Using augmented reality tools in the teaching of two-dimensional plane geometry

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Abstract. One of the successful components of quality assimilation of educational material and its further use in the learning process is visualization of material in secondary education institutions. Visualizations need the subjects of the school course, which are the most difficult to understand and essentially do not have at the beginning of the study of widespread practical application, mostly mathematical objects. That is why this study aimed to analyze mobile tools that can be used to visualize teaching geometry. The *object of the study* is the process of teaching geometry in the middle classes of secondary schools. The *subject of the study* is the use of augmented reality tools in teaching geometry to students in grades 7-9. The study used such *research methods* as the analysis and justification of the choice of mobile augmented reality for the study of mathematics. Analyses displayed two augmented reality tools: ArloonGeometry 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. The use of augmented reality means in the geometry lessons creates precisely such conditions for positive emotional interaction between the student and the teacher. 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.

Keywords: geometry, augmented reality tools, Arloon Geometry, Geometry – Augmented Reality.

1 Introduction

1.1 The problem statement

Modern rhythm of life and fast-changing information and communication technologies require to the younger generation to adapt quickly to different situations, to acquire knowledge in all conditions and to be able to apply the acquired knowledge in practice.

All the recently innovations of the Ministry of Education and Science of Ukraine are aimed to the fact that the graduate of the educational institution should possess certain competencies and be able to independently acquire the knowledge necessary for solving certain problems.

On the one hand, we have certain requirements for a modern graduate of an institution of secondary or higher education, who in the process of education must develop various competences, acquire knowledge and become competitive not only in the domestic but also in the world labor market.

On the other hand, the situation in the system of secondary and higher education is far from the State standard of education and requires changes, which have been described in the documentation of the Ministry of Education and Science of Ukraine for the last ten years.

1.2 Literature review

Analysis of scientific research has shown that one of the ways to change the situation in the Ukraine education system is a competent and systematic introduction mobile information and communication tools and technologies to the process of learning [2; 8; 10], and also changing the model of learning which means the transition from traditional forms and methods of learning to innovative.

According to Valerii Yu. Bykov [5], informatization of education has become a revolutionary lever that relies on the achievements of classical psychological and pedagogical science. This requires the development of specific tasks for the creation and effective implementation of information and communication technologies in educational practice.

Serhiy O. Semerikov [12] indicated that the introduction of mobile ICT high school education will contribute to the quality of education. It enhances the flexibility of the learning process and meets the requirements of lifelong education and training and this will also help to improve educational opportunities for people with disabilities by offering them more flexibility and choice of time and place of study by delivering training materials to their mobile devices to suit their needs.

Scientists see one of the ways to improve the quality of mathematics education, in particular in geometry, is the introduction into the education system of modern mobile technologies – augmented reality [13].

The work developed by [1], establishes a relationship between problem of development of students' spatial thinking and introducing into the learning process of augmented reality.

It considers that the application Construct 3D, as a tool for constructing three-dimensional geometric structures is a striking example of the use of augmented reality in the study of geometry. This application uses stereoscopic main displays and personal interactive panels. Construct3D allows multiple people to work in the same space and build different geometric models that overlap with the real world.

In [11] propose the possibility of using the SISEULER application in the study of convex polyhedra for the development of spatial imagination in the study of 3D geometry by means of augmented reality. You can use marker cards that show the number of vertices, edges, and faces of a convex polyhedron and see a convex polyhedron with the corresponding Euler characteristic.

Using the AR Math application [7] gives students the opportunity to establish connections between objects from the world around them and geometric shapes, to determine their properties, which creates conditions for the formation of not only spatial thinking, but also the ability to build logical connections. Such learning takes place through virtual manipulation of objects in augmented reality.

The use of AR Math application in the process of studying geometry provides an opportunity to implement the following tasks [6]:

- representation of both virtual and mathematical situation;
- search for specific household items in a real environment and their recognition on the basis of computer vision algorithms;
- solving the problem of determining geometric objects and their classification;
- interactive interaction of students with a virtual person helps the student to solve a problem or write a solution in the form of a mathematical expression based on understanding of semantics (or to compare the found solution to one of the proposed mathematical expressions).

The implementation of AR Math tasks is based on the use of machine learning algorithms, including, for example, the k-mean algorithm for selecting clusters of objects by color or shape. The presence of a virtual assistant that engages students in an augmented reality environment through the “Stories” of interesting history and problem statement contributes to the study of real mathematics.

Another interesting application that allows students to better understand the world of geometry is the program GeoGebra AR [9]. The authors of the article claim that this application will be useful not only for students to develop their spatial thinking, but also for future teachers of mathematics. The systematic use of GeoGebra 3D Calculator with AR can help develop students' research skills, expand their socialization opportunities through the acquisition of ICT, which ensures the development of universal STEM competencies. There is no question that the goal of every STEM teacher should be to motivate and engage students in research activities [15].

That is why the purpose of the article is to review some of the mobile ICTs that can be introduced into the secondary education system of Ukraine in the process of studying mathematics.

2 Research results

2.1 Main definitions and terms

The development of spatial visualization skills is one of the necessary skills required for a graduate. This gives the student a better understanding of the environment and its location. Well-developed spatial thinking makes the study of mathematics more interesting and simple, as it makes it possible to visualize teaching material and make mathematics more comprehensible.

Our own experience in secondary and higher education institutions has made it possible to single out a number of problems of teaching mathematics of high school students and students of the first year of engineering specialties:

- students of humanities subjects classes have no systematic knowledge of mathematics and are not able to integrate into the process of learning a new topic of previously known knowledge;
- students of 10th grade, mostly liberal arts, in the process of studying 3D geometry do not have sufficiently developed spatial thinking and do not understand the location of basic geometric concepts in space;
- according to a study conducted in the first year of full-time students at a technical university and high school students, 25% are unable to find the necessary information on the Internet and require constant monitoring and directed work by the teacher in the search for educational information;
- most of first year students are underdeveloped with independent work skills.

Building a blended learning model is one way to solve these problems [4]. It has proven itself on the positive side and is gaining more and more supporters in the world. This makes the learning process interactive, enables you to learn at your own pace, build a personal learning environment rich with mobile ICT [18].

Blended learning is a deliberate process of acquiring knowledge by learning subjects in the context of integrating classroom and extra-curricular learning. It is rich in information and communication tools and technologies, which facilitates the construction of its own learning trajectory independent of others.

One of the ICT that can be used to visualize learning material in a blended learning model is augmented reality technology. The application of this technology enables the student or student to dive into mathematics and not burden it with its complexity.

The development of students' spatial thinking is one of the pressing problems of mathematical education. Its formation begins in the grades 7-9 course of 2D geometry and deepens in the process of studying 3D geometry at grades 10-11. And if almost all students in grades 7-9 can represent a geometric figure, then upper-class students in the process of studying3D geometry have a problem with this:

- cannot represent the spatial figure depicted in the plane;
- cannot represent a spatial body, especially if there are additional conditions in the task;
- cannot give examples of geometric bodies from the outside world;

– cannot design a geometric body in space on a plane;
– cannot distinguish parts in spatial objects.

One of the ways to solve these problems can be to use mobile tools in geometry lessons or to visualize a geometric figure in the course of homework, namely augmented reality.

Today, there are two basic concepts of augmented reality construction [3]:

– based on a marker [17];
– based on user coordinates [14].

Marker-based technology is a new interactive system for using a special marker. A marker means an object that can be placed in space and which is defined and analyzed by special software to further visualize the object. Based on the data obtained from the token, the program automatically projects a virtual object on it, resulting in the effect of its physical presence in space.

Technologies based on user coordinates are used in mobile devices and rendering in them is due to special sensors.

2.2 Experience of cloud technologies application and their services in educational and scientific space

So, during the studying geometry in grade 7, is advisable to introduce students to the Spanish program Arloon Geometry (http://www.arloon.com/), which will make it easier to understand the process of obtaining knowledge of geometry. The developers recommend using this program, starting at the age of 10, to get acquainted with geometric shapes and bodies (fig. 1).

Fig. 1. The ArloonGeometry application window.

You can download this application from Google Play with minimal requirements to mobile device: Android 4.0.3 or higher, iOS 8.0 or higher.

This program is not affiliated with any textbooks, but is completely autonomous and is freely available but not free of charge, though its price is purely symbolic – $2.99.

Features of this program are:

- student can study geometry both in the plane and in space. Volumetric shapes have a planar sweep, and combinations of flat shapes created by the student on their own can be translated into space;
- if you work with spatial bodies, you can learn to determine the area of the side surface or volume of this body;
- in addition to getting acquainted with the spatial figures, the program can choose the mode of "perform exercises" and study formulas or calculations that work on one or another side face of a spatial polyhedron;
- using of the program will enable students to find and identify polyhedrons or other geometric bodies in the environment;
- independently perform the tasks in the sections "guess", "right / wrong" and "calculation" and check how much material was learned.

The disadvantages of the program are

- that it is not free;
- today, it is only supported in English and Spanish.

Introducing 7th grade students to this program in geometry lessons will not only create conditions for the development of spatial visualization skills, but will also allow students to see the differences between 2D geometry and 3D geometry. But to determine the applied orientation of geometry; understanding the essence of the geometric task.

In addition to the augmented reality application for geometry, you can also use programs in chemistry, biology, arithmetic, anatomy and astronomy.

It is advisable to use a mobile augmented reality tool such as Geometry – Augmented Reality during the studying geometric shapes in 7th, and especially in 8th grades (fig. 2).

Fig. 2. Geometry –Augmented Reality window.

Provided that Android 4.0 or higher, you can download this app for free on Google Play. This app was first introduced in 2017 and given time is not popular enough. To work with geometric shapes, you also need to download and print the letters that are labeled for this program. The four letters A, B, C, and D are included, but can be repeated to construct polygons.

With this application and mobile device, the student is able to:

- construct segments and determine their length in conventional units;
- build triangles and find their perimeter and area;
- build quadrangles and determine their perimeter and area;
- work with polygons.

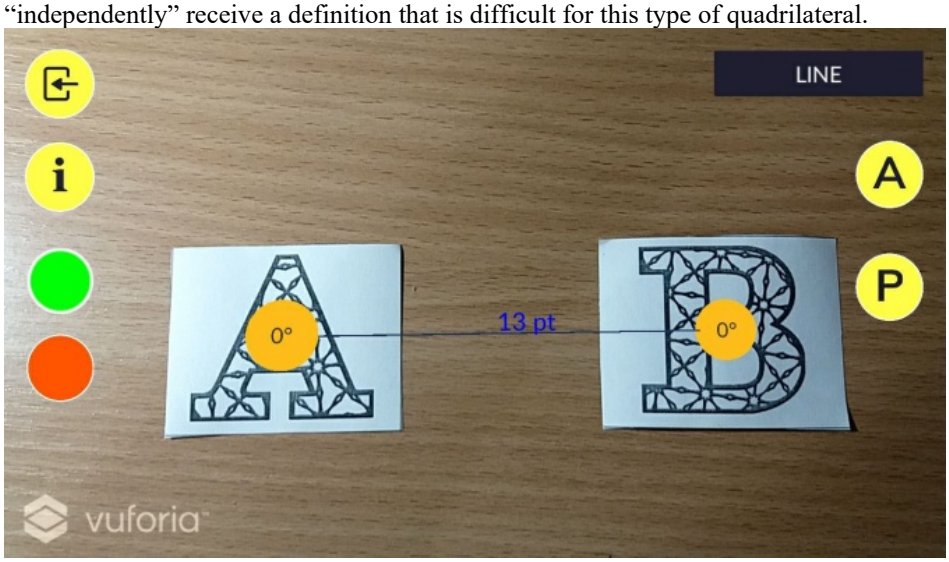
Through this program, students of 8th grade will be able to independently construct and clearly understand the difference between a convex and a non-convex quadrilateral when studying the theme “Quadrilaterals”. Determine this type of quadrilateral as a parallelogram by changing angles, and also consider its special cases – rectangle, rhombus, square (fig. 3).

Using this program in geometry lessons in the 7th and 8th grades of secondary schools will allow students to develop of spatial visualization skills as it enables them to visualize geometric constructions, independently work with geometric figures and change them at will.

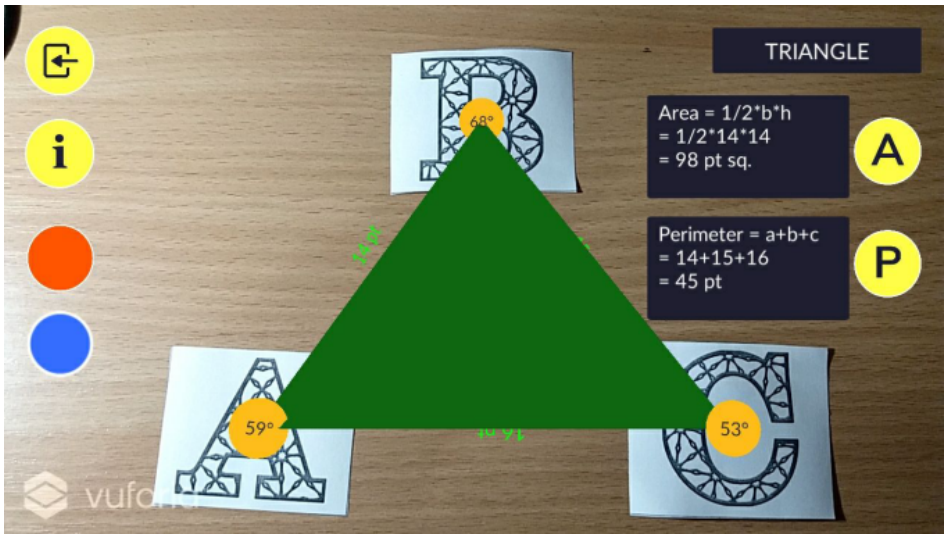
We will describe some possibilities of using Geometry AR when studying the topic “Convex quadrilaterals” in 8th grade.

After the teacher gives the definition of the concept of “quadrilateral”, it is advisable to give students the opportunity to independently obtain images of different types of quadrilaterals, so that the meaning of the definition is visualized in their understanding. It is advisable to show them the difference between convex and non-convex quadrilaterals by moving the labels (vertices of the quadrilateral) and changing the lengths of the segments.

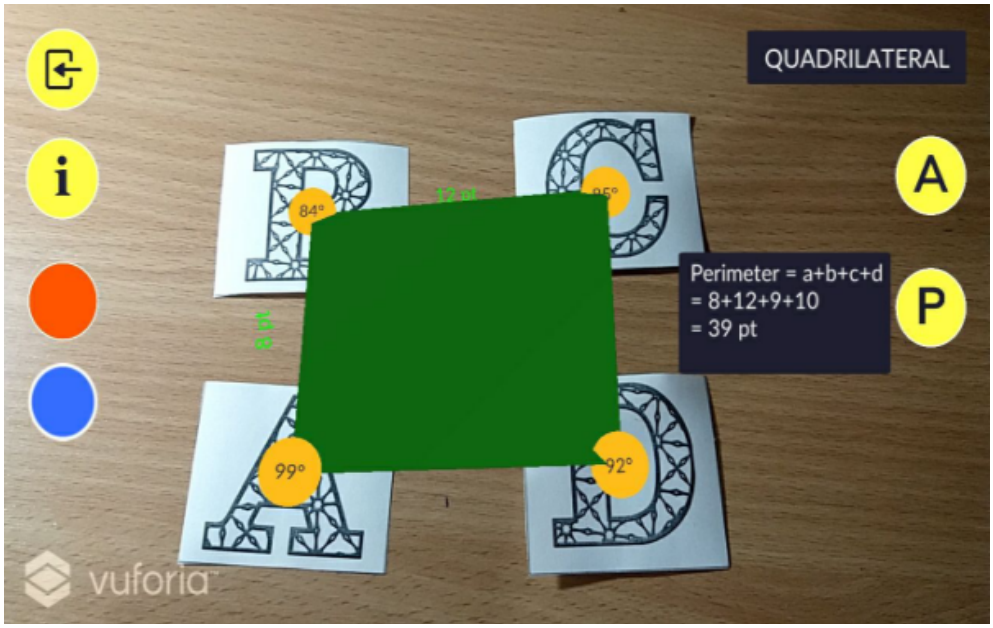
The use of this program will create conditions for the construction of problem-based learning in the study of different types of quadrilaterals. Students independently obtain the properties of the quadrilateral under consideration, formulate its features and “independently” receive a definition that is difficult for this type of quadrilateral.



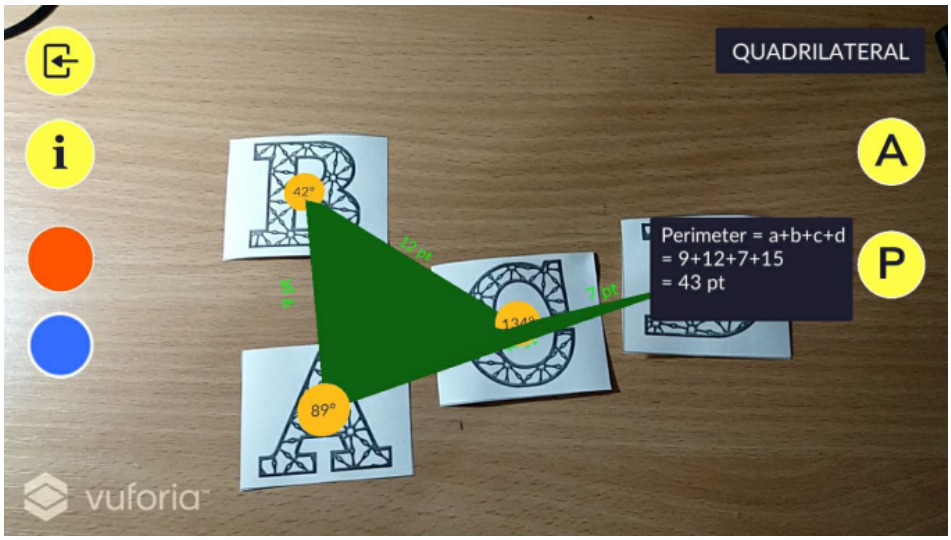
a) construction of a segment



b) construction of a triangle



c) construction of a convex quadrilateral



d) construction of a concave quadrilateral

Fig. 3. Buildings in Geometry – Augmented Reality.

The possibility of self-visualization of quadrilaterals and the separation of their features become even more important in the transition of the school system to the model of blended learning. Therefore, the means of augmented reality become a necessary tool in such a system of education.

The analysis of various technologies and tools of augmented reality showed that at present there are not enough developed and adapted programs for school education, particularly in geometry courses. But at the same time, a sufficient number of platforms have been developed to enable the teacher to create their own applications in AR format, or to provide this opportunity for students.

Consider some platforms for creating applications in AR format that are either freely distributed or require special educational licensing [16]:

- ***ARToolKit*** (http://www.hitl.washington.edu/artoolkit/) is a library of tools designed to create design solutions and augmented reality applications. This platform the most popular among developers.
- ***Vuforia*** (https://developer.vuforia.com/) is a platform that allows you to create applications in AR-format for smartphones on iOS, Android. The ability to create and analyze flat images and simple three-dimensional objects, create geometric shapes makes it usable with the help of virtual controls, the user can rotate the object, zoom it.
- ***HP Reveal*** (until 2018 ***Aurasma***) (can be downloaded from Google Play) is a platform for creating augmented reality projects. Creating educational materials on this platform is very interesting and gives the opportunity to show their creative abilities not only to teachers but also to students.

- ***Metaverse*** (https://studio.gometa.io/landing) is a platform that enables you to create interactive learning tasks without significant programming skills.
- ***EV Toolbox*** (https://nitforyou.com/ev-toolbox/) is a simple and convenient constructor for all programmer users. The student or teacher can create augmented reality on their own. EV Toolbox Designer customizes the ability to visualize textbook material: mathematical abstractions, display a generated object on a smartphone screen: three-dimensional geometric shapes and surfaces. At the same time, the students' drawings on the plane are transformed into interactive 3D objects. Virtual Object Interaction visualizes an action that is practically impossible to perform on a piece of paper.

Therefore, it can be argued that a teacher in his profession can not only be a user of developed augmented reality, but also become the creator of educational products that will develop his creative potential.

3 Conclusions and prospects for further research

An analysis of some augmented reality tools that can be used in geometry teaching at school has made it possible to draw the following conclusions:

1) creation of appropriate conditions for students' self-realization, their intellectual development and the development of their spatial imagination is the main task of the teacher, who is the organizer of the educational process;
2) the teacher in the learning process is the motivator for the construction of personal trajectory of learning. He / she demonstrates the ability to use a variety of information and communication tools and technologies for self-development and self-improvement;
3) the teacher, as an individual, also has a significant influence on the emotional state of the student. It is undeniable that the student's emotional attitude to the teacher reflects his / her attitude towards the subject. If the emotional component of the dialogue between the student and the teacher is some motivational component of their interaction, the learning outcomes are increased, the cognitive activity of the students increases, their creative potential is revealed, the learning process is intensified;
4) in the process of studying geometry, the emotional component has a significant impact on learning outcomes. It is advisable to begin every lesson in geometry precisely with the creation of a teaching dominance, which emotionally sets the students on to acquire knowledge and to apply them in everyday life;
5) the use of augmented reality means in the geometry lessons creates precisely such conditions for positive emotional interaction between the student and the teacher. First, students understand that a mobile device can be used precisely to organize the learning process, to intensify it and to build a personal learning path. Secondly, the emotional component of learning creates the conditions for better memorization of the educational material, promotes their mathematical interest, realizes their creative potential, and creates the conditions for finding different

ways of solving geometric problems. Third, the ability to solve simple geometric problems with augmented reality tools creates a positive disposition for the student to succeed and to solve more complex problems faster and more intensively.

References

1. Belova, O.P, Kaznin, A.A.: Application of augmented reality technology for graphical visualization of educational tasks in spatial geometry. Concept **39**, 3521–3525. http://e-koncept.ru/2017/971031.htm (2017). Accessed 21 Mar 2020
2. Bilyk, Zh.I., Shapovalov, Ye.B., Shapovalov, V.B., Megalinska, A.P., Dołhańczuk-Śródka, A.: Assessment of mobile phone applications feasibility on plant recognition: comparison with Google Lens AR-app. In: Burov, O.Yu., Kiv, A.E. (eds.) Proceedings of the 3rd International Workshop on Augmented Reality in Education (AREdu 2020), Kryvyi Rih, Ukraine, May 13, 2020, CEUR-WS.org, online (2020, in press)
3. Blagoveshchensky, I.A., Demyankov, N.A.: Technologies and algorithms for creating augmented reality. Modeling and analysis of information systems 20(2), 129–138 (2013)
4. Bondarenko, O.V., Mantulenko, S.V., Pikilnyak, A.V.: Google Classroom as a Tool of Support of Blended Learning for Geography Students. In: Kiv, A.E., Soloviev, V.N. (eds.) Proceedings of the 1st International Workshop on Augmented Reality in Education (AREdu 2018), Kryvyi Rih, Ukraine, October 2, 2018. CEUR Workshop Proceedings **2257**, 182–191. http://ceur-ws.org/Vol-2257/paper17.pdf (2018). Accessed 29 Nov 2019
5. Bykov, V., Dovgiallo, A., Kommers, P.A.M.: Theoretical backgrounds of educational and training technology. International Journal of Continuing Engineering Education and Life-Long Learning **11**(4-6), 412–441 (2001)
6. Dyulicheva, Y.Y.: About the Usage of the Augmented Reality Technology in Mathematics and Physics Learning. Open Education **24**(3), 44–55 (2020). doi:10.21686/1818-4243-2020-3-44-55
7. Kang, S., Shokeen, E., Byrne, V.L., Norooz, L., Bonsignore, E., Williams-Pierce, C., Froehlich, J.E.: ARMath: Augmenting Everyday Life with Math Learning. In: CHI '20: Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems. April 2020, pp. 1–15. doi:10.1145/3313831.3376252
8. Kazhan, Yu.M., Hamaniuk, V.A., Amelina, S.M., Tarasenko, R.O., Tolmachev, S.T.: The use of mobile applications and Web 2.0 interactive tools for students' German-language lexical competence improvement. In: Kiv, A.E., Shyshkina, M.P. (eds.) Proceedings of the 7th Workshop on Cloud Technologies in Education (CTE 2019), Kryvyi Rih, Ukraine, December 20, 2019. CEUR Workshop Proceedings **2643**, 392–415. http://ceur-ws.org/Vol-2643/paper23.pdf (2020). Accessed 20 Jul 2020
9. Kramarenko, T.H., Pylypenko, O.S., Zaselskiy, V.I.: Prospects of using the augmented reality application in STEM-based Mathematics teaching. In: Kiv, A.E., Shyshkina, M.P. (eds.) Proceedings of the 2nd International Workshop on Augmented Reality in Education (AREdu 2019), Kryvyi Rih, Ukraine, March 22, 2019. CEUR Workshop Proceedings **2547**, 130–144. http://ceur-ws.org/Vol-2547/paper10.pdf (2020). Accessed 10 Feb 2020
10. Lavrentieva, O.O., Arkhypov, I.O., Krupskyi, O.P., Velykodnyi, D.O., Filatov, S.V.: Methodology of using mobile apps with augmented reality in students' vocational preparation process for transport industry. In: Burov, O.Yu., Kiv, A.E. (eds.) Proceedings of the 3rd International Workshop on Augmented Reality in Education (AREdu 2020), Kryvyi Rih, Ukraine, May 13, 2020, CEUR-WS.org, online (2020, in press)

11. Lemos, B.M.: SISEULER: Um *software* para apoio ao ensino da Relação de Euler. Dissertation, Universidade Severino Sombra (2011)
12. Modlo, Ye.O., Semerikov, S.O., Nechypurenko, P.P., Bondarevskyi, S.L., Bondarevska, O.M., Tolmachev, S.T.: The use of mobile Internet devices in the formation of ICT component of bachelors in electromechanics competency in modeling of technical objects. In: Kiv, A.E., Soloviev, V.N. (eds.) Proceedings of the 6th Workshop on Cloud Technologies in Education (CTE 2018), Kryvyi Rih, Ukraine, December 21, 2018. CEUR Workshop Proceedings **2433**, 413–428. http://ceur-ws.org/Vol-2433/paper28.pdf (2019). Accessed 21 Mar 2020
13. Rashevska, N.V., Soloviev, V.N.: Augmented Reality and the Prospects for Applying Its in the Training of Future Engineers. In: Kiv, A.E., Soloviev, V.N. (eds.) Proceedings of the 1st International Workshop on Augmented Reality in Education (AREdu 2018), Kryvyi Rih, Ukraine, October 2, 2018. CEUR Workshop Proceedings **2257**, 192–197. http://ceur-ws.org/Vol-2257/paper18.pdf (2018). Accessed 29 Nov 2019
14. Shepiliev, D.S., Semerikov, S.O., Yechkalo, Yu.V., Tkachuk, V.V., Markova, O.M., Modlo, Ye.O., Mintii, I.S., Mintii, M.M., Selivanova, T.V., Maksyshko, N.K., Vakaliuk, T.A., Osadchyi, V.V., Tarasenko, R.O., Amelina, S.M., Kiv, A.E.: Development of career guidance quests using WebAR. Journal of Physics: Conference Series (2020, in press)
15. Shyshkina, M.P.: The Problems of Personnel Training for STEM Education in the Modern Innovative Learning and Research Environment. In: Kiv, A.E., Soloviev, V.N. (eds.) Proceedings of the 1st International Workshop on Augmented Reality in Education (AREdu 2018), Kryvyi Rih, Ukraine, October 2, 2018. CEUR Workshop Proceedings **2257**, 61–65. http://ceur-ws.org/Vol-2257/paper07.pdf (2018). Accessed 29 Nov 2019
16. Stolyarova, I.V., Shulzhenko, O.V.: Augmented Reality in Geometry Lessons. Mathematical Education in the Digital Society: Materials of the XXXVIII International Scientific Seminar of Teachers of Mathematics and Informatics of Universities and Pedagogical Universities, pp. 294-297 (2019)
17. Syrovatskyi, O.V., Semerikov, S.O., Modlo, Ye.O., Yechkalo, Yu.V., Zelinska, S.O.: Augmented reality software design for educational purposes. In: Kiv, A.E., Semerikov, S.O., Soloviev, V.N., Striuk, A.M. (eds.) Proceedings of the 1st Student Workshop on Computer Science & Software Engineering (CS&SE@SW 2018), Kryvyi Rih, Ukraine, November 30, 2018. CEUR Workshop Proceedings **2292**, 193–225. http://ceur-ws.org/Vol-2292/paper20.pdf (2018). Accessed 21 Mar 2020
18. Tkachuk, V., Semerikov, S., Yechkalo, Yu., Khotskina, S., Soloviev, V.: Selection of Mobile ICT for Learning Informatics of Future Professionals in Engineering Pedagogy. CEUR-WS.org, online (2020, in press)