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The use of immersive technologies in teaching mathematics to vocational students

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Abstract. This study examines the use of immersive technologies in teaching mathematics to vocational students. The purpose of the research is to develop theoretical foundations and practical applications for the use of immersive technologies in mathematics education, and to measure the impact of these technologies on student motivation and learning outcomes. The study considers the scientific and theoretical underpinnings of immersive technologies in mathematics teaching, as well as methods for using the AR-Book application. A theoretical model, criteria, and methodological support for evaluating the use of immersive technologies are developed. A pedagogical experiment is conducted to evaluate the impact of these technologies on vocational students. Based on the results of the experiment and training materials, the study presents generalizations on the use of immersive technologies in mathematics education.

1. Introduction

Virtual reality technologies refer to immersive learning that creates the effect of presence using technical devices of virtual and augmented reality [1,2]. The range of application of virtual reality technologies is very wide [3, 4]. Technology can be used to teach students in both elementary and high school.

The importance of using immersive technologies has increased during the period of introduction of distance learning in schools. Due to the spread of the COVID-19 pandemic and the introduction of martial law in Ukraine, a significant number of educational institutions have switched to distance learning for an indefinite period [5]. These circumstances had a negative impact on the level of knowledge of students due to the difficulty of explaining topics in the conditions of distance learning [6]. Since mathematics is often a difficult discipline for students to master, the use of immersive technologies will help to increase the effectiveness of mathematics teaching.

2. Literature review

Today, various concepts of immersive technologies are known. The most cited set of technologies is VR (Virtual Reality) – fully simulated reality. In the latest developments, VR can include visualization in three-dimensional space, a 360-degree view. AR (Augmented Reality) is complemented by virtual elements that are modeled. It is a visual combination of initially independent environments – real and virtual; superimposition of programmed interactive virtual objects on a real image [7].

Immersive technologies is a collective name for all technologies that include user interaction with space, information, content [8]. They blur the lines between real and fictional worlds, allow you to interact and immerse yourself in information and product [9]. Augmented reality is an interactive technology that allows you to overlay digital content on real world objects. Overlaid digital content can be computer graphics, textual information, electronic links, videos and 3D objects. The superimposed virtual objects are read by digital devices, including smartphones, tablets, etc.

Various mobile applications with augmented reality in educational activities are used in teaching physics (AR Physics; Atom Visualizer), chemistry (Arloon Chemistry; Sparklab), space and astronomy (Spacecraft AR; Space 4D+), anatomy and medicine (FLARE Atma; Arloon Anatomy; Humanoid 4D+; AnatomyAR, Anatomy 4D), etc.

Today there are platforms that allow you to create your own applications in the format of augmented reality using ready-made components. Most of them are focused on creating AR applications for Android, iOS, Linux, Windows. Here are examples of such platforms: ARToolKit, Kudan ARSDK, AR SDK and others.

The article by Burov [10] finds that AR increases learning efficiency, encourages cognitive activity, improves learning, provokes interest in studying, promotes both research skills development and students subject competencies. The conceptual model of AR use in the educational process is substantiated and its four components (technical-technological, educational-scientific, formative-developmental, and qualitative-educational) are determined. The authors substantiate the principles (expediency, accessibility, cognition, integrity, educational orientation, mobility) and approaches (cognitive, systemic, activity-based, differentiational, personality-oriented, innovative), as well as describe pedagogical conditions and clarify the advantages and disadvantages of using AR technology in education.

Nechypurenko et al. [11] considered the problems of supporting educational and research activities in chemistry using augmented reality. The researchers concluded that: introduction of the augmented reality technology in the training process at higher technical educational institutions increases learning efficiency, facilitates students' training and cognitive activities, improves the quality of knowledge acquisition, provokes interest in a subject, promotes development of research skills and a future specialist's competent personality.

Gayevska and Kravtsov [12] emphasize that an appropriate learning environment should be created to meet the educational needs of students. It is concluded that augmented reality tools provide a new paradigm of teaching materials, which has a positive impact on the formation of basic and professional competencies of future Japanese language teachers; it can be effective when used in blended learning that combines distance, online, traditional, and self-directed learning of Oriental languages.

In teaching geometry with augmented reality, you can use applications for mobile phones Arloon Geometry [13], GeoGebra [14], AR-Book [15]. Students can be offered 3D models of many geometric shapes for consideration.

The subject of the study Rashevska ar al. [16] is the use of augmented reality tools in teaching geometry to students in grades 7-9. Analyses displayed two augmented reality tools: Arloon Geometry [13] and Geometry AR. In order to gain geometry instruction's academic success for the students, these tools can be used by teachers to visualize training material and create a problematic situation. It also provided support to reduce fear and anxiety attitudes towards geometry classes. The emotional component of learning creates the conditions for better memorization of the educational material, promotes their mathematical interest, realizes their creative potential, creates the conditions for finding different ways of solving geometric problems.

Arloon Geometry is only supported in English and Spanish. Of particular interest was the research work of España-Leyton [17] on the use of Arloon Geometry [13]. This research work, presents the implementation of an educational strategy to that the students of sixth grade, to develop spatial thinking, through the identification and differentiation of elements and properties of geometric bodies, with the support of the mobile application based on augmented reality Arloon Geometry. The results allowed to show the degree of motivation and the migration of students between levels, which were at level 1 of visualization, and after the implementation of the educational strategy they advanced to levels 2 and 3 of analysis and classification, developing spatial thinking, therefore in the end they were able to visualize, analyze and classify the constituent elements of geometric bodies, learning a new vocabulary and developing a higher level of geometric thinking.

Kramarenko et al. [18] review the peculiarities of the mobile application 3D Calculator of Dynamic Mathematics GeoGebra system with Augmented reality, improves the methodology of teaching Mathematics using cloud technologies and augmented reality.

Kuzmich et al. [19] consider the methodology of studying the geometric properties of metric spaces. To build a geometric interpretation of rectilinear and flat placement of points of metric space, it is proposed to build the appropriate analogues in two-dimensional and three-dimensional arithmetic Euclidean spaces. To visualize these concepts, it is proposed to use a dynamic geometric environment GeoGebra 3D.

Many researchers, in particular Kolomoiets and Kassim [20], highlight the following advantages of using AR technology for educational purposes as the ability to learn from any digital device; conciseness and clarity of educational content; transition from information and informative learning to interactive interaction with educational content in real time; individual learning; practice-oriented learning; increasing motivation and interest of students, etc.

Publications [21–23] are evaluates the limitations in the use of AR technologies for educational purposes. For example, due to the lack of modern mobile phones and tablets that support the latest technologies; insufficient number of educational applications with augmented reality; not all disciplines can choose the appropriate augmented reality application, etc. It is worth noting the methodological unpreparedness of teachers to use AR technology in education. Today, both students and teachers do not have enough experience with AR projects.

As noted in [24–26], the principle of immersiveness contributes to the implementation of the principle of visibility of education, expands and supplements it, taking into account modern trends and technical capabilities. Immersive technologies in education contribute to strengthening the role of visualization in the process of knowledge acquisition by the student through deep immersion in the virtual environment. The principle of complexity in the immersive approach involves the impact on all human senses to the perception of educational material. Therefore, it is important to introduce new pedagogical technologies, create promising integrated educational systems in which immersive technologies will play an important role.

3. Purpose and objectives of the article

There is not enough research on the effectiveness of using immersive technologies in teaching mathematics to students. Many teachers are not sufficiently prepared to implement new methods, technologies, which include immersive approach. Therefore, the results of this study are relevant. The authors of the article present the methodology of using the Ukrainian language application AR-Book in teaching mathematics to students. The results of the pedagogical experiment show the effectiveness of the application AR-Book to increase the level of motivation of students in the process of learning mathematics and their level of academic achievement.

The purpose of our study was to theoretically substantiate and develop directions for the use of immersive technologies in teaching mathematics to students. We measured the impact of immersive technologies on the level of motivation and learning outcomes of vocational students. To achieve the purpose of the study, the scientific and theoretical foundations of the problem of using immersive technologies in teaching mathematics; methods of using the AR-Book application in teaching mathematics to students are considered.

4. Results and discussion

The use of immersive technologies in teaching mathematics to students is based on the organization of mobile learning, optimization of the work mode of teachers and students; loyalty to knowledge control, etc. The listed items can be considered as conditions for the effective use of the immersive approach.

Learning with immersive technologies is carried out at a higher level due to immersion in the environment and the inclusion of sensory mechanisms in contextual learning. This approach is considered the most effective at the stage of organizing practical activities of students using e-learning or distance technologies. At the same time, personalized feedback is provided, unique opportunities for organizing work at home are created, and training scenarios are managed in remote work.

All these conditions are satisfied by a new way of learning through augmented reality, which is still gaining popularity in Ukrainian realities. The use of virtual simulators in the education system has a number of features.

We consider the methodology of using the AR-Book application in teaching mathematics to students. The AR-Book application from Ukrainian developers allows students to conduct safe cognitive experiments at home using AR technology [15]. The mobile application is designed to increase the efficiency of home learning. The application is relevant in a pandemic, and currently in the context of hostilities. This mobile application is a virtual laboratory in which every student can conduct school experiments anywhere and anytime. The application for learning mathematics corresponds to the school curriculum of the "standard" level.

We introduced the AR-Book application to future mathematics teachers during laboratory work on the methods of teaching mathematics, as well as to mathematics teachers during in-service training courses. Intuitive interface, meaningful visuals make the virtual simulator attractive both for training courses and for self-study.

The use of virtual simulator by students should be based on a certain amount of theoretical knowledge. We took into account the results of some studies. Therefore, before using the AR-Book application, it is advisable to provide the teacher with explanations of theoretical information, checking the student's basic skills in working with computers.

When teaching mathematics to students of vocational schools using immersive technologies, the curriculum for 10-11 grades and its coverage in modern textbooks were followed. Textbooks of the standard level were used in the training, in particular by Merzlyak et al. [27].

In figure 1 shows examples of visualizations from the AR-Book application. Namely, the presentation of theoretical information about parallel lines in the AR-Book application.

In figure 2 shows an example of the task and the correct answer in the task of finding the volume of a cylinder in the AR-Book application.

The correct answer is highlighted in green, and the possible answers are highlighted in yellow. If the student could not answer the questions correctly the first time, he has a new chance to succeed. In the textbook, theoretical information about parallel lines is presented in the form of rules, and in the AR-Book application – in the form of three-dimensional drawings with voice explanation. The quality of pupils' perception of educational material significantly depends on what type of information perception they have more developed (auditory or visual). It is advisable to compare the tasks for the topic "Cylinder" in the textbook for grade 11 and in the AR-Book application. In the textbook, the task formulation is given in the form of text. There are few three-dimensional drawings in the textbook. In the AR-Book app, all tasks are accompanied by a three-dimensional image that the student can see better by zooming in or changing the viewing angle of the figure. The use of augmented reality technology can also develop spatial thinking in students and contribute to a more harmonious development of the individual.

Having compared the design of tasks in the textbook and in the AR-Book application, we can

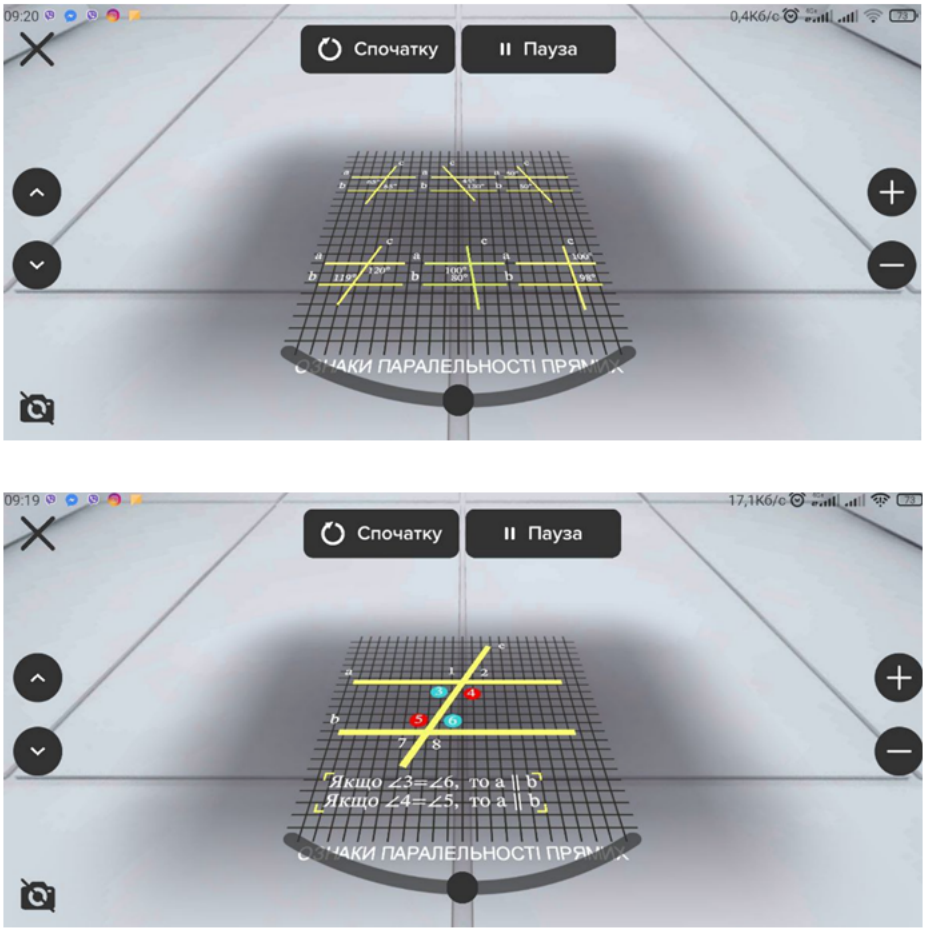

Figure 1. Presentation of theoretical information about parallel lines in the AR-Book application.

hope to increase the visibility of the presentation of theoretical material using AR-Book. The results of the survey of students show that the tasks from the application are more attractive for them. At the same time, high efficiency of mathematics teaching can be achieved by combining traditional and innovative teaching methods. In particular, using immersive technologies in teaching.

Educational communication is the main means of interaction between the teacher and students in the context of the use of AR-teaching tools. Using the means of educational communication, the teacher sets the parameters of learning, determines the conditions for performing the educational task, adjusts the course of students' activities, provides meaningful orientation and creates conditions for students to realize the results of their activities in the virtual reality environment.

Consider how to use the AR-Book application. The teacher offers to get acquainted with theoretical information, and then complete the task on the selected topic. If the student has difficulties with the task, the teacher gives recommendations on how to work with the application or further explains unclear points on the topic being studied. Or the student can listen to the lesson again.

For example, when studying the topic "Regular polyhedra", the teacher first provides students with theoretical information on the topic. The next step is to give an example of a task on the

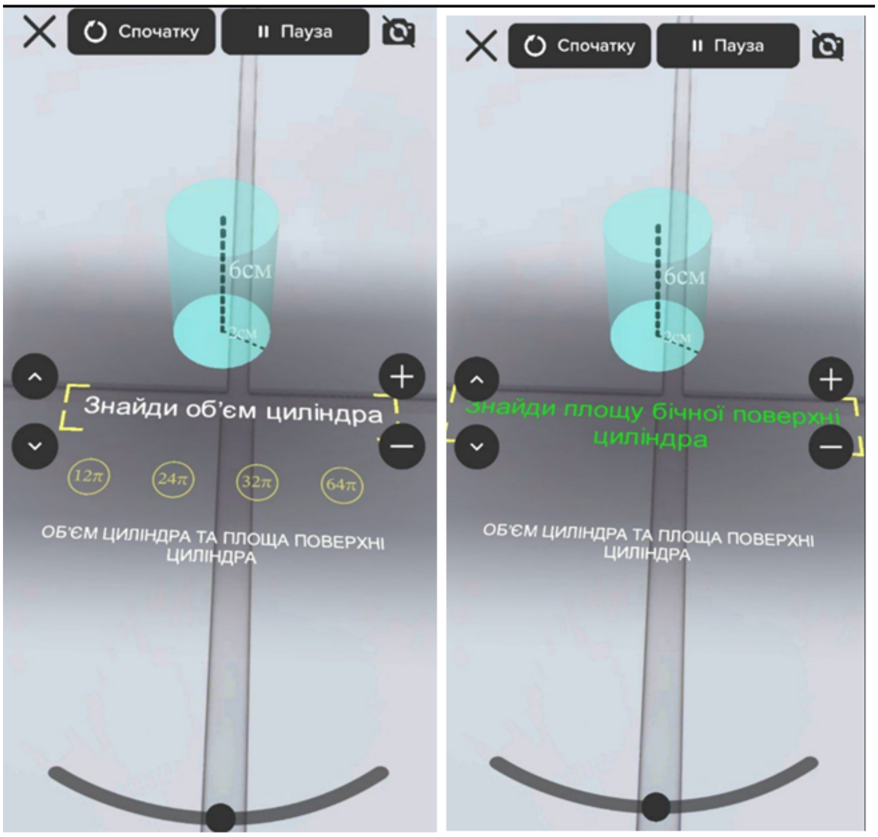

Figure 2. Presentation of theoretical information about parallel lines in the AR-Book application.

topic "Regular polyhedra". Then the teacher invites students to complete a practical task using the AR-Book application. When completing the task, the student can choose two options: virtual environment and augmented reality, which differ in the visual display when the student performs tasks. Everyone chooses the option that is more convenient for him.

In the AR-Book application, some of the practical tasks are called experiments. There are also tests for the topic, which include a list of questions and answers to them. When a student starts a practical task, he/she is offered basic information on the topic. Then you need to solve problems of medium complexity and answer simple questions. For example, to determine the number of vertices, the number of faces.

When the student moves from studying the tetrahedron to the hexahedron, the questions are repeated. Questions are asked about three shapes: tetrahedron, octahedron and hexahedron. The student can zoom in on the octahedron model in the app, rotate it and examine it. If the student is unable to logically answer a question about the number of vertices or edges, they can turn the model around and count. If the student chooses the wrong answer, he/she can correct the mistake and succeed. Considering each of these polyhedra, students are offered a summary table. It provides information on the number of vertices, faces, and the number of edges extending from one vertex for each of the regular polyhedra, including the dodecahedron and icosahedron.

In the course of the study, a theoretical model of the use of immersive technologies in teaching mathematics to students of vocational schools was developed and tested. The target block of the system of forming students' mathematical competence is represented by the unity of the goal and tasks, the complex solution of which ensures its achievement. One of the goals was to increase the motivation of students to study mathematics and improve the assimilation of educational material.

To achieve the goal, professional mathematical tasks were identified based on such competencies as readiness to learn; work with modern teaching technologies; use systematic theoretical and practical knowledge in the process of teaching mathematics and others. This model (figure 3) reflects the general didactic and professional principles of learning. In particular, the general didactic principles include the principles of scientificity, systematicity, visibility, strength of assimilation, consistency, continuity, activity and consciousness of learning. To professional we include the principles of integration and differentiation of mathematical knowledge and creative activity.

The didactic block includes structural and functional components of the content and technology of vocational training with the use of immersive technologies. It presents forms, methods and means of training.

We attach special importance in teaching mathematics to the method of scientific research using modern information and communication tools. Observations have shown that the development of independent activity allows students to use ICT to obtain the necessary amount and quality of knowledge, to use immersive technologies independently.

It should be noted that the achievement of the intended goal is impossible without appropriate pedagogical conditions. The general pedagogical conditions include the formation of students' positive motivation for independent work in the process of studying mathematical disciplines; the formation of professional culture. The organizational and pedagogical condition is the provision of didactic material that forms the readiness of students to use information technology. The technological conditions include the establishment of interdisciplinary links with the disciplines of natural and professional cycles on the basis of modular learning; timely and efficient filling of the information educational environment with educational content.

The evaluation and result block is represented by criteria and indicators corresponding to each of them. In particular, the motivational criterion is the motivational readiness for effective professional activity. The volume and quality of acquired knowledge in accordance with the requirements of the curriculum of mathematical disciplines is considered as a cognitive criterion. The personal criterion is the application of mathematical knowledge in solving professionally oriented knowledge, performing mathematical processing of statistical data, etc. Reflective and creative criterion is the ability to choose acceptable immersive technologies in the process of finding solutions to a specific problem, in the process of mastering heuristic operations in the course of solving professional problems.

Thus, the theoretical model of using immersive technologies in teaching mathematics to students of vocational schools consists of a target block, didactic block and diagnostic block. The purpose is to increase the motivation of students to study mathematics and increase the assimilation of educational material through the use of immersive technologies.

The development of psychological criteria for the formation of motivation to acquire knowledge in mathematics of students of vocational schools as content-activity, motivational-value and personal will contribute to the development of teaching mathematical disciplines to students of vocational schools. Students will receive sufficient knowledge, they will form a high level of motivation to learn.

Psychodiagnostic methods (questionnaires, testing) were used in the empirical study. To evaluate the formation of motivation to acquire knowledge in mathematics of students of vocational schools in the learning process, the questionnaire "determining the level of aspirations" by Magun and Engovatov [28] was chosen to determine the orientation of students to acquire knowledge; the method "Motivation of learning activity" by Rean and Yakunin [29] to determine the motivation of pupils to learn mathematics; methodology of Kučera and Smékal

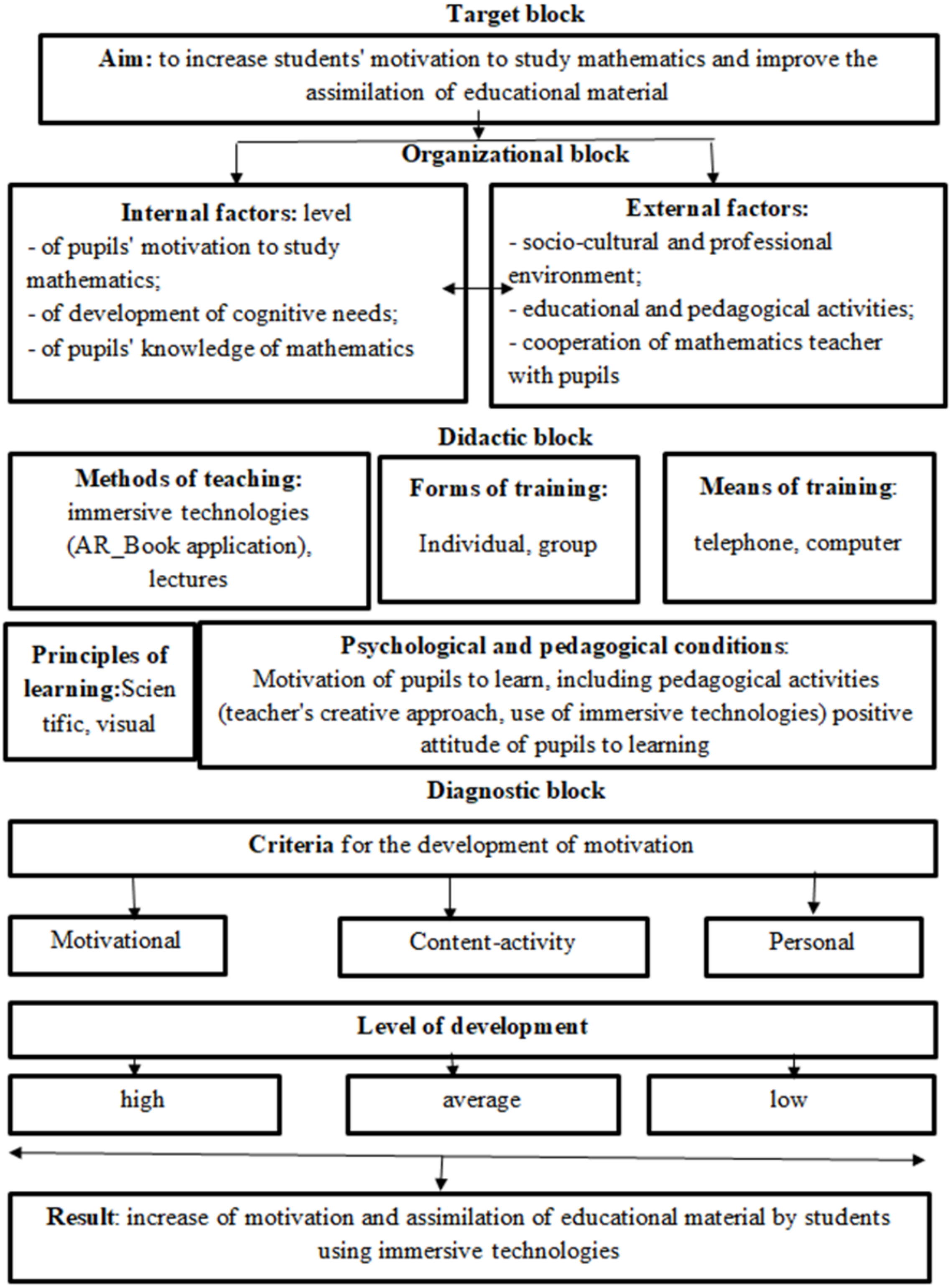

Figure 3. Theoretical model of using immersive technologies in teaching mathematics to students of vocational schools.

"Study of personality orientation" [30]; methodology "Value orientations" of Rokeach [31]; cut-off written testing. A pedagogical experiment was conducted for two months. Mathematics classes were held with the use of immersive technologies – AR-Book application. With the help of the educational mobile application AR-Book, students were offered to pass test tasks in mathematics. The list of topics is coordinated with the secondary school curriculum (which is also suitable for vocational school students). As already mentioned, the educational process was based on the use of curricula for 10-11 grades and the material was taught to students using modern mathematics textbooks.

AR-Book application was used as an additional tool for teaching mathematics to vocational school students. The tasks are accompanied by the teacher's explanation of certain aspects of the topic, formula, and after reviewing the educational material it is possible to pass a test task. For better learning of the topic, the student can take the test tasks the required number of times, because these applications are aimed at helping to learn the topic, not to control knowledge. To control knowledge, the teacher conducts traditional tests and cross-sectional independent work during the school semester.

After the pedagogical experiment, a repeated study of students' motivation to study mathematics and their level of knowledge after using the AR-Book application for two months was conducted.

The results of the study of the level of pupils' claims according to the methodology "Determination of the level of claims" by Magun and Engovatov after the experiment are presented in table 1. We tested the statistical hypothesis of differences in the frequency distribution for the pre- and post-experiment data using the chi-square test. We found that the alternative hypothesis of differences in frequency distributions was true. The significance level is 0.05 %, the critical value is 5.99; the empirical value is 12.00. This confirms the hypothesis of an increase in the level of motivation.

Table 1. Results of the study of the level of pupils' expectations according to the methodology "Determination of the level of expectations" by Magun and Engovatov after the experiment.

The level of claims	Before the experiment	After the experiment
Low	10 (36 %)	4 (16 %)
Medium	9 (36 %)	9 (36 %)
High	6 (24 %)	12 (48 %)
Total	25 (100 %)	25 (100 %)

We compared the proportions of high motivation before and after the experiment using the Fisher's Angle Transform criterion.

It was found that the alternative hypothesis about the differences in the proportions of high-level motivation was true. The significance level is 0.05 %, the critical value is 1.64; the empirical value is 1.71. The result confirms the hypothesis of an increase in the high level of motivation. Similarly, the sums of the shares of high and medium levels were compared. At the 0.05 % significance level, the alternative hypothesis for the post-experiment data was confirmed (critical value 1.64; empirical value 1.84).

As a result of the study of students' aspirations, it was found that the number of highly motivated students increased by 24% and low motivated students decreased by almost the same percentage. This allows us to draw conclusions about the high efficiency of using the AR-Book application to interest students in learning.

Table 2. Results of the study of the level of motivation of students' learning activities according to the method of Rean and Yakunin after the experiment.

Motivation factors	Before the experiment	After the experiment
to continue studying at a higher education institution	3 (12 %)	4 (16 %)
to get a diploma	5 (20 %)	1 (4 %)
to study to become a qualified specialist	8 (32 %)	9 (36 %)
to ensure the success of future career	6 (24 %)	5 (20 %)
to gain knowledge in the specialty	3 (12 %)	6 (24 %)
Total	25 (100 %)	25 (100 %)

The results of diagnostics of students' motivation for learning activities according to the methodology of Rean and Yakunin after the experiment are presented in table 2.

As we can see, the level of motivation to acquire knowledge in the specialty has increased, as evidenced by the factor of motivation to learn before the experiment, 12 % of students, and after the experiment, 24 % of students.

We compared the shares of the Fisher's Angle Transformation criterion before and after the experiment. It was found that the alternative hypothesis about the differences in shares was true. The significance level is 0.05 %, the critical value is 1.64; the empirical value is 4.07. The result confirms the hypothesis of an increase in motivation to acquire knowledge in the specialty.

The results of the study of the level of knowledge in mathematics after the experiment are shown in table 3.

Table 3. Results of the study of the level of knowledge in mathematics after the experiment.

The level of claims	Before the experiment	After the experiment
Low	12 (48 %)	5 (20 %)
Average	10 (40 %)	13 (52 %)
High	3 (12 %)	7 (28 %)
Total	25 (100 %)	25 (100 %)

We tested the statistical hypothesis about differences in frequency distributions for the pre- and post-experiment data using the chi-square test. We found that the alternative hypothesis about differences in frequency distributions was true. The significance level is 0.05 %, the critical value is 5.99; the empirical value is 12.78. This confirms the hypothesis that the level of math knowledge is increasing.

We compared the proportions of high motivation before and after the experiment using the Fisher's Angle Transform criterion.

It was found that the null hypothesis, i.e., for a high level of differences in the shares, has not yet been confirmed. The significance level is 0.05 %, the critical value is 1.64; the empirical value is 1.37.

Similarly, the sums of the shares of high and medium levels were compared. At the significance level of 0.05 %, the alternative hypothesis for the post-experiment data was confirmed (critical value 1.64; empirical value 2.03). That is, in total, the share of medium and high levels of knowledge is significantly higher after the experiment.

It was found that the level of knowledge in mathematics among pupils has also improved. The number of pupils with low level of knowledge decreased by 28%. The number of students with an average level of knowledge increased by 12%. The number of students with high level of knowledge increased by 16 AR-Book application was used as an additional tool for teaching mathematics to vocational school students. The tasks are accompanied by the teacher's explanation of certain aspects of the topic, formula, and after reviewing the educational material it is possible to pass a test task. For better learning of the topic, the student can take the test tasks the required number of times, because these applications are aimed at helping to learn the topic, not to control knowledge. To control knowledge, the teacher conducts traditional tests and cross-sectional independent work during the school semester.

After the pedagogical experiment, a repeated study of students' motivation to study mathematics and their level of knowledge after using the AR-Book application for two months was conducted.

As a result of the study of students' aspirations, it was found that the number of highly motivated students increased by 24 %, and low motivated students decreased by almost the same percentage. This allows us to draw conclusions about the high efficiency of using the AR-Book application to interest students in learning. The results of the study of the level of knowledge in mathematics after the experiment were analyzed. It was found that the level of knowledge in mathematics among pupils has also improved. The number of pupils with low level of knowledge decreased by 28 %. The number of students with an average level of knowledge increased by 12 %. The number of students with high level of knowledge increased by 16 %.

The statistical hypothesis was tested according to the criterion of differences in the distribution of values of the attribute. According to the Fisher's angular transformation, the alternative hypothesis of a decrease in the share of low level and an increase in the share of high level of pupils' motivation and learning achievements was confirmed.

5. Conclusions

Taking into account the results of the pedagogical experiment, we can conclude that the use of the AR-Book mobile application for teaching mathematics to students of vocational schools is appropriate. The systematic use of the application by students has brought a positive result in the form of increasing students' motivation and improving their level of knowledge.

Among the advantages of using immersive technologies in teaching mathematics to students are: full immersion in the learning process, "presence effect"; visibility and brightness of sensations; interactivity; facilitation of understanding and simplification of perception; use of visual and auditory channels of perception; the ability to simplify the perception of complex objects; the ability to scale, rotate, assemble and disassemble complex objects into their constituent elements; the possibility of gamification of education; the possibility of repeated repetition of information and training skills.

To use immersive technologies in teaching, it is necessary to create psychological and pedagogical conditions. The key requirements for the system of building interactive learning tools are: ease of use and versatility. By means of educational communication, the teacher sets the parameters of learning, determines the conditions for completing the learning task, adjusts the course of students' activities, provides meaningful orientation and creates conditions for students to realize the results of their activities in the virtual or augmented reality environment.

The theoretical model of using immersive technologies in teaching mathematics to students of vocational schools consists of a target block, didactic block and diagnostic block. The aim is to increase the motivation of students to study mathematics and increase the assimilation of educational material through the use of immersive technologies. Pupils will receive sufficient knowledge, they have a high level of motivation to learn.

Prospects for further research are the development of ways to solve the problems of using augmented reality technology in education and their implementation in practice.

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