Visualisation of educational material in geometry using digital technologies on the Unity 3D platform

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Abstract

Relevance. Digital technologies are progressively being incorporated into the educational framework. Training with the use of digital technologies corresponds to the modern way of life, which is inextricably linked with access to, receipt, and use of information. This entails the modernization of not only the content of education, but also the forms, methods, and means of teaching.

Purpose. This study aims to investigate the impact of augmented reality on the spatial abilities and academic performance of students. It involves the development and testing of an educational application for geometry classes to provide interactive material and improve learning efficiency.

Methodology. The study used pedagogical experiments, observations, and assessments. The Geometria mobile application with augmented reality for visualizing spatial geometry problems was developed for a tenth-grade geometry textbook.

Results. The study involved 40 tenth-graders studying the section "Parallelism in Space". Following the experiment, all participants except for four demonstrated improvements in their prior test outcomes, with ten out of nineteen participants achieving outstanding grades. According to the study results, teachers and students noted the originality of this product and the fact that its use increased the visibility and understanding of the geometric material.

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Conclusions. A positive experience of using augmented reality technology in the study of stereometry has been obtained. The study highlights the effectiveness of augmented reality in enhancing students' spatial abilities and academic performance in geometry. The results suggest that incorporating digital technologies like augmented reality can significantly improve learning outcomes and engagement in educational settings.

Keywords: secondary education system; geometry; spatial thinking; stereometry.

Introduction
Today, the informatisation of education is aimed at shifting the paradigm from conventional teaching methods with the use of chalk and blackboard to the digitalisation of the pedagogical process using technical means [1]. The active introduction of e-learning and the digitalisation 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, in the foreseeable future, Kazakhstan's education is waiting for online training, a cloud-based distance learning system, a digital ID passport for each student, interactive educational content [2]. 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, personalised and adaptive learning is being developed for each student and active teacher training is being conducted, explanatory work is being conducted with parents.

By 2020, the volume of investment in educational technologies in the world has exceeded USD 250 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 USD 350 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 [3].

The author of the world's largest study on evidence-based pedagogy, J.A.S. Hattie [4] 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 to 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.

The study highlights the main trends in the development of technologies that have occurred in recent years:
- replacement of desktop computers with mobile devices;
- widespread use of the mobile internet;
- development of augmented reality technologies – augmented and virtual.

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 [5]. Geometric education and the attainment of geometric competencies should hold a prominent position in the comprehensive education of contemporary individuals [6]. As contemporary individuals exist within a material world characterized by inherent geometric structures, it is crucial to prioritize geometric education in their learning process. [7]. 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 [8]. Amidst these transformations, the fundamental principles of geometry not only endure their significance but also continue to evolve [9]. 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, and the formation of research and creative skills in general education schools, is not easy for many students [10]. 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, on 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 [11].

Geometry at school is divided into 2 sections: planimetry and stereometry. Two-dimensional objects are studied in the geometry course in grades 7-9 in Kazakh schools. The knowledge obtained during the study of planimetry is necessary for such disciplines as physics, chemistry, and geography. However, due to the fact that the content of the planimetry course is too simplified, students do not work with spatial figures, do not develop their imagination and do not understand the adequate relationship between geometric figures and surrounding figures. When studying stereometry in the 10th grade, many students face the following difficulties:
- poorly developed spatial thinking;
- inability to build a figurative model;
- inability to perceive a flat drawing as a spatial one;
- inability to determine the relationships between the individual elements of the depicted three-dimensional objects;
The authors of this study used the developments of scientists on issues related to interactive multimedia tools that can be used to study geometry, the results of the author's research and teaching experience. In this study, the following objectives were accomplished: identification of the primary challenges encountered in the teaching of geometry within the secondary education system of Kazakhstan; also, a mobile application with elements of augmented reality for visualisation of geometric material was proposed.

The main research methods are pedagogical experiment, observation, questionnaire, assessment, experimental work and its methodological analysis, and the method of 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 [17]. 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. Creation of tasks for diagnosing 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.

Results and Discussion

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-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 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. An example of how the application operates is shown in Figure 2.

Figure 2. Application operation

This mobile application can be used as an auxiliary tool for solving stereometric problems within the framework of a cognitive-visual approach to teaching mathematics [18]. The application was tested at geometry lessons in the regional specialised boarding school No. 3, in the city of Kokshetau among students of the 10th grade. During the research, a cohort of 40 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 19 students in the experimental group, while 21 students in the control group underwent conventional subject-related instruction. Following the completion of the geometry lessons, a post-test was administered.
Subsequently, a statistical analysis was performed to assess and compare the scores obtained by both groups.

The findings indicate that the utilization of augmented reality in teaching fundamental geometry concepts may offer a marginally superior instructional approach. Specifically, the post-experiment results revealed that nearly all participants, except four individuals, exhibited improvements in their pre-test scores. Furthermore, a noteworthy proportion of the participants, specifically ten out of the 19 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. Teachers and students noted the originality of this product and the fact that its use increased the visibility and understanding of the geometric material. The students showed independence in using the application, creating personal ways of interacting with the augmented reality. According to the students, visual cues helped to understand the essence of the tasks, and subsequent tasks are performed more easily even without using the application, since it is possible to build analogies.

Analysing 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 programmes 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 [19; 20].

From a pedagogical standpoint, the use of augmented reality is justified, because it allows solving some didactic tasks, increases the motivation of students [21], 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 [16]. The 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. M. Fernandez [13] 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 regularly.

In addition, the teacher can manage tags anywhere and at any time without the need to inform students about changes. The economic feasibility is explained by the fact that the services used are free, and students require only 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 [22; 23; 24].

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. Educational institutions must stay abreast of the evolving times and acquaint students with the tools they will encounter shortly. 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, pace, and skill levels, providing customized instruction and feedback, thereby enhancing the effectiveness of learning.

In addition, 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 [15]. 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 [13]. 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 carefully consider these advantages and disadvantages while implementing AR in education, ensuring appropriate planning, training, and support to maximize its benefits and minimize potential drawbacks.
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Conclusions
Based on the conducted research, it can be concluded that it is advisable to use modern services for generating augmented reality objects when teaching geometry. The use of digital technologies allows for revising the established approaches to studying geometry since their use in teaching geometry is relevant not only because of their rapid development and penetration into education but also because of the specifics of the subject. Simultaneously, the utilization of digital technologies in pedagogy should extend beyond mere illustration of oral presentations, encompassing the full range of their capabilities, including visual representation, modelling, and dynamic interaction.

Primarily, augmented reality can be employed in the educational process as a supplementary tool to enhance the visibility and interactivity of the subject matter, facilitating a more immersive learning experience. The integration of augmented reality goes beyond the study of stereometry and extends to project-based tasks, enabling the visualization and interactive exploration of students' project outcomes. The effectiveness of the use of this technology is entirely determined by the level of organisation of the educational process. Achieving a favourable outcome necessitates a well-defined, coherent, and logically interconnected arrangement of all components involved in the teacher-student activities. Thus, augmented reality is a technology with huge potential and excellent pedagogical opportunities. This approach enables the teacher to engage students in research, create educational scenarios, and utilize contemporary technologies, tools, and methodologies to attain a superior outcome. The mobile application can be used as an auxiliary tool for solving stereometric problems within the framework of a cognitive-visual approach to teaching mathematics.

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Conflict of Interest
None.

References


Візуалізація навчального матеріалу з геометрії з використанням цифрових технологій на платформі Unity 3D

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Анотація

Актуальність. Цифрові технології поступово впроваджуються в освітній простір. Навчання з використанням цифрових технологій відповідає сучасному способу життя, який нерозривно пов'язаний з доступом, отриманням і використанням інформації. Це тягне за собою модернізацію не лише змісту освіти, а й форм, методів та засобів навчання.

Мета. Метою дослідження є вивчення впливу доповненої реальності на просторові здібності та академічну успішність студентів. Воно передбачає розробку та тестування освітнього додатку для занять з геометрії, який забезпечить інтерактивність матеріалу та підвищить ефективність навчання.

Методологія. У дослідженні використовувалися педагогічні експерименти, спостереження та оцінки. Мобільний додаток Geometria з доповненою реальністю для візуалізації задач з просторової геометрії було розроблено для підручника геометрії для десятого класу.

Результати. У дослідженні взяли участь 40 десятикласників, які вивчали розділ "Паралельність у просторі". Після експерименту всі учасники, окрім чотирьох, продемонстрували покращення результатів попередніх тестів, а десять з дев'ятнадцяти учасників отримали відмінні оцінки. За результатами дослідження, вчителі та учні відзначили оригінальність цього продукту і те, що його використання підвищило наочність і розуміння геометричного матеріалу.

Висновки. Отримано позитивний досвід використання технології доповненої реальності при вивченні стереометрії. Дослідження підкреслює ефективність доповненої реальності для покращення просторових здібностей учнів та академічної успішності з геометрії. Результати свідчать про те, що впровадження цифрових технологій, таких як доповнена реальність, може значно покращити результати навчання та залучення до освітнього процесу.

Ключові слова: система середньої освіти; геометрія; просторове мислення; стереометрія.