Prospects of using the augmented reality application in STEM-based Mathematics teaching

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Abstract. The purpose of the study is improving the methodology of teaching Mathematics using cloud technologies and augmented reality, analyzing the peculiarities of the augmented reality technology implementing in the educational process. Attention is paid to the study of adaptation of Augmented Reality technology implementing in teaching mathematical disciplines for students. The task of the study is to identify the problems requiring theoretical and experimental solutions. The object of the study is the process of teaching Mathematics in higher and secondary education institutions. The subject of the study is augmented reality technology in STEM-based Mathematics learning. In the result of the study an overview of modern augmented reality tools and their application practices was carried out. The peculiarities of the mobile application 3D Calculator with Augmented reality of Dynamic Mathematics GeoGebra system usage in Mathematics teaching are revealed.

Keywords: Augmented Reality, GeoGebra 3D Graphing Calculator, Geometry, Probability theory, STEM-competence, teaching methods of Mathematics, cloud technology in education.

1   Introduction

Teaching aids visualization during lectures and practical classes, in particular in Mathematics, allows students to understand the learning material better, to increase the applied orientation of learning and the communication competence both learners and teachers. One of the ways to improve the abstractions visualization in Mathematics is a pedagogically sound and appropriate application in the teaching the modern ICT.

Gartner attributes Artificial Intelligence Education Applications, Conversational User Interfaces, Blockchain in Education, Immersive Technology Applications in

Education, Design Thinking, Competency-Based Education Platforms and Adaptive Learning Platforms to the main tendencies of using ICT in education [25].

Since augmented reality technology already has an important place in innovative development, it can also have significant potential for implementation in Mathematics learning. That is why this technology needs more detailed study. Because augmented reality is intrinsically linked to 3D construction, its usage in conjunction with Dynamic Mathematics systems like GeoGebra, can significantly increase the level of visualization in Mathematics and enhance students learning. In addition, Augmented Reality can become a tool for enhancing STEM-based learning for students majoring in Mathematics and Computer Science.

At present, the use of augmented reality technology in teaching, including Mathematics, requires development, research, and testing. Therefore, the review of tools for developing augmented reality and current practices is relevant. It is important the new technologies usage contribute to improving the quality of education.

2   Materials and methods

A number of works of scientists and software developers are devoted to the research of integration issues of the augmented reality technology into the educational process. In particular, Tim Brzezinski [2], James Purnama [29], Serhiy O. Semerikov [22; 34], Svitlana V. Shokaliuk [33], Iryna S. Mintii [21], Andrii M. Striuk [9], Yuliia V. Yechkalo [35], Maiia V. Marienko [27] focus on the general trends and special issues of the augmented reality application in education. Pavlo P. Nechypurenko [23; 24] shares her experience of using AR in teaching chemistry pupils and future chemistry teachers. Svitlana L. Malchenko raises the issue of the AR application to the astronomy teaching and others [18].

The problems of STEM-training, in particular the training of staff for STEM-education in the modern innovative educational and research environment are covered by Mariya P. Shyshkina. The aim of the article [31] is to describe the problems of personnel training that arise in view of extension of the STEM approach to education, development of innovative technologies, in particular, virtualization, augmented reality, the use of ICT outsourcing in educational systems design. The results of the research are the next: the concepts and the model of the cloud-based environment of STEM education is substantiated, the problems of personnel training at the present stage are outlined. Recently in the field of STEM education the following ICT trends have been developed, such as new interfaces, screenless displays, 3D technologies, augmented reality, "emotional" computing, wearable technologies (devices) and others. All these areas are united under the common name of "new opportunities" (emerging technologies) [31].

Having analyzed the state of research into the problem of STEM-education in the secondary education institutions in psycho-pedagogical, methodical and educational literature, we can conclude that in Ukraine the educational landscape is aimed at the innovative student. Teaching a student to learn for life, to think critically, to set goals

and achieve them, to work in a team, to communicate in a multicultural environment - all this is the urgency of the present, which forms the basis of a specialist's competitiveness in the labour market.

The issues of using GeoGebra were highlighted by us in a teaching manual designed to train mathematics teachers in higher education institutions [12]. The methodological recommendations were presented there, which teach how to create and apply for the tool of different topics in elementary mathematics. The visuals are hosted in a file repository GeoGebra. They can be accessed either via traditional links or via QR codes.

STEM approach in teaching mathematics to students using GeoGebra have been partially covered in our publication [11]. However, the problems of using the augmented reality tools in mathematics teaching are covered by us for the first time.

The purpose of this publication is the overview of the augmented reality tools practices in the educational process, analysis of application prospects in STEM-training of mathematics and to train mathematics teachers. In order to use the new technologies to improve the quality of education.

3   Results

3.1   Augmented reality toolkit overview

The article [31] discusses the prospects of the augmented reality using as a component of a cloud-based environment. It is revealed that the attraction of the augmented reality for the educators requires the development of new methodologies, didactic materials, updating and updating of the curriculum. The main conclusions and recommendations: the main principles of augmented reality use in the learning process are: designing of the environment that is flexible enough, attention should be paid to the teaching and didactic issues; adjusting the educational content for mastering the material provided by the curriculum; the research methods that can be used in training along with the elements of augmented reality are to be elaborated; development of adaptive materials; training of teachers, which will include augmented reality in educational practice.

Olga Yu. Chubukova and Igor V. Ponomarenko article [5] is devoted to the study of the augmented reality technology use to meet the needs of modern society. The peculiarities of the augmented reality realization as an innovative product that has significant prospects for integration into the real economy are considered. The role of this technology in improving the teaching subjects process in Ukraine's higher educational institutions is determined. The main directions of communication intensification with students during conducting of classes with the help of using the augmented reality are given. The key benefits for the national education system from implementation of the augmented reality into the educational process are highlighted.

In paper [17] Hong-Quan Le and Jee-In Kim propose a framework for learning geometry using a software tool based on augmented reality (AR) and hand gestures recognition technologies. These technologies are combined into a system that can address some current issues in geometry education and provide students with an

easier way for studying geometry. They compare the speed of development and the quality of the developed geometry training using Cabri and GeoGebra.

The objective of research is to develop an AR and hand gesture based application for learning 3D geometry. This paper aims to present a novel approach for effective learning 3D geometry in school. The research basically focused on two main technologies: AR and hand gesture recognition to build up a hands-on learning method for students. With AR, the students can understand the basic concepts of 3D geometrical shapes, their relationships and ways to construct the 3D shapes and the objects in 3D space. Importantly, AR can provide a dynamic visualization of 3D structures of geometrical shapes. This feature helps the students to understand a comprehensive background of 3D geometrical shapes and improve the abilities of geometrical structures. Moreover, the hand gesture based interactions furnish an intuitive and convenient way for the students to directly control and interact with geometrical shapes in 3D space. With the experiences of interacting with the 3D shapes using their own hand gestures, the students can improve their own awareness of the relationships of the 3D shapes and easily remember or retain the knowledge about the 3D shapes.

3.2   Application practices GeoGebra AR technology

A number of examples that can be used in mathematics training are offered by the developers of the GeoGebra Dynamic Mathematics system [6] on the YouTube page [7].

GeoGebra is a free software, dynamic mathematics system for all levels of education that integrates geometry, algebra, tables, graphs, statistics and calculations in one easy-to-use package [30]. GeoGebra has become a leading provider of dynamic mathematics programs used to support Science, Technology, Engineering and Mathematics (STEM), education and innovation in teaching and learning worldwide.

We can highlight the benefits of GeoGebra, such as free distribution; easy-to-use interface with powerful functionality; availability in many languages, including Ukrainian; a number of freeware developments, models, exercises, lessons and games for math, as well as video tutorials and courses to help you use GeoGebra applications.

GeoGebra is a few free offline apps for iOS, Android, Windows, Mac, Chromebook and Linux. Among these mobile phone applications there is the 3D Graphics application (3D-feature graphs, surface, and 3D-geometry) that can be used while developing the visuals with AR. Today, the app is only available to users of gadgets on the iOS operating system. This program includes some examples of 3D mathematical objects that can be placed, such as on a desktop, floor, or any other flat surface. Today, the app is only available to users of gadgets on the iOS operating system. This program includes some examples of 3D mathematical objects that can be placed, such as on a desktop, floor, or any other flat surface. The fixed models will be managed. They can be resized. Such visualization will allow you to see more mathematics in the surrounding world.

With AR you can build polyhedra, surfaces (Fig. 1), rotation bodies, visualize their rotation, and show cross 3D sections.
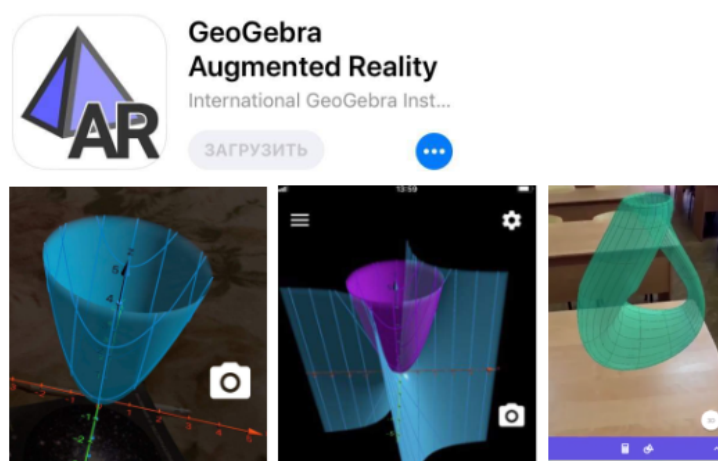

Fig. 1. The surfaces in AR.

GeoGebra developers note that they created this application to explore the AR potential for mathematics training and teaching. This is just the beginning for GeoGebra AR. In the future, the application will be improved, supplemented with new ideas for 3D models, which will allow to see and explore 3D mathematics in the environment more.

Let's see what kind of manipulation can be done using the AR app. We can, for example, write down the surface equations and examine the result, change individual parameters, and observe changes in real time. We can also "scan" the objects around us, get the appropriate models, and further explore them. Before researching we have to place mathematical objects on any surface. Built and fixed models can be "bypassed" from all sides, "look" in the middle, take screenshots of internal structures.

3D Graphics mode is designed to work with 3D objects. You can create objects using Algebra or Tools tabs. In Algebra mode, we add objects using mathematical functions, and in Tools mode, we use a toolbar that offers a large set of tools for creating three-dimensional objects. In addition to the well-known tools: creating points, segments, straight lines, angles and polygons – there are also specialized tools for constructing bulk bodies such as: sphere, pyramid, prism, cone, cylinder. You can build cross sections of volumetric figures and form a sweep.

Tim Brzezinski closely uses the 3D Graphics AR application in his activities. Based on his research, we can conclude that the using AR is a powerful tool for the explore and formatively assess student constructions. Brzezinski offers some developed GeoGebraBook, targeted at both teachers and students. His collections provide ideas for lessons and various means by which math teachers can use

GeoGebra 3D Grapher with AR (iOS) to create dynamic, learner-centered learning environments [2]. In the mathematics teaching it is advisable to use some of his works [1; 3; 4].

In the workshop on mastering the package of dynamic mathematics GeoGebra Liudmyla E. Gryzun, Valentyna V. Pikalova, Iryna D. Rusina and Valentyna A. Tsybulka [8] focused on the training and retraining of mathematics teachers, as well as on extracurricular work with students. Because the training is based on examples and models that can be attributed to the objects of mathematical art, this allowed the authors to present GeoGebra as a powerful tool for realizing STEAM education. One of the sections of the practicum is AR. The authors present the brief information about the AR application and provide examples of its use.

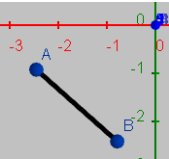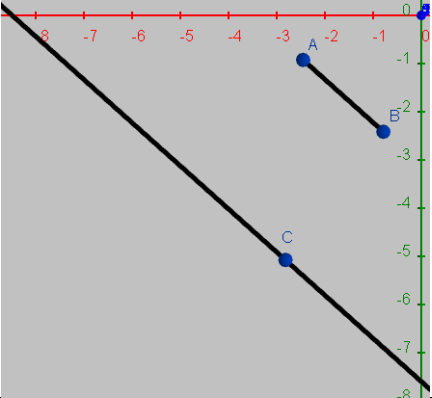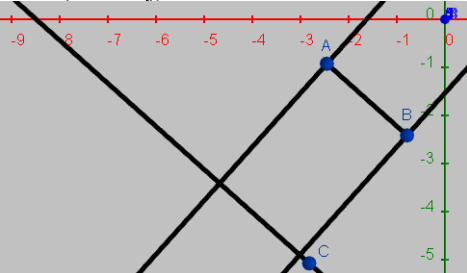### 3.3 Development of visibility tools with GeoGebra 3D Graphics and AR

To create a mathematical model in the AR application, first of all, you need to create a model in 3D Graphics using appropriate tools (Table 1), and then using the button "AR" to project into the real world. To place an object in the real world, you must select a location, point it at the camera, and tap the screen on your phone. Then the figure locks in the selected location. To change the size, color of the object, we use a touch screen.

**Table 1.** Examples of tools for 3D Graphics implementation

Icon	Tool	Application
	Cube	double-click in the 3D view to create points that set the rib of the cube
	Move	allows you to move objects, the first click on the point will change its position in the xOy plane, the second click - the coordinate along the z axis
	Extrude to Pyramid	allows you to construct a pyramid from a polygon or a cone from a circle
	Rotate 3D Graphics View	allows rotation in three-dimensional space
	Net	allows you to build a sweep to the specified polyhedron
	Sphere: Centre and Point	allows you to construct a sphere by selecting the center point and any point of the surface
	Plane through 3 Points	constructing a plane by successively selecting three points
	Reflect in Plane	select the object you want to display and then specify the display plane
	View in front of	select an object to move the point of view of the construction in front of the selected object

Because the application has the ability to build a prism, the difficulties can arise while creating certain types of prisms. Consider in detail the example of a straight prism, the basis of which is a rectangle (Table 2).

Table 2. An algorithm for creating a rectangular parallelepiped in 3D graphics

No	Stage	Instruction and drawing
		Construction of a dynamic rectangle
1	Build a segment	In order to plot a segment in the XOYU plane, you need to select the "View in front of" (located in the Edit group) and specify this plane. Then select the "Segment" tool and specify the two points through which the segment AB is automatically constructed.
2	Construct a line that is parallel to the segment	Use the "Point" tool to put a point in any place (point C). We select the "Parallel Line" tool, point to the constructed segment and point, and automatically construct a line g.
3	Construct perpendiculars to the line passing through the ends of the segment	Select the tool "Perpendicular line", point to a straight line g and point A – get a straight line perpendicular to the line g passing through the point A (denote i). Similarly, we construct a line through point B (denote j).

No	Stage	Instruction and drawing
4	Construct rectangle	a We select the "Polygon" tool and point to the intersection points of straight lines and segments. In the Algebra tab, we remove the visibility of unnecessary straight lines, change the color of objects if desired. We can resize the rectangle by moving the points A, B, C.
	Construction of a rectangular prism	
5	Construct a straight line perpendicular to the rectangle	Select the "Perpendicular Line" tool, point to the rectangle and its vertex. Received a line h that is perpendicular to the rectangle ABDE and passes through its vertex.
6	Build a prism	Select the "Prism" tool, point to a rectangle and a straight line h. The prism is built, you can resize it using points A, B, C, I. In the Algebra tab we remove the visibility of the straight h.

No	Stage	Instruction and drawing
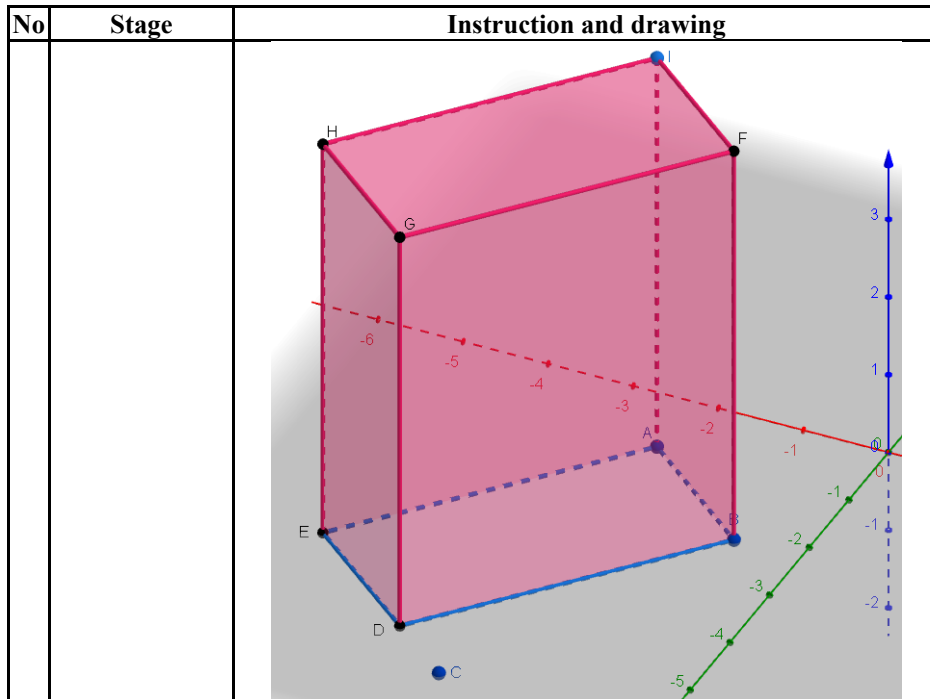
After constructing a prism in GeoGebra 3D Calculator [28], we press the "AR" button. Next, you need to use the camera to select the environment in which we plan to move the object. For example, on the table. By tapping on the screen, the figure will be transferred to the real world [13] where it can be explored. The phone camera will serve our eyes. Immersing the phone in a virtual figure we will see it from the inside, we can bypass it, also the application allows you to resize, color. Due to the AR with GeoGebra you can see that we are surrounded by mathematical objects, shapes everywhere [14; 15; 16] we can explore them, walk around them, peek in, or step inside a figure.

We can insert real objects that have the shape of a rectangular parallelepiped into a fixed figure (see Fig. 2).

Considering the creating a geometric body, the prism automatically calculates its volume, we can determine the relationship between the volume of the real body and the result that is offered by the software. In this case, the student must have the apparatus to apply the properties of such bodies.

Previously, we offered students a STEM approach in addition to the traditional formula output when learning the topic of "Body volumes". The approach was that the students were asked to propose some hypothesis how the volumes of a prism and a pyramid, a cylinder, and a cone correlate. For this purpose, made models of these geometric bodies were used and poured dry matter from the cone into the cylinder, from the prism into the pyramid.
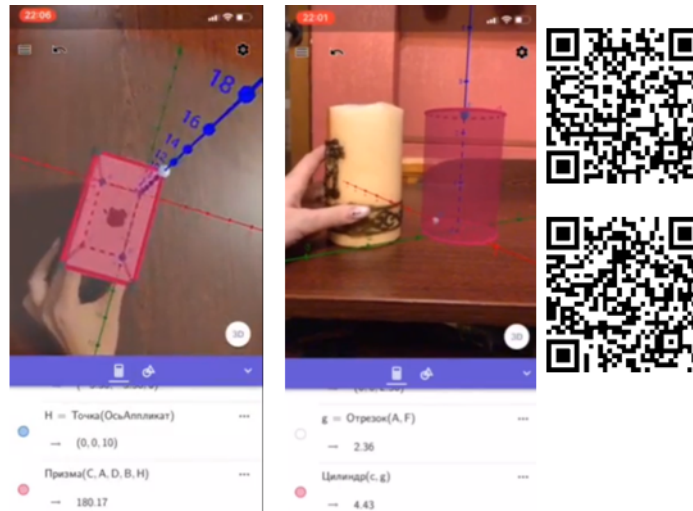
Fig. 2. GeoGebra AR demos

3.4 Perspectives of using AR application in teaching calculus and probability theory

An analysis of the studies conducted to date indicates that the greatest effectiveness in teaching elementary mathematics, calculus, probability theory is achieved through a complex combination of traditional tools, forms and methods of teaching with computer-oriented. For plotting functions, surfaces are quite convenient to use software tools, including CoCalc, GeoGebra, Wolfram|Alpha [10; 19; 20; 26; 32].

With GeoGebra we can construct a surface, examine it from different sides, examine the change of values of a function at one of the fixed independent variables, or at certain relationships between independent variables. Similar observations are useful in the study of the function of many variables for continuity. However, we cannot calculate extrema by symbolic transformations, although partial derivatives can be calculated.

With GeoGebra 3D Calculator and AR the visualization capabilities for solving the types of tasks outlined above are greatly enhanced.

Particularly effective can be the use of a 3D Calculator with AR when studying the topic of "Multiple integrals" (Fig. 3). Students often have difficulty with constructing bodies that are restricted to certain surfaces.

Using AR, you can not only see the built body, but also "travel" inside. Today, the construction of surfaces is available with the application. Often, students have problems in calculating the boundary of the function of two variables, while substantiating continuity.

It is advisable to use the software tools for both the construction of surfaces and the search for extrema of functions.

Here is an example of a problem where, when investigating the function of many variables, additional research is needed. An interesting example is the function

$z = 1 - \sqrt{x^2 + y^2}$. At point $(0; 0)$ partial derivatives of the first order do not exist. To investigate a function on extremum, we examine the increment of the function at this point. As the gain is negative, we can conclude that the function acquires the maximum value at this point.
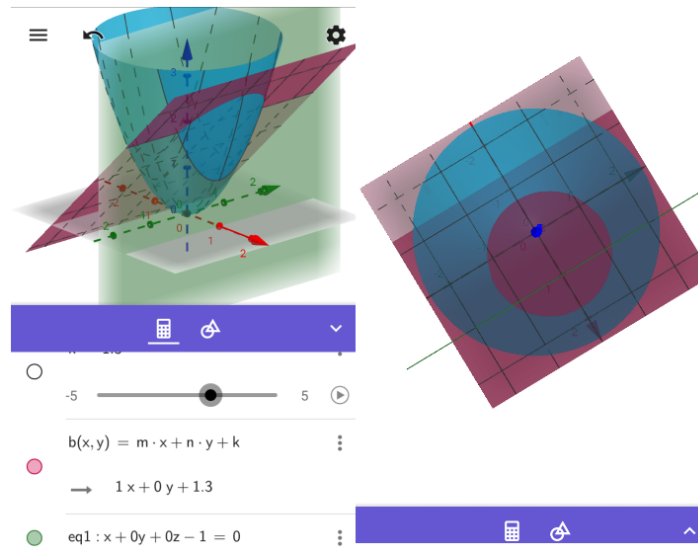

Fig. 3. a) a geometric body constructed in parallel projection, b) a projection on the Ox plane

In the teaching of probability theory, it is possible to visualize such concepts as the probability distribution function and the probability distribution density function for a two-dimensional continuous random variable. By constructing the respective planes, it will be possible to demonstrate graphs of the probability density functions for each of the components.

For example, by plotting the probability distribution function by the formula, we can consider the surface formed in more detail. Next, we cross the surface with the planes x = const or y = const. We can view the graphs of the probability density functions for each of the components of a two-dimensional continuous random variable (see Fig. 4).

4   Conclusions and prospects for further researches

Researches show that the GeoGebra AR should be used both in the profile teaching of mathematics students, and in the train of future mathematics teachers of higher mathematics, probability theory, calculus, analytical geometry.

At the same time, one of the major problems today in using the GeoGebra 3D Graphing Calculator with AR is that it is designed for iOS. Available mobile phones with Android operating system have become widespread in Ukraine.
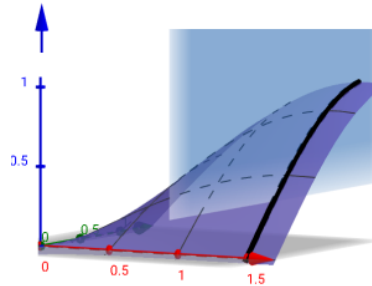
Fig. 4. Graph of the probability distribution function of two-dimensional random variable.

Investigating the possibilities of using GeoGebra in the learning calculus and geometry, found out that engaging students to research using GeoGebra helps to expand the range of educational tasks, including STEM problems. This allow to achieve the high level of learning motivation and individualize the learning process.

Implementation of applied aspect in teaching mathematics using GeoGebra 3D Calculator with AR will help to solve one of the main problems of STEM education – individualization. We can explore AR objects because this application brings 3D math to the real world.

Systematic using of GeoGebra 3D Calculator with AR can help to develop students' research skills, enhance their socialization opportunities through the acquisition of ICT, which should lead to the systematic development of universal STEM competencies.

Having looked at a number of forms and methods and tried out some of them, we found that the goal of every STEM teacher should be to motivate and involve students into research activity. Then more varied and interesting the lessons will be, then more students will admire the subject. Implementation of the STEM education in mathematics teaching makes it possible to improve the quality of learning, which will further enhance the students' academic competences.

We see the prospect of further research in the development and investigation of the effectiveness of the use of AR-based tools in both elementary and higher mathematics.

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