry in the 10th grade, they frequently encounter challenges such as underdeveloped spatial thinking, difficulty constructing mental models, and struggle to perceive flat drawings as three-dimensional representations. Additionally, they may find it challenging to discern the interconnections between the elements of depicted three-dimensional objects or to mentally manipulate spatial arrangements. These obstacles underscore the need for a more comprehensive and interactive approach to geometry education that bridges the gap between planimetry and stereometry, fostering a deeper understanding of spatial concepts and their applications across disciplines.

At the Unified National Test – the system of assessing the knowledge of graduates used in the Republic of Kazakhstan – most students solve only planimetric problems and ignore geometric tasks in general. In this regard, the primary objective of this research is to examine the influence of augmented reality on students' spatial abilities and academic achievement to justify the introduction of such an educational application in geometry courses in Kazakh schools, which will provide students with useful interactive material that can improve the learning efficiency. Given the challenges Kazakh students face in spatial visualization and applying geometry concepts, this study investigates whether the integration of an augmented reality mobile application can enhance 10th-grade students' understanding of spatial relationships, 3D visualization abilities, and comprehension of geometry concepts in comparison to traditional instructional methods.

Geometry forms a crucial foundation of STEM education, fostering spatial cognition and logical reasoning skills needed for fields like engineering (Lin et al., 2016). However, many students struggle with visualizing and manipulating 3D geometric concepts (Rohendi et al., 2018). This presents a barrier to math proficiency. As Kazakhstan pursues digitization initiatives in education, interactive technologies like augmented reality (AR) offer the potential to enhance engagement and understanding. AR integrates virtual objects into real environments, facilitating visualization of abstract concepts. Though prior research shows promise, few rigorous studies have evaluated AR math applications (Ibáñez et al., 2020). This study addresses a key research gap by developing an AR-based mobile app called Geometria and experimentally testing its educational impact in a Kazakh secondary school. Findings will inform technology integration in Kazakhstan's STEM curriculum.

LITERATURE REVIEW

The assessment of educational quality encompasses the acquisition of knowledge, the cultivation of creative attributes, and the development of practical competencies essential for fulfilling social and professional responsibilities (Herppich et al., 2017). Geometric education and the attainment of geometric competencies should hold a prominent position in the comprehensive education of contemporary individuals (Pervushkina & Efimovich, 2015). As contemporary individuals exist within a material world characterized by inherent geometric structures, it is crucial to prioritize geometric education in their learning process (Kaigorodtseva, 2014; Kulyk, 2023). Nevertheless, as time progresses, novel realms of spatial perception, such as virtual spaces and multidimensional environments, along with advancements in digital and industrial technologies, have emerged (Suh & Prophet, 2018). Amidst these transformations, the fundamental principles of geometry not only endure their significance but also continue to evolve (Isak et al., 2023; Mammarella et al., 2017). Consequently, the objectives and methodologies of geometric orientation, as well as geometric education within the secondary education system of the Republic of Kazakhstan, ought to be reconfigured to incorporate the utilization of information and computer technologies.

The geometry course, which has a huge reserve of effective tools that serve the comprehensive development of students' thinking, the formation of research, and creative skills in general education schools, is not easy for many students (Rohendi et al., 2018). For many decades, methodologists and teachers have been solving one of the most pressing problems of the theory of teaching mathematics – how to effectively teach geometry at school. Discussions of scientists, teachers, and parents are unfolding on the pages of scientific journals in various forums on the Internet. The opinion is often expressed that one of the reasons for poor academic performance and a decrease in interest in studying geometry is the use of analytical teaching approaches that are incomprehensible to students. The logical thinking of students, especially at the very beginning of studying geometry, is not sufficiently developed, and imaginative thinking is not yet ordered (Bhagat & Chang, 2015).

Similar to any emerging technology, augmented reality (AR) presents both advantages and disadvantages. On one hand, it considerably broadens the horizons of the educational process. It is crucial for educational institutions to stay abreast of the evolving times and acquaint students with the tools they will encounter in the near future. AR can overlay digital information onto the real world, providing students with contextual information relevant to their surroundings. For example, history students can use AR to view historical landmarks and events in their actual locations, creating a more tangible connection to the past. Furthermore, AR enables personalized learning experiences by tailoring content to individual student needs and preferences. It can adapt to different learning styles, paces, and skill levels, providing customized instruction and feedback, thereby enhancing the effectiveness of learning. Also, this technology facilitates collaboration among students, as they can share their augmented experiences and work together on projects. It promotes teamwork, communication, and problem-solving skills, allowing students to learn from each other and engage in collective learning experiences. Besides, AR can provide equal opportunities for all learners, including those with disabilities. It can offer alternative modes of representation and sensory experiences, accommodating diverse learning styles and abilities (Ibáñez et al., 2020).

Despite the potential benefits, there may be disparities in access to AR technology, especially among disadvantaged communities or schools with limited resources. This can create a digital divide, where some students may not have equal opportunities to benefit from AR-enhanced education. Moreover, implementing AR in educational settings can be expensive, as it often requires specialized hardware, such as AR-enabled devices or headsets, and software development. Schools and institutions with limited budgets may face challenges in adopting AR technology. AR, if not properly managed, can become a distraction for students (Fernandez, 2017). It is essential to strike a balance between the use of AR and maintaining focus on educational objectives. Additionally, overreliance on AR could hinder the development of essential cognitive and problem-solving skills that can be honed through traditional learning methods. It is important to consider these advantages and disadvantages carefully while implementing AR in education, ensuring appropriate planning, training, and support to maximize its benefits and minimize potential drawbacks. The main gaps identified relate to the need for more rigorous, large-scale, and context-specific research evaluating AR applications for math and geometry education, as well as comparisons to other technologies and in-depth qualitative analysis of user experiences. While prior research shows promise for AR in education, there are few rigorous studies that have specifically evaluated AR applications for improving math and geometry outcomes.

MATERIALS AND METHODS

The main research methods are pedagogical experiments, observation, questionnaires, assessments, experimental work, methodological analysis, and expert evaluation. The methodology of the study encompassed both general scientific and specific cognitive methods. A pedagogical experiment, as a particular arrangement of educational activities involving teachers and students, was employed to test and validate preconceived theoretical assumptions or hypotheses (Sosnin & Poizner, 2017). The execution of the pedagogical experiment in this research encompassed the following stages:

1. The establishment of control and experimental groups comprising schoolchildren to evaluate the efficacy of digital technology utilization.
2. Implementation of a sequence of geometry lessons incorporating the use of digital technology in the experimental group and the absence of its use in the control group.
3. The creation of tasks to diagnose the level of knowledge based on the outcomes of the lessons.
4. Evaluation of students' knowledge within the control and experimental groups.

To integrate this technology into education, a mobile application named Geometria was developed. It utilizes augmented reality technology and offers an extensive range of features designed for both teachers and students. The application was developed for one of the geometry textbooks intended for tenth-graders. The Geometria augmented reality mobile app was developed using Unity 3D and the Vuforia SDK. Virtual 3D models and 2D drawings were imported into Unity to create interactive scenes linked to image targets. The app allows users to visualize and manipulate geometric shapes in 3D when viewing textbook images through their smartphone camera.

RESEARCH DESIGN

This study utilized a quantitative experimental design with a pedagogical experiment approach. A control group and an experimental group were established to compare traditional geometry instruction to an augmented reality-enhanced geometry curriculum. The independent variable was the integration of AR technology (Geometria app) in the experimental group. The dependent variables were students' spatial thinking skills and academic achievement in geometry, measured through pre-post testing. Thus, the study aimed to determine if using the Geometria AR app as an instructional tool results in significant improvements in spatial, 3D visualization, and overall geometry skills for 10th-grade students.

SAMPLE AND DATA COLLECTION

The sample consisted of 82 students of the 10th grade of a specialized boarding school No. 3 in the city of Kokshetau in Kazakhstan. They were evenly divided into a control group (n=42) and an experimental group (n=40) through random assignment. Both groups were given a pre-test on spatial thinking and geometry concepts prior to the intervention. The experimental group then participated in 5 geometry lessons over two weeks using the Geometria app on their mobile devices. Lessons were 40 minutes long and held in a classroom with desks arranged into groups.

Students worked through geometry problems in their textbooks while using Geometria to visualize shapes and constructions in 3D. The teacher provided guidance as needed. The control group covered the same curriculum during the same time period through traditional instruction without Geometria. After the intervention, both groups completed a post-test assessing spatial and geometry knowledge. To offer a comprehensive and detailed analysis of the students' proficiency post-intervention, the post-test scores were meticulously dissected and segmented based on three pivotal evaluation criteria. These criteria were carefully selected to align with both the curriculum's objectives and the capabilities of the Geometria application:

1. **Spatial Relationships:** This criterion was designed to measure the students' aptitude in discerning the position and relation of geometric shapes and objects in a given space. Assessments tailored to this criterion involved tasks that required students to identify, compare, and evaluate the positioning of various geometric entities in relation to one another.
2. **3D Visualization:** Given the Geometria application's focus on augmented reality and three-dimensional representation, this criterion was paramount. Evaluations under this segment aimed at understanding students' capability to perceive, interpret, and mentally manipulate three-dimensional structures. Tasks involved the transformation of 2D representations into 3D visualizations and vice versa, as well as the rotation and analysis of 3D geometric shapes.
3. **Geometry Concepts:** This broader criterion encompassed foundational to advanced principles of geometry. Assessments were designed to gauge the depth of students' understanding of geometric postulates, theorems, properties, and proofs. Questions ranged from basic shape identification to more intricate problems involving geometric reasoning and problem-solving.

For each of these criteria, a series of 20 questions and tasks were formulated, ensuring they spanned a range of difficulty levels and effectively captured the essence of the respective competency. Tests were scored from 0% to 100%. The scores from these segments were then aggregated to derive individual and group averages, facilitating a comparative analysis between the control and experimental groups.

A questionnaire gathered qualitative feedback about students' perceptions of Geometria (Herwin et al., 2023). It included five Likert scale ratings and open-ended questions. The same teachers were involved in both groups to control instructor effects.

ANALYZING OF DATA

Students' pre-test and post-test scores were statistically analyzed using t-tests to determine significant differences between the control and experimental groups. Qualitative data was also collected through teacher and student feedback surveys about using the Geometria app. Their responses were reviewed for common themes and reactions to the AR technology intervention.

RESEARCH STAGES

The research was conducted in several key stages. First, the Geometria augmented reality mobile application was developed using Unity 3D and the Vuforia SDK to allow visualization and manipulation of 3D geometric shapes linked to images from a 10th-grade geometry textbook. Next, 82 students from a specialized boarding school were randomly assigned to a control group (n=42) and an experimental group (n=40). Both groups took a pre-test assessing spatial thinking and geometry knowledge. Then, the experimental group participated in five lessons over two weeks where they used the Geometria app on their mobile devices to work through geometry problems, while the control group covered the same material through traditional instruction methods. After the intervention period, both groups completed a post-test evaluating spatial relationships, 3D visualization, and geometry concepts comprehension. The experimental group also provided feedback on the Geometria app through a questionnaire. Finally, the pre/post-test scores and questionnaire data were analyzed to compare learning outcomes and student perceptions between the two groups.

RESULTS

DESIGN AND DEVELOPMENT OF THE SOFTWARE

The C# programming language was used to develop the application. For computer vision, the Vuforia SDK library was used, which is well combined with the Unity 3D platform, which is a tool for developing two-dimentional and three-dimensional applications and games. The necessary images for markers were added to the Vuforia platform, which will have key features identified and subsequently entered into a special database. The generated database should be downloaded and imported into the Unity project: with the help of the information contained in it, markers will be determined on the general image from the camera. Three-dimensional objects and two-dimensional drawings made in special software are also imported into the project. The main working objects of the application are: ARCamera – an augmented reality camera; ImageTarget – a target for working with flat markers; and VirtualButton – a virtual button. To control the application using a virtual button, it is necessary to bind a Script to the target, and then prescribe the actions performed in it. Figure 1 depicts a captured image of the progress of one of the scenes in the Unity 3D development environment.

To utilize the application, users must initiate its operation and align the camera of their smartphone or tablet with the image displayed in the textbook. The main advantage of using augmented reality in the created mobile application is that students can really see three-dimensional objects that they previously had to imagine, calculate, and build using conventional methods such as paper and pen. Using virtual controls, users can rotate the object, change its scale, and, if necessary, change the representation to a two-dimensional drawing object. These models empower users to delve deep into the intricacies of complex geometric shapes, allowing them to rotate and view these figures from a myriad of angles. An example of how the application operates is shown in Figure 2.

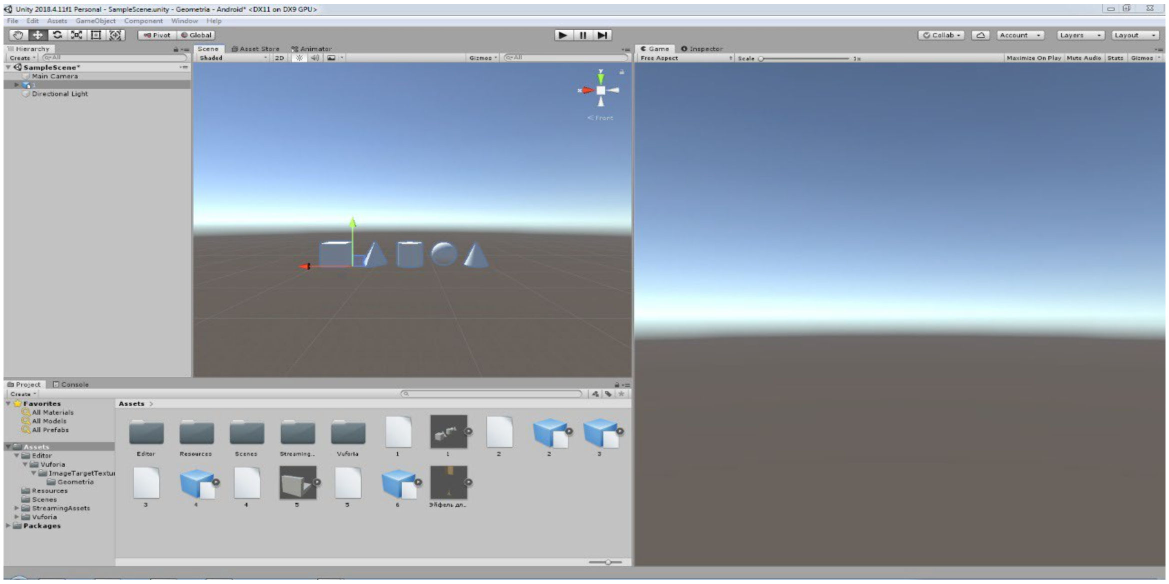

Figure 1. The application scene in unity

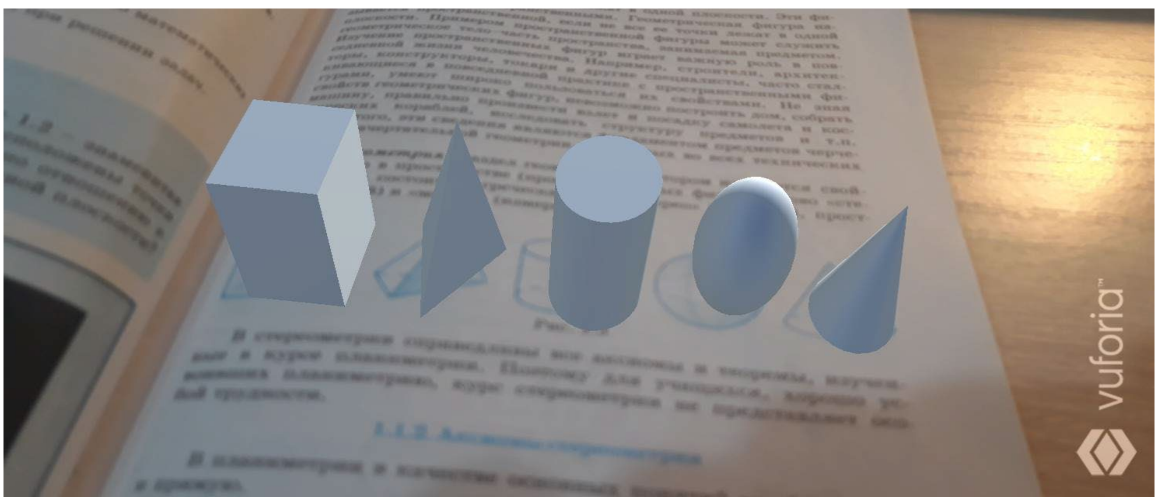

Figure 2. Application operation

Geometria's design prioritizes user experience. Keeping its primary users in mind, which are 10th-grade students, the interface is crafted to be intuitive and user-friendly, ensuring that students can effortlessly navigate and capitalize on all its features.

Evaluation of the software

The application was tested at geometry lessons in the regional specialized boarding school No. 3, in the city of Kokshetau, among students of the 10th grade. During the research, a cohort of 82 students was divided into two distinct groups, namely the control group and the experimental group. A preliminary assessment was administered to students in both groups. Subsequently, a sequence of five lessons integrating augmented reality was conducted for 40 students in the experimental group, while 42 students in the control group underwent conventional subject-related instruction. Following the completion of the geometry lessons, a post-test was administered. The results of the tests are presented in Table 1.

Table 1. Application operation

Group	Pre-test mean score (%)	Post-test mean score (%)	Change (%)
Control	64.5	67.5	+3.0
Experimental	64.0	75.0	+11.0

At the onset of the study, both the control and experimental groups showcased nearly identical competencies in geometry, as reflected by their closely matched pre-test mean scores of 64.5% and 64.0%, respectively. This similarity ensured that any subsequent differences in post-test scores could be primarily attributed to the teaching methods employed rather than initial disparities in the groups' understanding of geometry.

Upon completion of the study's intervention phase, distinct variations were observed between the two groups. The control group, which was taught using conventional methods, exhibited a modest improvement in their understanding, with an increase of 3.0% in their mean score, elevating it to 67.5%. On the other hand, the experimental group, which was introduced to the Geometria application, manifested a more substantial enhancement in their comprehension of geometry concepts. Their post-test mean score surged by 11.0%, culminating at a notable 75.0%. In essence, while both groups experienced advancements in their geometry proficiency, the experimental group's gains were almost four times greater than that of the control group.

Figure 3 provides a granular breakdown of the post-test results, segmenting the scores into three pivotal evaluation criteria: Spatial Relationships, 3D Visualization, and Geometry Concepts.

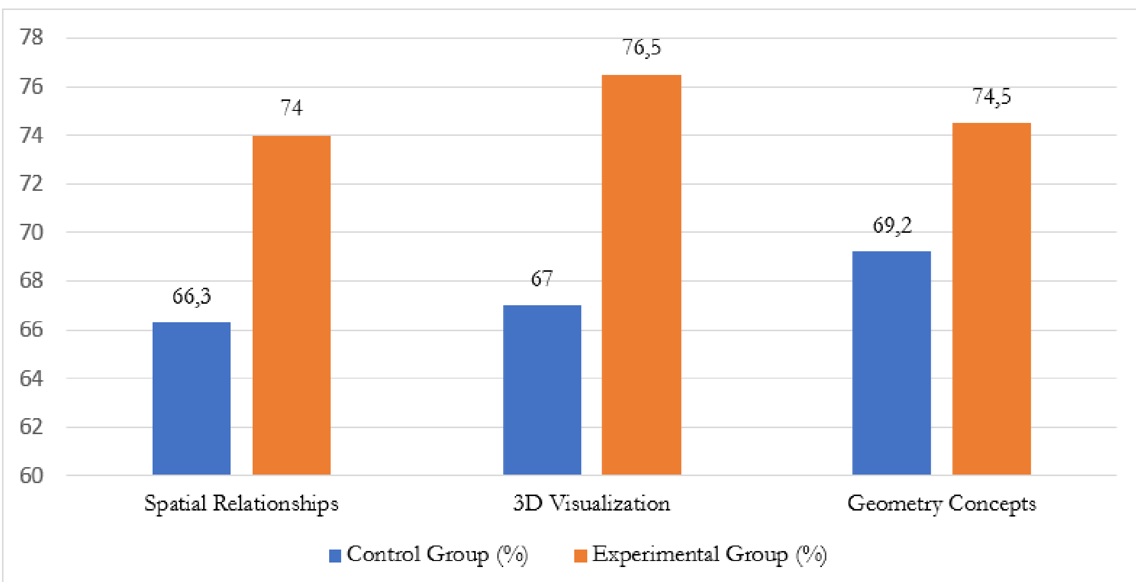

Figure 3. Difference in post-test mean scores between the control and experimental groups

For Spatial Relationships, which evaluates students' ability to discern and understand the position of shapes and objects in relation to one another, the control group scored a mean of 66.3%. In contrast, the experimental group, which utilized the Geometria application, showcased a substantially enhanced understanding with a score of 74.0%. This indicates that the application might significantly aid students in grasping spatial relationships.

Diving into 3D Visualization, an area intrinsically linked to Geometria's augmented reality features, the distinction becomes even more pronounced. The control group secured a mean score of 67.0%, while the experimental group demonstrated a remarkable score of 76.5%. Given the 9.5% difference between the groups, it is evident that the Geometria application could be highly beneficial in helping students visualize geometric concepts in three dimensions.

Lastly, for Geometry Concepts, which gauges the students' overall grasp of foundational and advanced geometry principles, the control group achieved a score of 69.2%. The experimental group, having been exposed to the Geometria application, managed to surpass this with a score of 74.5%. Although the difference here is more subtle than the previous criteria, the experimental group's advantage remains noticeable, suggesting that the Geometria application can elevate the general understanding of geometry concepts.

In summation, Figure 3 reveals that across all evaluation criteria, students who were exposed to the Geometria application consistently outperformed those who engaged with traditional teaching methods. The most significant gains were observed in areas directly related to the application's augmented reality capabilities, emphasizing the potential of such technologies in enhancing geometry education.

Table 2 offers a comprehensive analysis of the feedback scores provided by students concerning their experience with the Geometria software. Feedback was collected on a Likert Scale, ranging from 1 to 5, with higher scores indicating more positive responses.

Table 2. Summary of feedback scores from students regarding the Usability and Effectiveness of Geometria

Feedback parameter	Average Likert scale rating (out of 5)
Usability	4.3
Effectiveness in Understanding	4.5
Engagement Level	4.6
Preference over Traditional Methods	4.4
Willingness to Continue using Geometria	4.5

The first feedback parameter, Usability, assesses how user-friendly and intuitive students found the Geometria application. With an average rating of 4.3 out of 5, it is evident that the majority of the students found the application to be easy to navigate and interact with, underscoring the application's thoughtful design tailored to its target demographic.

The parameter Effectiveness in Understanding captures whether students felt the application enriched their grasp of geometry concepts. The score of 4.5 suggests that the Geometria application not only aids in visual representation but substantially enhances conceptual understanding as well.

Engagement Level, which gauges the students' interest and involvement while using the application, received an impressive score of 4.6. This high rating underscores the application's capability to capture and retain student interest, making learning fun and interactive.

When students were asked about their Preference over Traditional Methods, the application again received positive feedback with a score of 4.4. This implies that the majority of students found the augmented reality approach more appealing and beneficial compared to conventional teaching techniques.

Lastly, the Willingness to Continue Using Geometria parameter serves as a testament to the application's potential long-term adoption in the learning process. A score of 4.5 suggests that students are not only content with the current experience but are also keen on integrating the application into their future learning endeavors.

In essence, Table 2 reflects an overwhelmingly positive reception of the Geometria software by the students across various parameters. The consistently high Likert Scale ratings emphasize the application's potential in revolutionizing the traditional geometry learning experience.

The findings indicate that using augmented reality to teach fundamental geometry concepts may offer a marginally superior instructional approach. Specifically, the post-experiment results revealed that nearly all participants, with the exception of four individuals, exhibited improvements in their pre-test scores. Furthermore, a noteworthy proportion of the participants, specifically ten out of the 40 individuals, achieved excellent grades following the intervention. Thus, it can be noted that a positive experience of using augmented reality when studying stereometry has been obtained.

DISCUSSION

The data gathered from this study provides a compelling insight into the transformative potential of integrating augmented reality into traditional geometry education. The central focus of this investigation was to assess the efficacy of the Geometria application, an AR tool designed to bolster the comprehension and visualization of geometric concepts.

A pivotal observation is the stark contrast in learning outcomes between the control and experimental groups. While both cohorts began with nearly identical baseline knowledge, as evidenced by their pre-test scores, the disparities in post-test outcomes are profound. The moderate improvement in the control group's scores attests to the gradual learning curve typically associated with conventional teaching methodologies. Conversely, the substantial surge in the experimental group's post-test scores underscores the catalytic role that tools like Geometria can play in accelerating and deepening learning. Such findings resonate with existing literature that emphasizes the benefits of interactive and immersive learning environments, particularly in subjects like geometry that often require a spatial and three-dimensional understanding.

Delving deeper into specific geometric competencies, the results further elucidate areas where AR tools might have a pronounced impact. For instance, the most significant performance gap between the two groups was in 3D visualization – a competency directly linked to Geometria's AR capabilities. This underscores that while traditional methods provide foundational knowledge, AR tools like Geometria can bridge the gap between two-dimensional representations and three-dimensional comprehension. Such a bridge is pivotal in a subject like geometry, where visualizing concepts in space can drastically enhance understanding.

Feedback from students, as encapsulated in the Likert Scale ratings, further amplifies the potential of Geometria. High scores across usability and engagement parameters highlight that not only is the application educationally effective, but it also resonates with the preferences and inclinations of its primary users: 10th-grade students. The willingness of these students to continue using Geometria suggests the application's potential for sustainable integration into the curriculum.

These findings align with prior research showing the benefits of augmented reality for spatial cognition and STEM education more broadly (C. H. Chen et al., 2015; Ibáñez et al., 2020). The results add to the literature by demonstrating the viability of implementing AR apps like Geometria at scale in Kazakh schools to improve national geometry and math outcomes. Widespread adoption faces barriers like teacher training and overreliance on technology, but the study shows the promise of AR as an inclusive educational tool.

Analyzing the current situation with the introduction of augmented reality in the Kazakh education system, it was concluded that, unfortunately, today there is no clear movement on these matters. Moreover, there are no programs that allow incorporating augmented reality technologies into the educational system. The conservatism of teachers and the leadership of educational institutions regarding new technological ideas hinder the creation and application of such a practical technology in the field of education, which could help significantly speed up the process of perception and increase the efficiency of teaching geometry. Nonetheless, numerous specialists in the realm of digital technologies concur that augmented reality holds promising prospects for various domains of human existence in the future (Y. C. Chen, 2019; Lin et al., 2016).

From a pedagogical standpoint, the use of augmented reality is justified because it allows for solving a number of didactic tasks, increases the motivation of students (Bacca et al., 2019), promotes the development of skills to work with modern technologies, expands the forms of presentation of educational content. The incorporation of these instructional materials into teaching practices amalgamates the sensory experiences of touch and sight with the process of learning, thereby facilitating the comprehension of essential mathematical concepts associated with three-dimensional space (Medina Herrera et al., 2019). Augmented reality is of great interest; it allows teachers to make the lessons fascinating and understandable.

From the standpoint of the teacher's resource costs, the preparation of augmented reality elements does not require significant time from the teacher. A once-conducted instruction on working with the augmented reality program among students allows using the tags repeatedly during subsequent training. Fernandez (2017) proposes a six-step approach aimed at integrating these technologies as fundamental components within traditional education. The methodology includes teacher training, conceptual prototyping, collaborative efforts involving a teacher, a technical programmer, and an educational architect, and practical experience acquisition, which yields outcomes for the subsequent two stages. In these stages, teachers receive training to implement augmented reality solutions as part of their instructional methodology, drawing from their existing subject-specific expertise. Finally, they apply their acquired experience on a regular basis.

In addition, the teacher can manage tags anywhere and at any time without the need to inform students about changes. Economic feasibility is explained by the fact that the services used are free, and students only need smartphones to start working with them. This approach enhances the cultivation of practical geometric competencies among students through personalized education, fostering independent learning and facilitating differentiated instruction (Kiss & Gastelú, 2015; Rambousek et al., 2015).

Future research could examine the long-term impacts of AR geometry instruction across demographic factors like gender, socioeconomic status, and geographic region. Comparisons between AR apps and other educational technologies would also be beneficial. While this initial study was limited to one school, larger trials are warranted.

Overall, the Geometria experiment highlights the potential of augmented reality to transform STEM education in Kazakhstan. Visualization and hands-on learning can make geometry engaging and understandable for more students. However, while the results are promising, it is essential to approach them with a degree of caution. The sample size, though reasonably representative, is limited to a specific demographic within a singular educational institution. It would be beneficial for future research to replicate this study across diverse settings to ascertain the universal applicability of these findings. AR presents advantages but also risks like distraction and inequality, requiring ongoing research and careful implementation. Further integration of augmented reality can help develop students' spatial abilities and prepare Kazakhstan's next generation for success in the digital world.

CONCLUSIONS

The findings of this study provide compelling evidence supporting theoretical arguments that geometry education should evolve to incorporate emerging technologies like augmented reality (AR) to enhance students' spatial cognition and ability to visualize abstract 3D concepts. The results demonstrated that integrating the Geometria AR application into geometry instruction yielded significant improvements in students' understanding of spatial relationships and 3D visualization skills compared to traditional teaching methods alone.

These outcomes align with existing theoretical frameworks that posit that immersive, interactive technologies can facilitate the translation of 2D geometric representations into accurate 3D mental models. By allowing direct manipulation of virtual 3D shapes, the Geometria app seemingly bridged conceptual gaps that often hamper students' comprehension when relying solely on static diagrams and illustrations. The authentic 3D visualization experience provided by AR apps like Geometria maps onto theoretical principles, emphasizing the importance of cultivating robust spatial thinking abilities for success in STEM fields.

Moreover, the overwhelmingly positive student feedback affirms theoretical propositions about AR's potential to boost engagement and maintain motivation for abstract STEM topics like geometry. By creating an immersive, hands-on learning environment aligned with contemporary students' digital inclinations, the Geometria application appeared to reinforce conceptual understanding while fostering interest and enthusiasm. While limitations exist regarding generalizability and comparisons to other technologies, this study serves as an empirical cornerstone substantiating long-standing theoretical arguments for adopting computer-based visualization and simulation tools in mathematics education.

References

Akçayır, M., & Akçayır, G. (2017). Advantages and challenges associated with augmented reality for education: A systematic review of the literature. *Educational Research Review*, *20,* 1-11. https://doi.org/10.1016/j.edurev.2016.11.002

Bacca, J., Baldiris, S., Fabregat, R., & Kinshuk, K. (2019). Framework for designing motivational augmented reality applications in vocational education and training. *Australasian Journal of Educational Technology, 35*(3), 102-117. https://doi.org/10.14742/ajet.4182

Bhagat, K. K., & Chang, C. Y. (2015). Incorporating GeoGebra into geometry learning – A lesson from India. *Eurasia Journal of Mathematics, Science and Technology Education, 11*(1), 77-86. https://doi.org/10.12973/eurasia.2015.1307a

Chen, C. H., Ho, C.-H., & Lin, J.-B. (2015). The development of an augmented reality game-based learning environment. *Procedia – Social and Behavioral Sciences, 174,* 216-220. https://doi.org/10.1016/j.sbspro.2015.01.649

Chen, Y. C. (2019). Effect of mobile augmented reality on learning performance, motivation, and math anxiety in a math course. *Journal of Educational Computing Research, 57*(7), 1695-1722. https://doi.org/10.1177/0735633119854036

Fernandez, M. (2017). Augmented-virtual reality: How to improve education systems. *Higher Learning Research Communications, 7*(1), 1-15. https://doi.org/10.18870/hlrc.v7i1.373

Forbes Education. (2020). https://education.forbes.ru/authors/online-education-vs-covid.

Gloria, R., & Benjamin, A. E. W. (2018). Attitude of teachers towards techno-pedagogy. *International Journal of Engineering Technologies and Management Research, 5*(4), 87-89. https://doi.org/10.29121/ijetmr.v5.i4.2018.212

Government of the Republic of Kazakhstan. (2017, December 12). *Resolution of the Government of the Republic of Kazakhstan. On approval of the State program "Digital Kazakhstan".* (2017). https://online.zakon.kz/document/?doc_id=37168057#pos=5;-106

Hattie, J. A. S. (2017). *Visible learning: Synthesis of the results of over 50,000 studies, reaching over 86 million students*. Natsionalnoye Obrazovaniye.

Herppich, S., Praetorius, A.-K., Förster, N., Glogger-Frey, I., Karst, K., Leutner, D., Behrmann, L., Böhmer, M., Ufer, S., Klug, J., Hetmanek, A., Ohle-Peters, A., Böhmer, I., Karing, C., Kaiser, J., & Südkamp, A. (2017). Teachers' assessment competence: Integrating knowledge-, process-, and product-oriented approaches into a competence-oriented conceptual model. *Teaching and Teacher Education, 76,* 181-193. https://doi.org/10.1016/j.tate.2017.12.001

Herwin, H., Prasojo, L. D., Saptono, B., & Dahalan, S. C. (2023). Analyzing the impact of augmented reality on student motivation: A time series study in elementary education. *Ingénierie Des Systèmes D Information, 28*(5), 1197-1203. https://doi.org/10.18280/isi.280507

Ibáñez, M. B., Portillo, A. U., Cabada, R. Z., & Barrón, M. L. (2020). Impact of augmented reality technology on academic achievement and motivation of students from public and private Mexican schools. A case study in a middle-school geometry course. *Computers & Education, 145,* 103734. https://doi.org/10.1016/j.compedu.2019.103734

Isak, L., Babak, O., & Hren, Y. (2023). Digital Tools in professional education training. *Professional Education: Methodology, Theory and Technologies*, *18*, 104-125. https://doi.org/10.31470/2415-3729-2023-18-104-125

Kaigorodtseva, N. V. (2014). Geometry, geometric thinking and geometric-graphic education. *Modern Problems of Science and Education*, *2*. http://science-education.ru/ru/article/view?id=12330

Kiss, G., & Gastelú, C. A. T. (2015). Comparison of the ICT literacy level of the Mexican and Hungarian students in the higher education. *Procedia – Social and Behavioral Sciences*, *174,* 137-142. https://doi.org/10.1016/j.sbspro.2015.01.546

Kulyk, O. (2023). Digitalization of education: The experience of France. *Professional Education: Methodology, Theory and Technologies*, *17*, 108-128. https://doi.org/10.31470/2415-3729-2023-17-108-128

Lin, C. Y., Chai, H. C., Wang, J. Y., Chen, C. J., Liu, Y. H., Chen, C. W., Lin, C. W., & Huang, Y. M. (2016). Augmented reality in educational activities for children with disabilities. *Displays, 42,* 51-54. https://doi.org/10.1016/j.displa.2015.02.004

Mammarella, I. C., Giofrè, D., & Caviola, S. (2017). Learning geometry: The development of geometrical concepts and the role of cognitive processes. In D. C. Geary, D. B. Berch, R. J. Ochsendorf, K. Mann Koepke (Eds.), *Acquisition of complex arithmetic skills and higher-order mathematics concepts* (pp. 221-246). Elsevier. https://doi.org/10.1016/B978-0-12-805086-6.00010-2

Medina Herrera, L., Castro Pérez, J., & Juárez Ordóñez, S. (2019). Developing spatial mathematical skills through 3D tools: Augmented reality, virtual environments and 3D printing. *International Journal on Interactive Design and Manufacturing, 13,* 1385-1399. https://doi.org/10.1007/s12008-019-00595-2

Pervushkina, E. A., & Efimovich, J. A. (2015). One of ways of realization of competence-based approach to training of geometry at school. *Young Scientist, 14,* 513-517.

Rambousek, V., Štípek, J., & Wildová, R. (2015). ICT competencies and their development in primary and lower-secondary schools in the Czech Republic. *Procedia – Social and Behavioral Sciences, 171,* 535-542. https://doi.org/10.1016/j.sbspro.2015.01.158

Rohendi, D., Septian, S., & Sutarno, H. (2018). The use of geometry learning media based on augmented reality for junior high school students. *IOP Conference Series: Materials Science and Engineering, 306,* 12029. https://doi.org/10.1088/1757-899X/306/1/012029

Shyshenko, I., Lukashova, T., Drushlyak, M., & Hvorostina, Y. (2024). Ways to develop soft skills in pre-service mathematics and physics teachers when studying certain topics of Olympiad mathematics. *Scientific Bulletin of Mukachevo State University. Series "Pedagogy and Psychology," 10*(1), 56-67. https://doi.org/10.52534/msu-pp1.2024.56

Sosnin, E. A., & Poizner, B. N. (2017). *Experiment methodology*. Inform-M.

Suh, A., & Prophet, J. (2018). The state of immersive technology research: A literature analysis. *Computers in Human Behavior, 86,* 77-90. https://doi.org/10.1016/j.chb.2018.04.019

Ye, S. H., Onpium, P., & Ying, F. (2024). The effectiveness of a 3D interactive learning environment as a mechanism for sharing and retaining knowledge. *Scientific Bulletin of Mukachevo State University. Series "Pedagogy and Psychology," 10*(2), 17-28. https://doi.org/10.52534/msu-pp2.2024.17

AUTHORS

Galiya K. Beisenbayeva is a Doctoral Student at the Department of Physics and Mathematics, Sh. Ualikhanov Kokshetau University, Republic of Kazakhstan. Her research interests are the secondary education system, AR's role in the modernization of education, and the integration of augmented reality in secondary education.

Akan M. Mubarakov is a Full Doctor in Pedagogy and a Professor at the Department of Computer Science, L.N. Gumilyov Eurasian National University, Republic of Kazakhstan. His scientific interests are the impact of digital transformation in education, the effectiveness of AR apps in geometry learning, and equity in access to educational technologies.

Zoya T. Seylova has a PhD in Pedagogy and is an Associate Professor in the Department of Higher Mathematics, S. Seifullin Kazakh Agrotechnical University, Republic of Kazakhstan. Her research interests are enhancing spatial visualization through digital tools, student engagement with AR in education, and the use of AR in improving geometry proficiency.

Larissa U. Zhadrayeva has a PhD in Pedagogy and is an Associate Professor in the Department of Mathematics, Physics, and Informatics Teaching Methods, Abai Kazakh National Pedagogical University, Republic of Kazakhstan. Her scientific interests include learning geometry, AR-assisted teaching methodologies, and future trends in educational AR technology.

Botagoz N. Artymbayeva is a Lecturer at the Department of Russian Language and Literature, Nazarbayev Intellectual School of Chemistry and Biology in Petropavlovsk, Republic of Kazakhstan. Her scientific interests are traditional teaching methodologies in secondary geometry education and educational innovations through digital technologies.