Immersive learning tools for teaching mathematics to high school students in general secondary education institutions

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Abstract

For the dynamic and sustainable development of an individual throughout life, the ability to shape a personal learning trajectory, communicate and collaborate in a team, prioritize life goals, and achieve them becomes a key aspect. Forming this kind of personality is one of the objectives of general secondary education institutions. Creating an educational environment that allows every student to realize their potential is impossible without innovative technologies, among which immersive technologies stand out as some of the most progressive. The use of immersive technologies in the educational process for high school students makes this process dynamic and engaging due to the interactivity of such technologies and their high level of visual representation. In Ukraine's secondary education system, the practice of implementing immersive technologies has demonstrated their effectiveness by increasing motivation to learn, which, in turn, has led to better academic performance. This study focuses on the use of immersive technologies in the teaching of mathematics to high school students in general secondary education institutions. Scientific literature highlights four main topics regarding the use of immersive technologies in education: 1) the impact of immersive technologies on learning outcomes; 2) the use of immersive technologies for learning and simulation; 3) the influence of immersive technologies on interaction and user engagement; 4) ethical and social implications of immersive technologies. In Ukrainian secondary education institutions, platforms for immersive learning include developments from both Ukraine and other countries. These platforms, such as AR Book, mozaBook, GeoGebra, and Desmos, are user-friendly, require no software installation, allow interaction with educational materials, and include both pre-designed tasks and the ability for students to create their own projects.

Keywords

immersive tools for teaching mathematics, high school students, general secondary education institutions, immersive learning platforms, AR Book, mozaBook, GeoGebra, Desmos

1. Introduction

According to the State Standard for Specialized Secondary Education in Ukraine [1], one of the key objectives of teaching in academically oriented high schools is to develop students' competency potentials, reflected in learning outcomes.

Among the identified competency potentials essential for a high-quality and effective learning process in mathematics for students of academic high schools, we consider:

- *mathematical competency*, which involves the ability to develop and apply mathematical knowledge and methods to solve a wide range of real-world problems, model processes and situations using mathematical tools, and understand the role of mathematical knowledge and skills in personal and societal life;
- *information and communication competency*, which entails the confident, critical, and responsible use of digital technologies for personal development and communication; the ability to safely apply information and communication tools in education and other life situations while adhering to the principles of academic integrity.

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Given these priorities, there is an urgent need to develop innovative teaching approaches that foster the development of these competencies. One promising direction is the use of immersive technologies [2, 3], which have already proven effective in organizing learning processes in general secondary education institutions.

Immersive learning, which involves immersing students in an interactive environment, creates unique opportunities for developing problem-solving skills, critical thinking, and creativity [4, 5, 6, 7]. The use of immersive technologies is particularly relevant in teaching mathematics, as they enable the visualization of abstract concepts, the modeling of real-world processes, and the creation of interactive environments for the practical application of mathematical knowledge.

The purpose of this study is to analyze the potential of immersive technologies in developing mathematical and information-communication competencies among high school students in specialized classes of general secondary education institutions.

2. Literature review

The analysis of scientific studies on the use of immersive technologies in the learning process confirms that their first large-scale implementation in education began in the United States with the adoption of the National Education Technology Plan, titled *Transforming American Education: Learning Powered by Technology* [8]. According to this plan [8], the learning process should be based on the integration of educational courses with modern technologies to create engaging, relevant, and personalized learning experiences that reflect students' daily lives and future realities.

Although the first virtual schools appeared in the U.S. in the late 20th century, their initial purpose was to complement traditional education. Most virtual schools in the U.S. do not issue general secondary education diplomas or fulfill the traditional functions of schools. Instead, they offer online courses and related virtual services for schools [9].

Through intensive educational reforms, the U.S. addresses critical global pedagogical challenges, including [10]:

- updating the educational environment by leveraging advanced digital tools and cloud services for managing institutions and the educational process;
- modernizing educational content to align with scientific and technological progress;
- integrating immersive technologies into education;
- enhancing adaptive teaching methods, especially differentiation and personalized learning, and fostering the development of specialized skills.

The introduction of information and communication technologies (ICT) in education has driven systemic changes not only in the U.S. but also in Europe and Ukraine. The most significant transformation occurred during the COVID-19 pandemic, which accelerated the adoption of remote learning and increased the reliance on virtual platforms for education [11, 12, 13]. The largest platforms supporting immersive learning include the Immersive Education Initiative (http://immersiveeducation.org) and the Immersive Learning Research Network (iLRN) (http://www.immersivelrn.org). These platforms aim to help in creating educational environments enriched with immersive technologies.

According to an industry report on education [14], the targeted use of digital, particularly immersive, technologies in the learning process is essential for improving the education system. These technologies are grounded in:

- innovative pedagogical models, such as game-based learning, online laboratories, and real-time assessments, which enhance thinking skills, comprehension, creativity, imagination, and problem-solving abilities [15, 16];
- simulations, such as remote or virtual online laboratories, offering cost-effective and flexible access to experimental learning [17];

- international collaboration, which removes learning barriers and facilitates personalized learning paths, course selection, and technology integration;
- formative assessments, powered by technology, enabling teachers to monitor students' knowledge acquisition and adjust the learning process accordingly;
- e-learning, incorporating open educational resources and massive open online courses (MOOCs) to build personalized learning trajectories.

The recommendations of the European Union's Digital Education Action Plan (2021–2027) [18] and Goal 4 of the United Nations' *Transforming our world: The 2030 Agenda for Sustainable Development* [19] emphasize:

1. the necessity of creating innovative learning environments enriched with high-quality educational materials to mitigate learning losses;
2. the importance of enhancing digital competencies, including digital literacy, computer science education, awareness of immersive technologies (e.g., artificial intelligence), continuous upgrading of digital skills, and ensuring gender equality in digital education and careers.

As for the frontrunner in immersive technology integration, the U.S., it is worth noting that virtual schools are funded both by the government and private investors, facilitating the digitization of education and addressing learning gaps.

An analysis of scientific publications in databases such as Scopus and Google Scholar highlights the fields where immersive technologies are most actively used to enhance learning, including medicine, architecture and construction, design (e.g., urban planning), foreign language learning, shipbuilding and navigation, aviation, history and archaeology, and museum studies.

3. Results

The evolution of immersive technologies and their integration into the education system began with their use in foreign language learning, where they were established as a tool that enhances motivation and makes the learning process engaging. As early as the mid-1960s, it was proven that immersion in foreign language learning intensifies the educational process. According to Bloom's taxonomy of educational objectives, the application of immersive technologies affects the cognitive, affective, and behavioral aspects of learning, showcasing their versatility and effectiveness in improving literacy, creative thinking, communication, and collaboration [20].

The combination of immersive technologies with artificial intelligence has the potential to lead to innovative intellectual learning [21, 22]. Such technological integration enables the creation of more dynamic, interactive, and personalized learning environments, transforming traditional approaches into innovative ones [23].

This study focuses on the use of immersive technologies in teaching mathematics to high school students in general secondary education institutions. Scientific literature identifies four primary themes regarding the use of immersive technologies in education [24]:

1. the impact of immersive technologies on learning outcomes;
2. the use of immersion technologies for learning and simulation;
3. the influence of immersive technologies on user interaction and engagement;
4. the ethical and social implications of immersion technologies.

This article explores how teachers can leverage various immersive platforms in their professional activities.

3.1. AR Book

The AR Book platform was created in July 2022 in Ukraine and is supported by the Ministry of Education and Science of Ukraine as part of a project aimed at sustaining the educational process during wartime. This guarantees that all lessons available in the app align with the current curricula of Ukrainian general secondary education institutions.

Using this platform, every user gains access to interactive educational materials that incorporate elements of immersive technologies. The learning materials provided in the app are designed to be easy for students to understand and offer them opportunities to:

- build personalized, mobile learning trajectories;
- visualize educational content while independently studying topics through augmented and virtual reality tools;
- break down learning materials into manageable structural units tailored to their psychological characteristics;
- receive teacher support during the learning process and feedback for reflection.

The platform offers several benefits for teachers, including:

- the ability to prepare high-quality lessons regardless of the teaching format;
- tools to create interactive lessons using a lesson constructor, which includes various templates and customization tools, or to utilize lessons, quizzes, and experiments developed by other teachers and shared in the app;
- built-in artificial intelligence that allows teachers to analyze and adapt educational materials to meet the needs of individual students, monitor students' comprehension, and track their progress in mastering topics or sections;
- integration with any learning management system (LMS) used by Ukrainian general secondary education institutions, as well as with video conferencing services or calendar applications.

For general secondary education institutions, the platform ensures:

- the ability to monitor and analyze students' academic achievements;
- simple administration and compatibility with other systems used by schools to organize the educational process;
- a wide range of tools for effective teacher training in lesson organization.

To begin using the AR Book platform, teachers must register on its website (https://arbook.info/). They can log in using their credentials or Google account. After registration and entering their profile information, teachers can select a personal teacher workspace and access their profile tab in AR Book (figure 1).

Let us examine some elements of the platform that every teacher can access for free, and describe the potential use of the AR Book app for teaching mathematics in high school. The app is accessible to every student on any mobile device running iOS or Android.

1. **Calendar.** In the "Calendar" section, teachers can schedule their class activities according to their lesson timetable (figure 2).
2. **Lesson creation.** By clicking the event arrow in the calendar, the teacher can access templates for creating lessons or select a pre-made lesson (figure 3). When creating a lesson, teachers can include the following elements in their presentations: images, 360-degree images, text, slides, videos, experiments, VR experiments, and test assignments.
3. **Immersive educational materials.** These are available in the "All Content Types" section (figure 4). As the app is constantly updated with new educational materials, it is worth noting that for high school mathematics subjects, there is still a lack of fully developed content.

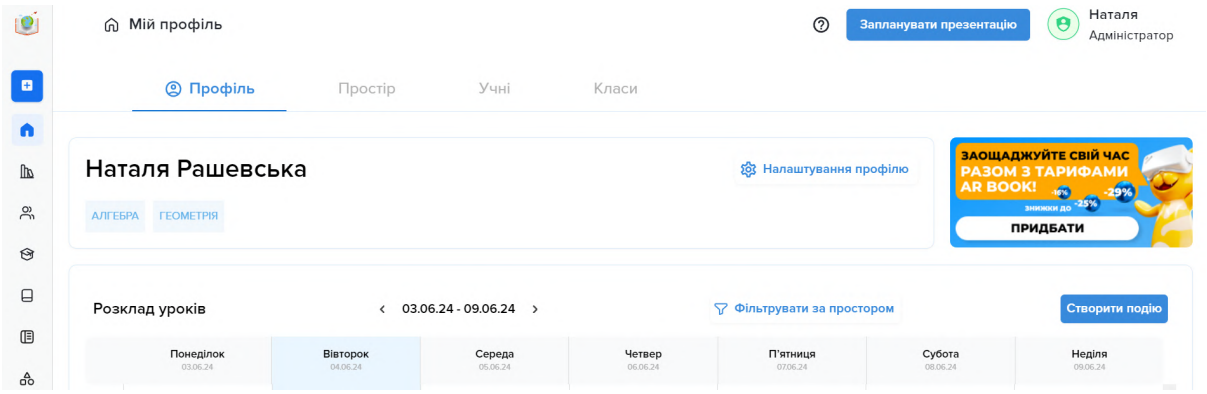

Figure 1: Getting started with AR Book.

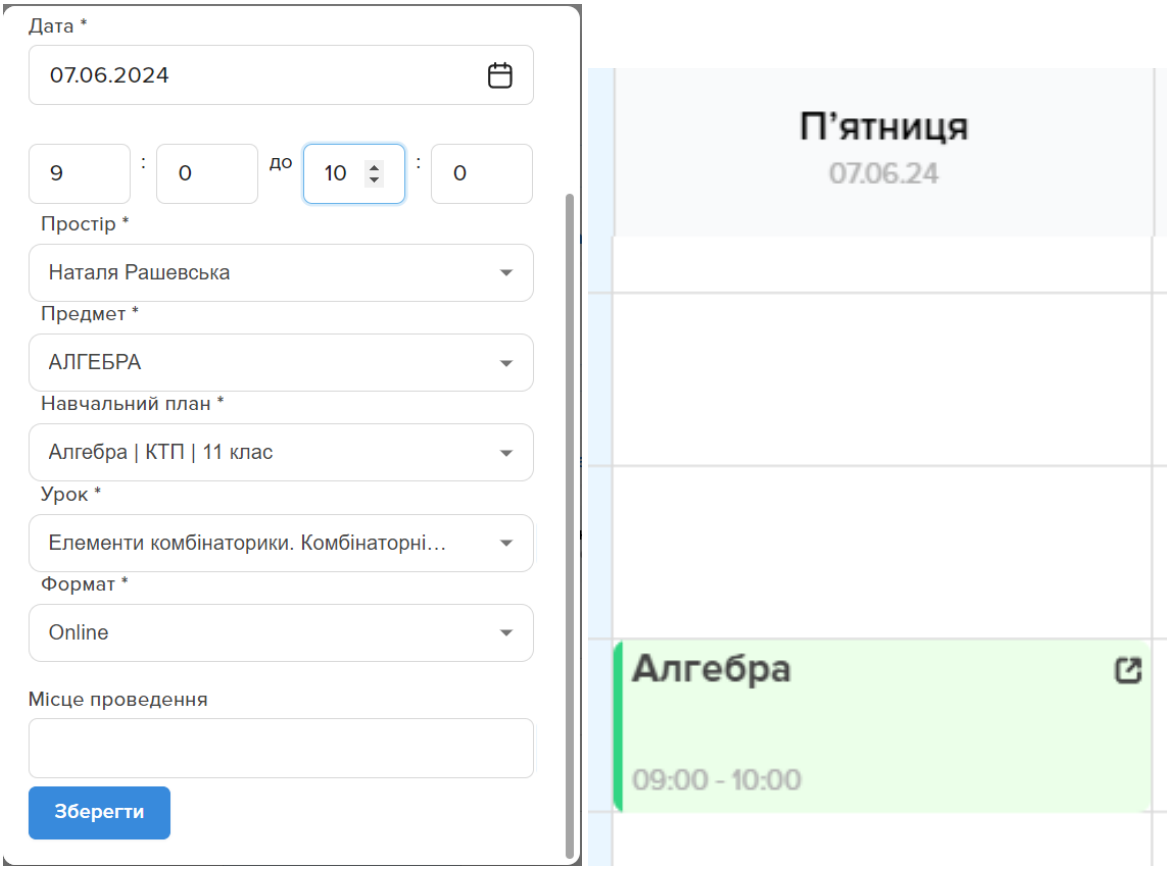

Figure 2: Creating an event in the calendar.

One key drawback of the platform is that only a relatively small portion of the material is available for free. Therefore, one way to address the issue of quality lesson preparation is to procure a school-wide subscription to the platform.

In the "Experiment" section, which corresponds to the practical portion of the curriculum, AR and 3D educational materials have been developed for the following mathematics topics for high school:

- **Probability theory and mathematical statistics:** combinatorics; the sum and product rules; statistics; combinatorics; and the frequency of random events.
- **Introduction to stereometry:** axioms of stereometry; basic concepts of stereometry; consequences of the axioms; and visualizing figures in stereometry.
- **Basic stereometry concepts:** points, lines, and planes; perpendiculars and obliques; the theorem

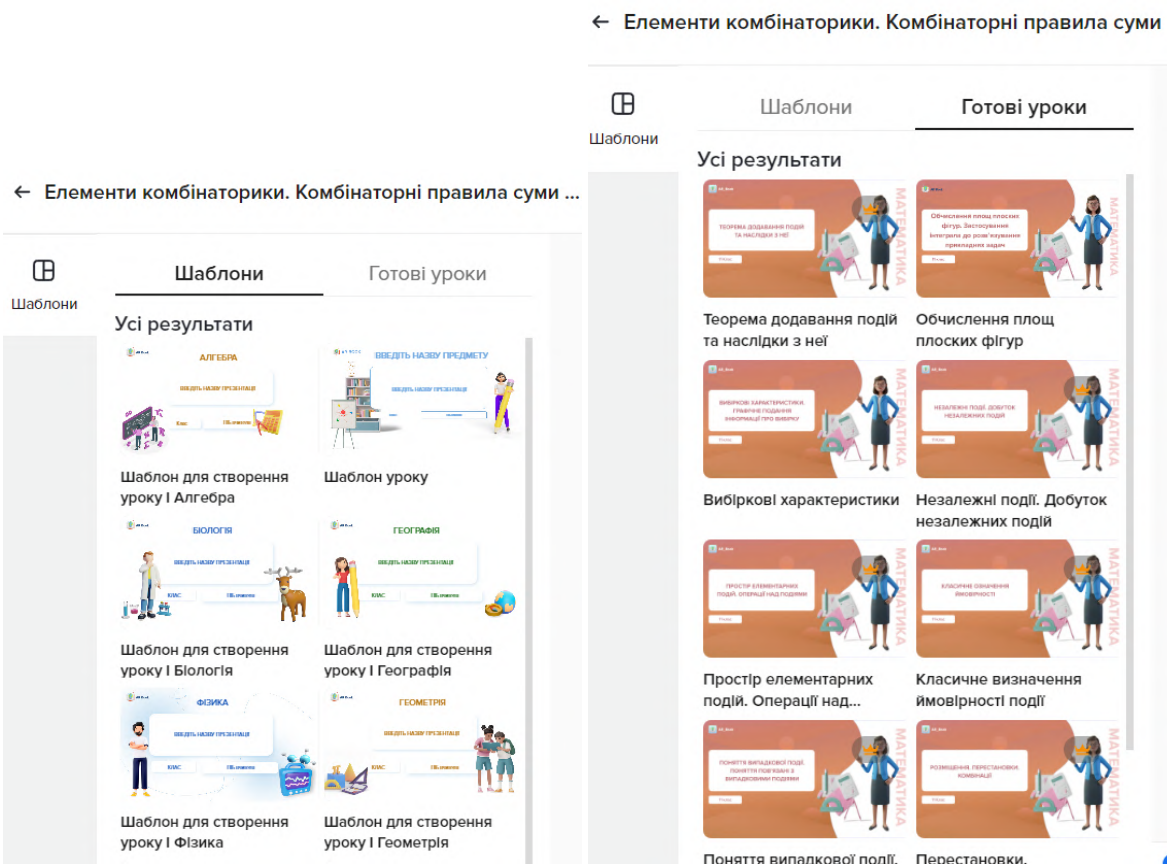

Figure 3: Lesson creation.

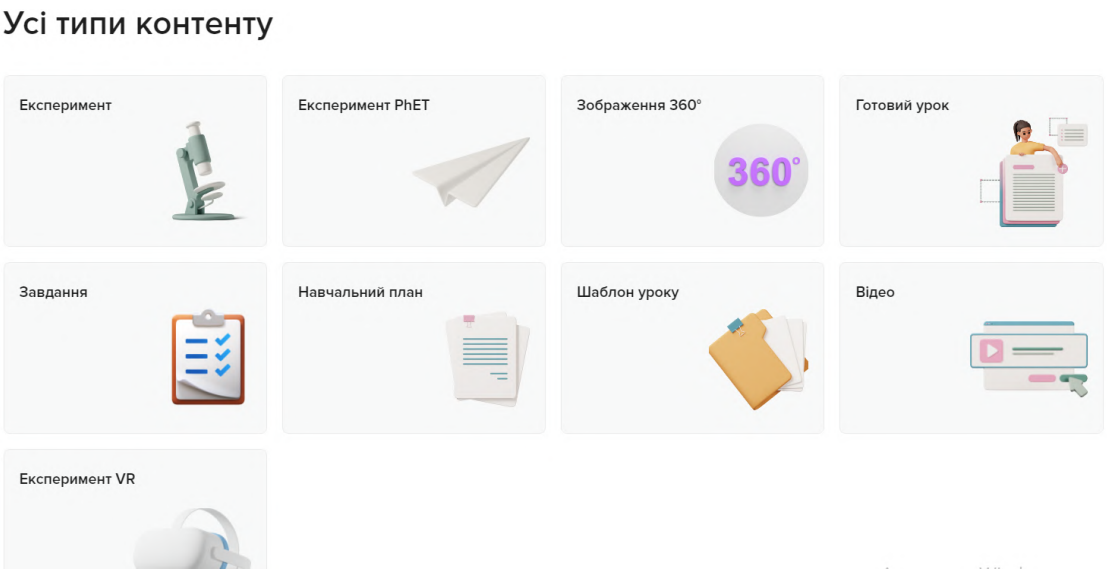

Figure 4: List of educational materials.

of three perpendiculars; mutual positions of lines in space; perpendicularity of lines in space; skew lines; dihedral angles; perpendicularity of planes; parallelism of planes; parallel projection; angle measurements in space; distances in space; parallel lines in space; and parallelism between a line and a plane in space.

- **Coordinate systems in space:** the coordinate system; Cartesian coordinates in space; plotting points in space by given coordinates; and calculating distances between two points in space.

- **Polyhedra:** volumetric geometric figures; prisms; prism sections; pyramids; parallelepipeds; the volumes of prisms, parallelepipeds, and pyramids; and regular polyhedra.
- **Solids of revolution:** cylinders; cylinder sections; the volume and surface area of cylinders; cones; the volume and surface areas of cones; sections of cones by planes; spheres and balls; and the volume and surface area of spheres.

The listed topics are not static and are continuously updated and modified. Each topic includes a visualized explanation of the material, test questions for self-assessment, and the ability to review the explanation multiple times. Some topics are available in the free version of the platform, but most are included in extended packages.

When the app was first launched in Ukraine's education system, access to AR and 3D learning materials was free of charge. We hope that over time, these resources will again become freely available for all Ukrainian teachers and students.

To differentiate between free and premium content, the platform uses specific labels for desktop and mobile applications:

 Material available in extended packages

 Material available in the free version

3.2. mozaBook

The mozaBook Platform by Mozaik Education has been made free for teachers and students in Ukraine since the beginning of the full-scale invasion. The app can be downloaded onto mobile devices via Google Play (https://play.google.com) and is compatible with Android and iOS operating systems. After downloading the app, users must register on the platform or on its website (https://ua.mozaweb.com/uk). During registration, users need to specify their region of residence, the educational institution they work at, and the classes they teach. Upon completing registration, teachers are provided with a personal workspace (figure 5) containing ample educational materials to organize lessons in various formats.

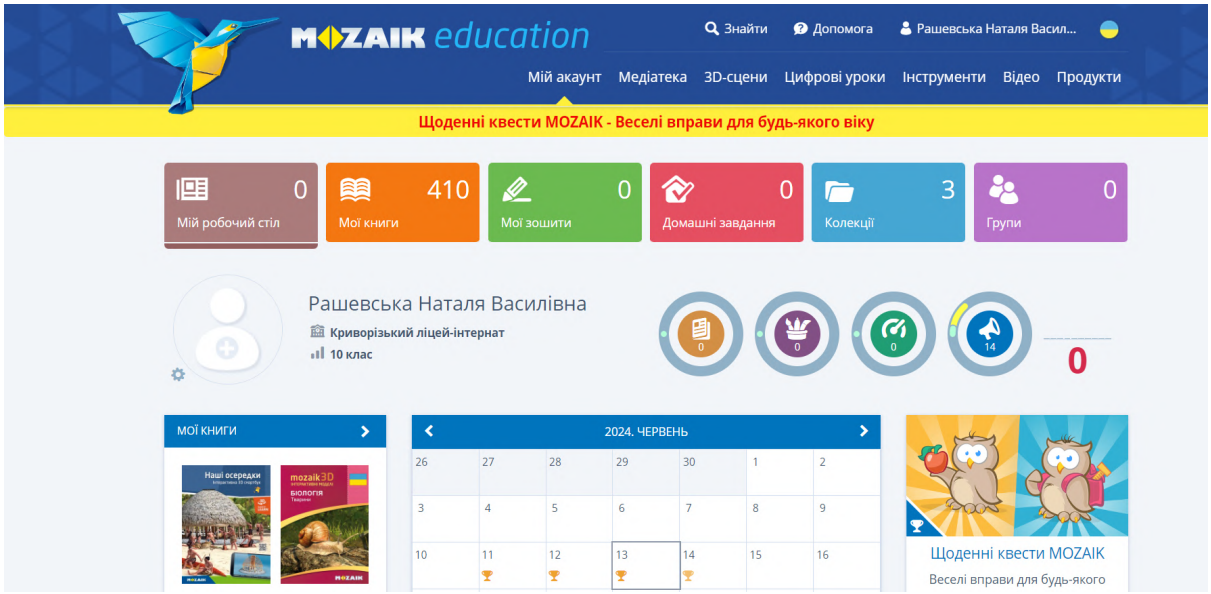

Figure 5: Initial screen of the platform.

Let us consider the possibilities of this platform in terms of immersiveness of mathematics learning material for senior high school students. The "3D Scenes" folder contains video applications on the following topics:

- **Probability theory and mathematical statistics**;

- **Basics of stereometry:** the positioning of planes in space, mutual arrangement of lines and planes in space, classification of geometric bodies based on various examples, angles in space, Cartesian coordinate system in space;
- **Polyhedra:** prisms, pyramids, Platonic solids, polyhedron nets, constructing their sections;
- **Solids of revolution:** solids of revolution around the axis of symmetry, 3D puzzles (a game to develop spatial perception), sphere, cylindrical bodies, conic sections, various types of surfaces, sphere, total surface areas;
- **Additionally:** Cavalieri's principle, interesting surfaces, polyhedra.

By choosing a 3D visualization of a topic, the teacher can provide students with a link for independent study or demonstrate it during a lesson, regardless of the teaching format. This can be particularly relevant when organizing instruction using one of the blended learning models, such as the flipped classroom model.

For enabling 3D visualization, a video player offered by the platform must be installed on a desktop computer or laptop.

Let us examine the topic of "The coordinate system in space". After launching the demonstration, it is possible to view the coordinate system in three variations: through axes, through coordinate planes, and with unit grid gradation (figure 6). The demonstration allows you to move the coordinate axes, visualize or hide labels.

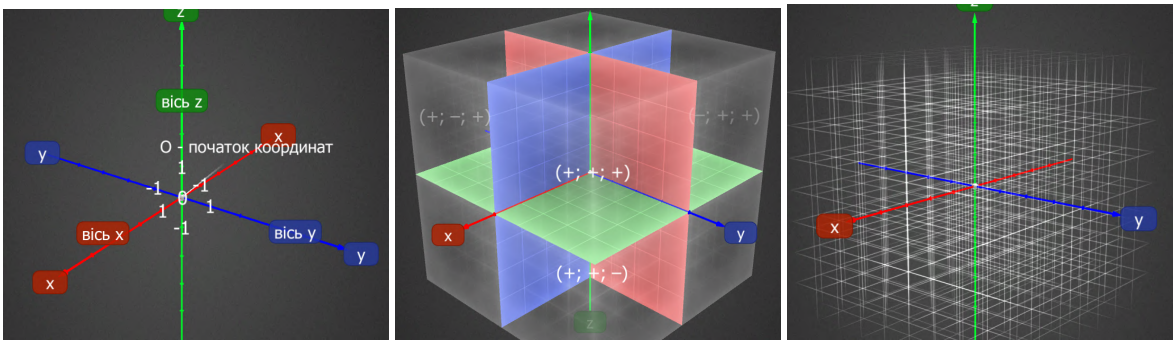

Figure 6: Various representations of the coordinate system in space

There is also a full demonstration of the theoretical material on the topic, a visualization of constructing a point in space based on given coordinates (figure 7), and a system of test tasks to assess the acquired knowledge on the topic (figure 8).

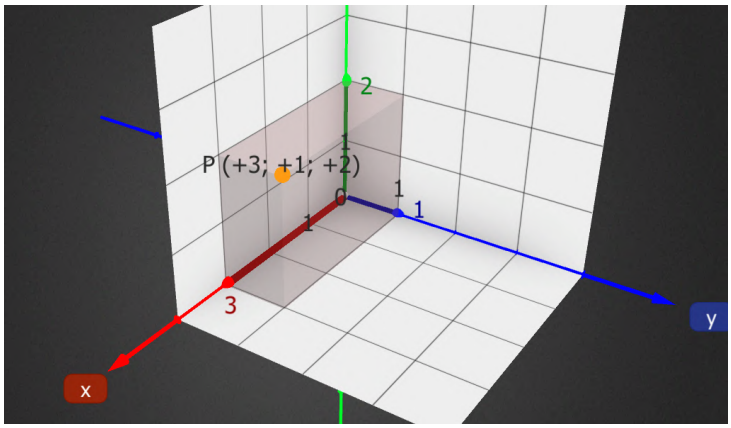

Figure 7: Constructing a point in space.

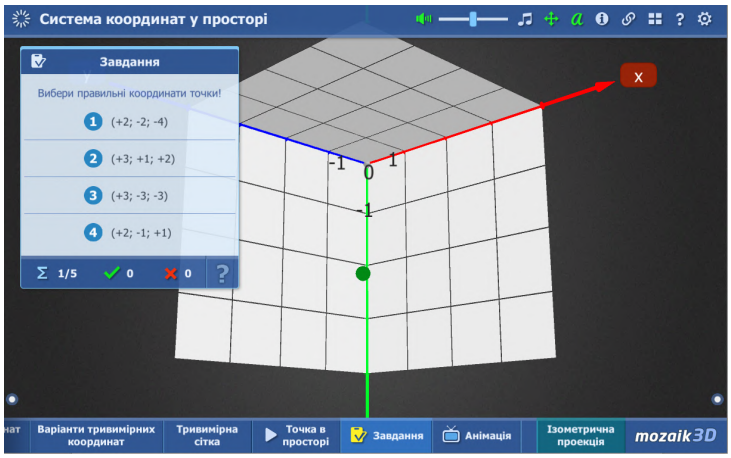

Figure 8: Test assignments.

3.3. GeoGebra 3D

GeoGebra 3D (https://www.geogebra.org/3d) is part of the GeoGebra Computer Mathematics System (CMS) (https://www.geogebra.org/), which can be downloaded as a standalone app for mobile devices or used directly on a desktop computer without registration, either with Internet access or by downloading specific applications. Additionally, users can register to save 3D constructions or other examples, which will be stored in the cloud. Registration in GeoGebra CMS not only allows saving completed constructions or studies but also enables simultaneous collaboration between teachers and students on a project.

This computer mathematics system is well-known in the educational community and does not require extensive review.

When studying algebra in grades 10–11, it is advisable to use the app for graphing functions, exploring them, or visualizing the calculation of the area of a flat figure. More interestingly, GeoGebra 3D can be used for constructing geometric solids, creating cross-sections of these solids, and gaining a comprehensive understanding of stereometry.

The app's initial workspace includes a three-dimensional Cartesian coordinate system and a set of tools on the left side (figure 9).

The coordinate system, along with the depicted solids, can be explored within a 360° range.

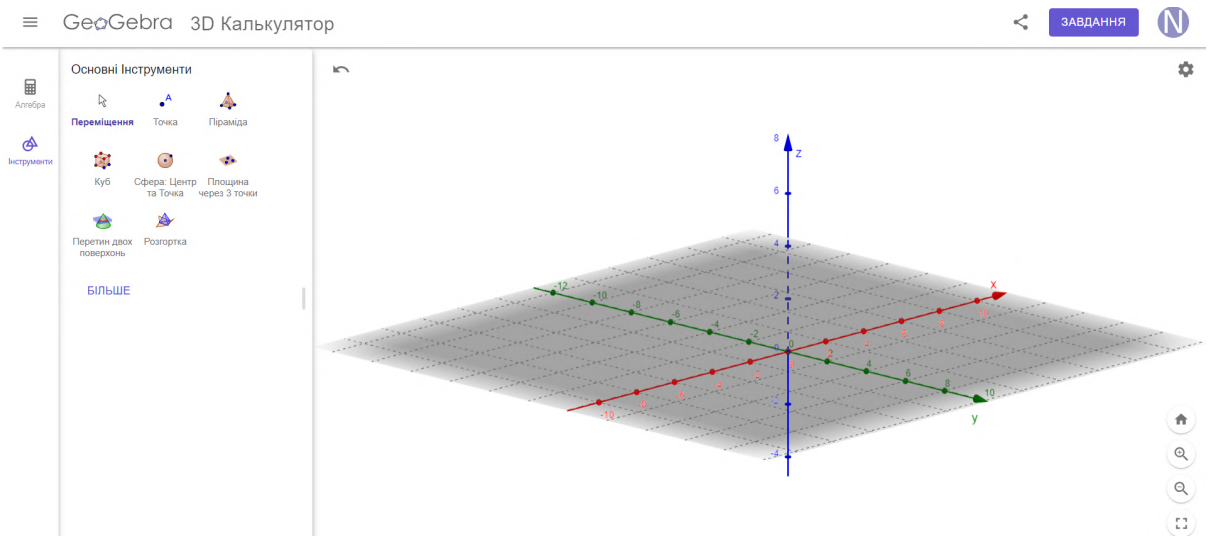

Figure 9: Starting work in GeoGebra 3D.

In the top-right corner, a gear icon allows access to coordinate system settings: showing axes, displaying grid lines, selecting scale, and other adjustments. You can also choose the language, set font sizes, determine whether labels are displayed, and specify the range for constructing geometric solids.

When studying geometry in senior grades, the app can be applied for the following types of tasks:

1. **Working with the three-dimensional Cartesian coordinate system** – constructing points and planes. Points can be created by specifying their coordinates or through a step-by-step explanation of their construction. Planes can be constructed: a) by three points, by a point and a line, or by two intersecting lines; b) by a plane parallel to a given one; c) by a plane perpendicular to a given one;

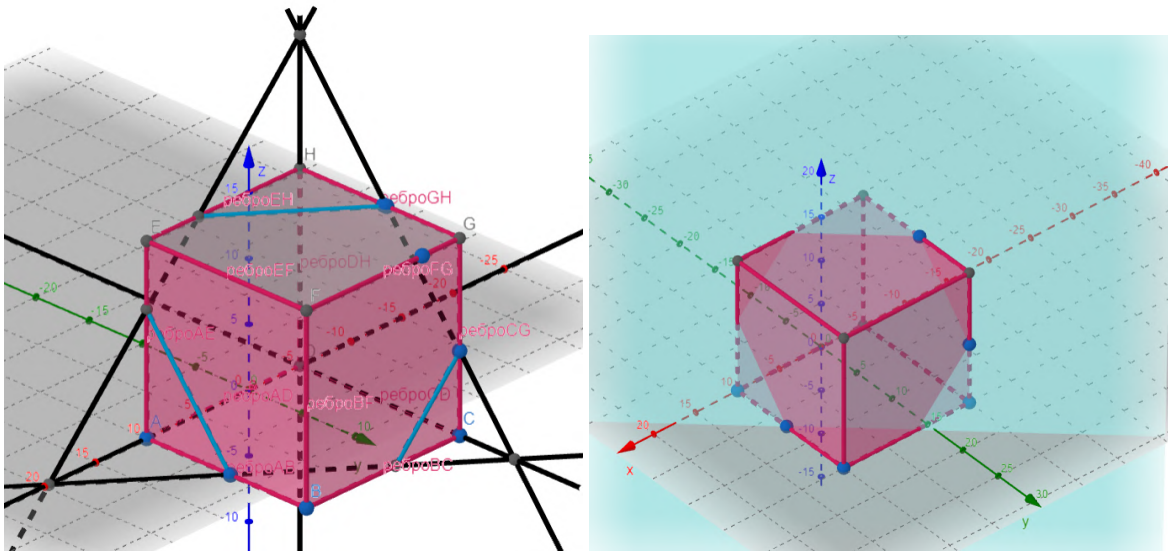

Figure 10: Constructing cross-sections

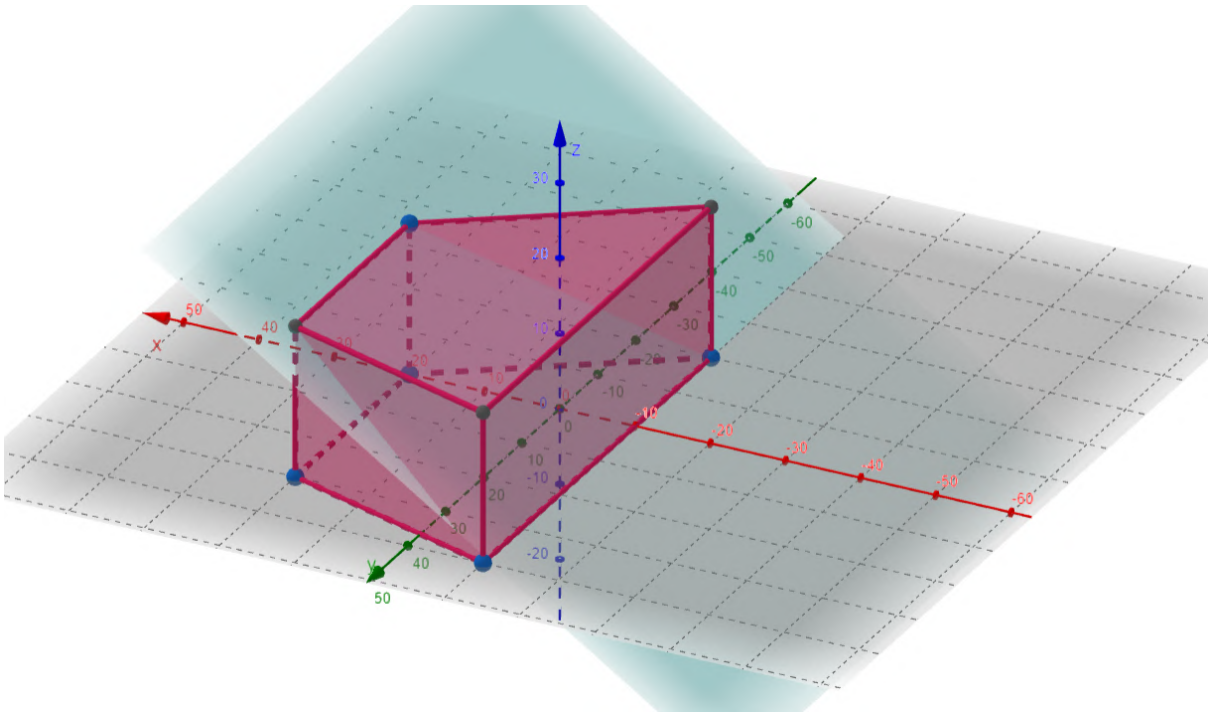

Figure 11: Visualization of geometric solids.

2. **Constructing cross-sections of solids** – a critical concept in 10th-grade geometry. The app's tools make it possible to visualize the entire construction process, make it dynamic, and illustrate it from different angles (figure 10).
   It is worth noting that cross-sections can be constructed either by using the traces method (Fig. 10a) or by utilizing a built-in tool on the app's toolbar (figure 10b).
3. **Constructing geometric solids.** The app allows for the creation of various geometric solids, cross-sections, the display of angles between faces and edges, and the study of solid properties (figure 11).

Additionally, the app contains a sufficient number of resources that can be utilized during the learning process, enabling the personalization of student education (https://www.geogebra.org/t/solids?lang=uk – figure 12).

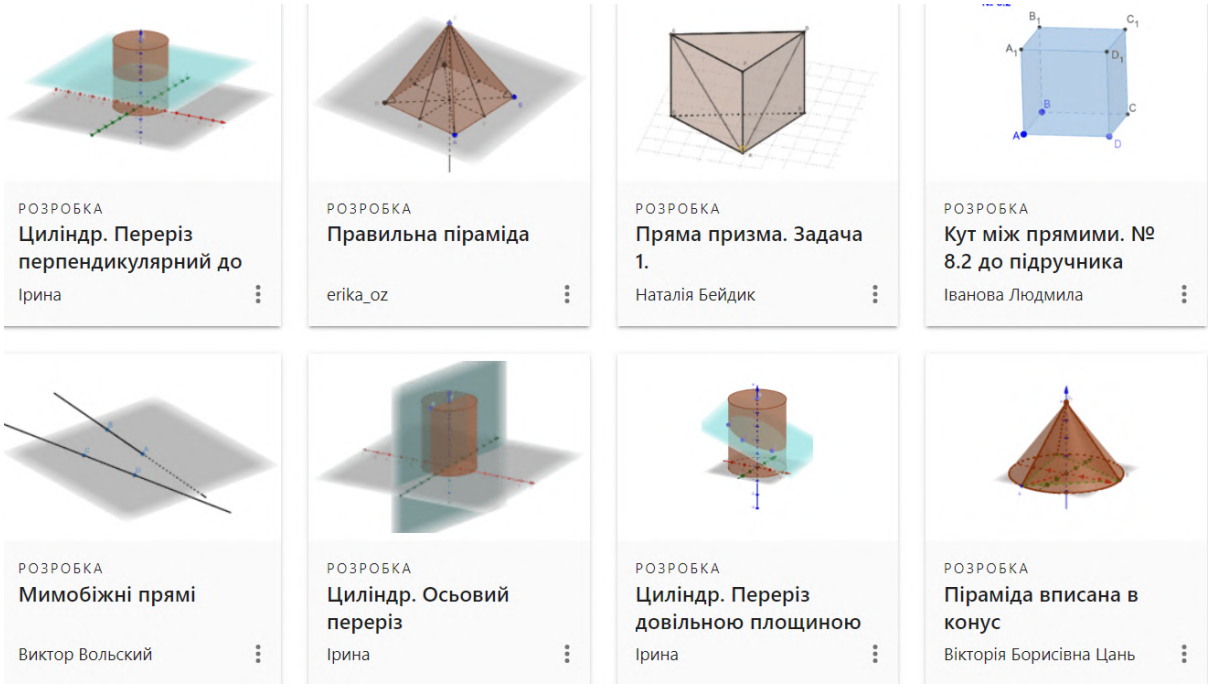

Figure 12: Educational materials with 3D visualization.

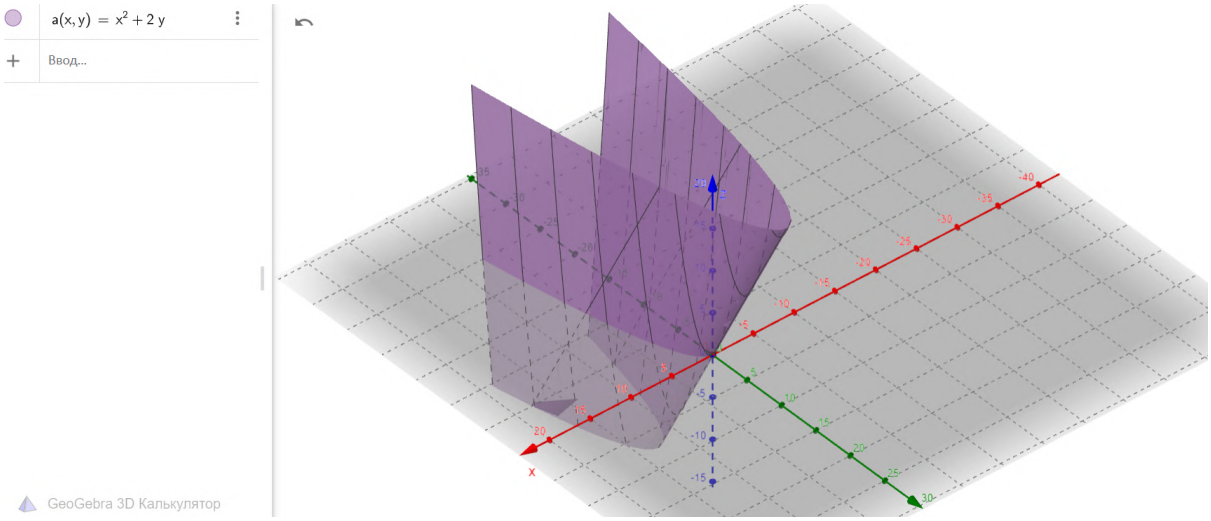

Figure 13: Working with surfaces.

For students specializing in mathematics, the app can be used to work with various surfaces. The ability to visualize and study surfaces provides opportunities for developing spatial thinking and understanding one's position in space (figure 13).

3.4. Desmos

For organizing interactive learning in a blended learning model, it is also advisable to use the Desmos graphing calculator, which is currently actively recommended for addressing students' learning gaps.

Desmos is a graphing calculator available on any device, whether mobile or desktop (https://www.desmos.com), with the option to register in the program or work online.

Although this graphing calculator is more suitable for middle school students, let us consider its potential applications in senior high school.

The mathematics section "Functions, their analysis, and graph construction" in the 10th-grade algebra course has always posed challenges for students. It is important to note that the topics in this section are actively tested during external independent assessments (ZNO) and the national multi-subject test (NMT). This means that studying these topics requires ample visualization of the learning material and a thorough understanding of all function properties.

The graphing calculator provides a set of pre-designed explorations that can be conducted with functions during its use, as well as the ability to independently select functions for analysis.

More engaging for senior high school students is the Desmos 3D Calculator, which enables the creation and exploration of geometric solids by transitioning from flat constructions to three-dimensional models.

4. Conclusions and prospects for further research

The reviewed platforms for organizing mathematics education for senior high school students using immersive technologies do not exhaust all the advantages and possibilities of immersive learning but rather outlines key directions for further research.

1. Integration of immersive technologies into the Ukrainian education system is necessary for their systematic use, as they enable deep engagement in the learning process through visualization of educational material.
2. Development of adaptive curricula for studying subjects such as mathematics, physics, chemistry, geography, and history will create conditions for personalized learning trajectories for each student.
3. Organizing a high-quality learning process based on immersive technologies requires the development of a methodological system for the most challenging subjects for students—those in the natural sciences and mathematics.
4. Special attention should be given to the training of teachers, who will be able to implement immersive learning in general secondary education institutions, develop their digital competencies, and foster these competencies in their students.

Declaration on Generative AI: The authors have not employed any Generative AI tools.

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