Development and implementation of educational resources in chemistry with elements of augmented reality

Pavlo P. Nechypurenko[0000-0001-5397-6523], Viktoriia G. Stoliarenko[0000-0002-4665-5710], Tetiana V. Starova[0000-0001-7995-3506], Tetiana V. Selivanova[0000-0003-2635-1055]

Kryvyi Rih State Pedagogical University, 54, Gagarina Ave., Kryvyi Rih, 50086, Ukraine
acinonyxleo@gmail.com, st_viki@ukr.net,
simaneneko@ukr.net, vitro090@gmail.com

Oksana M. Markova[0000-0002-5236-6640]

Kryvyi Rih National University, 11, Vitaliy Matusevych Str., Kryvyi Rih, 50027, Ukraine
markova@mathinfo.ccjournals.eu

Yevhenii O. Modlo[0000-0003-2037-1557], Ekaterina O. Shmeltser

Kryvyi Rih Metallurgical Institute of the National Metallurgical Academy of Ukraine,
5, Stephana Tilhy Str., Kryvyi Rih, 50006, Ukraine
eugenemodlo@gmail.com

Abstract. The purpose of this article is an analysis of opportunities and description of the experience of developing and implementing augmented reality technologies to support the teaching of chemistry in higher education institutions of Ukraine. The article is aimed at solving problems: generalization and analysis of the results of scientific research concerning the advantages of using the augmented reality in the teaching of chemistry, the characteristics of modern means of creating objects of augmented reality; discussion of practical achievements in the development and implementation of teaching materials on chemistry using the technologies of the augmented reality in the educational process. The object of research is augmented reality, and the subject - the use of augmented reality in the teaching of chemistry. As a result of the study, it was found that technologies of augmented reality have enormous potential for increasing the efficiency of independent work of students in the study of chemistry, providing distance and continuous education. Often, the technologies of the augmented reality in chemistry teaching are used for 3D visualization of the structure of atoms, molecules, crystalline lattices, etc., but this range can be expanded considerably when creating its own educational products with the use of AR-technologies. The study provides an opportunity to draw conclusions about the presence of technologies in the added reality of a significant number of benefits, in particular, accessibility through mobile devices; availability of free, accessible and easy-to-use software for creating augmented-reality objects and high efficiency in using them as a means of visibility. The development and

implementation of teaching materials with the use of AR-technologies in chemistry teaching at the Kryvyi Rih State Pedagogical University has been started in the following areas: creation of a database of chemical dishes, creation of a virtual chemical laboratory for qualitative chemical analysis, creation of a set of methodical materials for the course “Physical and colloidal chemistry”.

Keywords: augmented reality, chemistry education, technology of the augmented reality (AR-technology), tools for the development of objects of augmented reality.

1 Introduction

The educational process in higher education institutions in Ukraine has recently become aware of serious changes related to both the forms of its organization and its structure. In particular, curricula for training bachelors and masters in most areas of learning are built in such a way that the share of independent work ranges from 50 to 70% of their total volume. In addition, one should take into account the possibility of different force majeure circumstances, both objective and subjective, that can significantly increase the proportion of self-training students within individual disciplines.

Also, the organization of a modern educational process in the institutes of higher education is significantly influenced by the tendencies towards globalization, which are manifested in the needs of students in distance education, continuing education, and so on.

Higher education institutions should address the challenges associated with the above-mentioned changes, with no loss as educational services provided. The most optimal way of modernizing the educational process in these cases is the widespread and methodically balanced use of information and communication technologies (ICT), namely, modern and high-quality ICT tools [13; 14; 16].

For a long time, the most demanded ICT tools in the learning process were multimedia and cloud technologies [6; 10; 15; 21]. Recently, however, one of the most trending tools has become tools of the augmented reality (AR), which to some extent combine the properties of multimedia and cloud technologies, and at the same time have a number of features and benefits [18; 25; 27].

Augmented reality, AR technology has recently expanded rapidly in a wide variety of human activities, from virtual simulation of gaming situations to sports events and virtual online games (ARQuake, Pokemon Go, Silent Streets), to a powerful tool for modeling and visualizing various objects:

- products in online stores [12];
- cultural monuments and geographic landmarks;
- online excursions;
- various natural phenomena and processes [5; 11; 28], etc.

Also, the technologies of the augmented reality have recently become widespread in those industries, for which the development of them was mainly carried out more than 50 years ago – for the creation of training simulators for the training of physicians, military specialists (pilots, sailors, gunners, etc.), specialists in other fields, who have to master complex, expensive or hazardous health devices and equipment.

The tasks described above are solved by developing and implementing more advanced software and devices for its implementation, among which there are various specialized training programs; AR-tutorials, markers on pages which with the camera and the corresponding application on the smartphone launch animated 3D images, videos, etc.; educational games and more [1; 7; 9; 19; 22; 24; 29].

2 Results and discussion

It was shown [2; 3; 8; 20] that the augmented reality has a significant potential for stimulating and motivating students, it has a positive influence on the concentration of attention on the subject of study, and also it creates an active learning environment that positively affects the learning process and the creation of a student knowledge system. However, there is a risk of students being overloaded with a large amount of information and a large number of technological devices that provide AR-support for learning material. Therefore, in order to create a high-quality educational product with elements of the complementary reality, cooperation of specialists from many industries is needed: administrators, engineers, programmers, designers, teachers and students.

The use of any tools of ICT (and AR-technologies too) in the teaching of chemistry should take into account a number of chemistry features as a science.

On the one hand, chemistry operates a huge amount of concepts that are inaccessible to direct sensory perception (atoms, molecules, chemical bonds, etc.), studies processes and mechanisms of their flow, most of which can not be directly perceived (the chemical and biochemical processes, which are too dangerous for students, etc.). Therefore, the simulation and visualization of such concepts and phenomena by the AR tools clearly has a high efficiency.

On the other hand, chemistry as applied science requires specialists in this field to be able to properly handle chemical laboratory ware, facilities and chemical reagents, etc. In this case, the technologies of augmented reality can only partly affect the effectiveness of educational process, since most of the necessary skills student must receive while still working with real materials and utensils.

Nevertheless, the positive moments of the use of augmented reality to support chemistry teaching process prevail, as reflected in a large range of relevant chemistry teaching materials [17].

One more advantage of modern AR-technologies is the technical aspect of the issue of wide introduction them into educational process.

So for the implementation of training using the addition of reality, you need:

1. special software, much of which is freely available;
2. the gadgets on which it will be installed.

As a rule, the introduction of AR-technologies into the educational process does not require significant financial costs.

To date, fully or partially free access has a number of applications for creating Augmented reality products, among which the most popular ARToolKit, HP Reveal (Aurasma), Vuforia, Augment platforms. A brief description of these tools is given in Table 1.

Table 1. Creature and use tools of AR-products characteristics

Platform name	Application access	Simplicity of use	Features
HP Reveal (Aurasma)	Free access	Simple and intuitive interface	HP Reveal works on smartphones and tablets running Android 4.0 and above, and iOS 8.0 and beyond. The program requires a battery charge of at least 15%.
ARToolKit	Free access	Sufficiently complex, requires special programming skills	The ARToolKit Supplementary Reality Library supports Unity, Android (Android build support for Unity), iOS (iOS build support for Unity and Apple Xcode 4.2 and higher)
Vuforia	There are free versions, as well as extended paid apps	Sufficiently complex, requires special skills in working with the application and programming	Vuforia SDK (Software Development Kit) is a software suite that includes an add-on reality platform and an add-on software developer toolkit for using AR on mobile devices: Android tablet, Android smartphone, and U-score glasses (Windows). The Vuforia SDK is integrated with the Unity 3D gaming engine.
Augment	Free access	Simple and intuitive interface	The mobile app allows you to visualize the 3D model in Augmented Reality, with the ability to add your own 3D models and customize trackers. Supports the most popular 3D formats: obj, stl, collada, etc. Works on smartphones and tablets running the iOS and Android operating system.
EasyAR	Free access	Simple and intuitive interface	Platforms: Android, iOS, UWP, Windows, OS X, and Unity. Features of the 3D object recognition application, environmental perception, cloud recognition, smart pointing, cloud deployment of applications

The availability of a sufficiently large number of different complexity and application capabilities enables the use of AR-technologies in the teaching of chemistry to teachers who do not have special knowledge and skills in programming. Yes, HP Reveal and Augment have a fairly simple interface and easy-to-understand

working principle that makes it possible to use them without special long-term training [23].

In the case of gadgets for the use of AR-products, in most cases either special glasses, tablets or smartphones with installed AR-software. And if the AR points are not publicly available for students due to their high price (about $ 1500), then almost every student has a smartphone or tablet for today.

Studies conducted on the basis of Kryvyi Rih State Pedagogical University (KSPU) showed that 99% of the students interviewed either have a smartphone or tablet, 62% have both a smartphone and a tablet, 34% have smartphones based on iOS and 58% on Android, 7% do not know, which mobile operating system is installed in their gadget (see Figure 1). Participation in the survey was taken by 100 students of I-IV courses and magistracy majoring in Secondary education (Chemistry) (additional specialty – Secondary education (Informatics)) and Secondary education (Biology) (additional specialty – Secondary education (Chemistry)) [23].

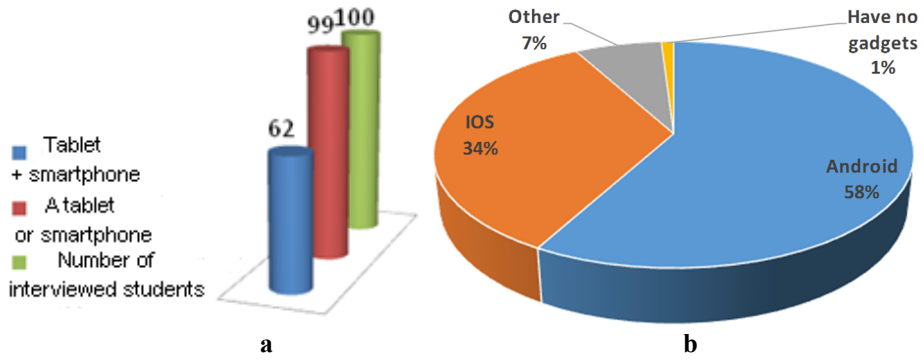

Fig. 1. Analysis of technical capabilities for the implementation of augmented reality technologies in the system of training students of the Natural Sciences Faculty of the KSPU: a) the provision of students with the gadgets necessary for the implementation of training using elements of augmented reality; b) type of mobile operating systems on gadgets.

Thus, in most cases, the problems of technical support for the use of AR-technologies in teaching chemistry students of the corresponding specialties are solved by themselves.

However, there are problems of educational and methodological nature. Most products of the technology of complementary reality, designed to support chemistry training, are oriented on modeling of molecular structures, atom's structure, provision of reference or training information from chemistry individual sections. A certain amount of funds is aimed at familiarizing with chemical devices and the course of chemical reactions. Often these products are of high quality and non-standard approach to the design [17]. In particular, a group of Turkish scientists for the chemical education of students was developed an application designed to study the periodic system of chemical elements structure, their properties, atom's and molecule's structure, which involves the use of special glasses and a high level of

interactivity – manipulation of AR-objects occur with the help of hands-on movements, so students play an active role in learning, and not passive observers of the process [26].

A significant disadvantage of the situation for domestic educators in the AR-application market for chemistry training is the fact that the lack of Ukrainian-language products is virtually complete, as well as a limited set of directions for the application of the above-mentioned applications.

Taking into account the advantages and disadvantages of implementation of the augmented reality in the educational process of the institute of Ukrainian higher education, we began to develop and implement our own AR-technologies products.

We use the online resource HP Reveal (former Aurasma) [4] to create the right products, as a simple and easy-to-use, reliable resource. A free HP Reveal application (for Android) must be installed to use the created AR-objects.

HP Reveal Rebuilding Objects is a fairly simple technology and involves several steps:

1. Register on the site of the relevant resource and create a user account.
2. Confirmation of registration by e-mail of the user.
3. Creating a new object - aura:
   (a) load an image that will be a marker for this aura;
   (b) uploading a file that will augmented reality when you hover over an appropriate marker (video, photo and other file types up to 100 MB);
   (c) setting match marker and file, previewing the result;
   (d) creation of the name of the aura, its short description and hashtag;
   (e) preserving the aura, after which the user will have the opportunity to use it, provided that the appropriate application is installed on the gadget.

Separately there is a possibility to make the aura public, with the possibility of viewing by any user.

Creating the appropriate AR-learning resources for chemistry teaching, we carry out our own. At this stage, educational resources are created for teaching to KSPU with the use of AR-technologies in three directions:

1. Creating a database of chemical laboratory ware. When you move the gadget camera to the marker, on its screen appears the image of the representative of the chemical ware with a brief description of its features. Such a database is designed to help solve the problem of familiarizing students with the basics of working with chemical ware and devices. Mostly this is true for students of the specialty Secondary education (Biology), since their laboratory practice is considerably inferior to the volume of the similar practice of chemists-students. Therefore, at least theoretical and visual familiarization with feature of the most necessary chemical ware can be carried out on independent study with the use of technologies of the augmented reality. For students of the specialty Secondary education (Chemistry), this resource should provide familiarization with feature of expensive or rare chemical apparatus, with which they will not work frequently in a real laboratory.

2. Creation of a virtual chemical laboratory for qualitative chemical analysis. The essence of this educational resource is to create a bank of objects of the augmented reality, which are videos, on which there is a course of high-quality chemical reactions of detection of cations and anions. Verbal description of the results of a quality chemical reaction (in particular, the description of the analytical effect) does not always form the idea of the real outcome of such a reaction. In addition, in laboratory classes, only the most important, classical reactions of qualitative detection of substances are usually carried out, and there is not enough time for other qualitative reactions. A certain number of qualitative reactions can not be carried out due to lack of reagents, their high price or significant health hazard. Also, there are cases when students have to master a part of the material from this section of chemistry on their own (for example, because of the state of health), therefore the creation of such a resource will definitely provide an opportunity to better organize independent work of students in the study of analytical chemistry.

The work of this resource is organized in such a way that a student can feel certain autonomy while working in such a virtual laboratory. Aura is a video of a quality reaction performed on a certain cation or anion with the attached text information about it: reaction equation, chemical reaction's conditions, products' feature formed by the reaction, etc. The marker consists of two parts, one of which encodes the corresponding cation and the other anion or other reagent used in qualitative detection (see Figure 2).

The marker triangle plays the role of a landmark for its location - it must be centered on the top, one part of the marker is above the other (cation marker - bottom). Eight circles, which may either have white or black color, make it possible to encrypt such a marker with 28 = 256 variants, that is, 256 different substances (cations, anions, organic reagents), which at present looks more than adequate for full coverage of laboratory workshop on qualitative chemical analysis .

Thus, having a set of appropriate markers, student has opportunity to choose which reaction to see him in the augmented reality by combining markers in a different sequence.

3. Creation of a set of methodical materials for course "Physical chemistry" with the use of AR-technologies. This direction provides an opportunity for a demonstration of complex processes for perception, by transferring educational animations, videos, images in GIF format into AR-objects, access to which is provided by markers placement on pages of relevant educational materials.

Students who study remotely or can not attend practical or laboratory classes can see devices and models of the course of various physical and chemical processes that are not available for real perception. The set created for the course "Physical and colloidal chemistry" can be attributed to educational literature with elements of virtual reality. This kit includes a brief summary of the theoretical material from separate topics of following sections: "Electrochemistry", "Thermodynamics", "Substances aggregate state", "Kinethics", as well as individual laboratory work using AR-technologies.

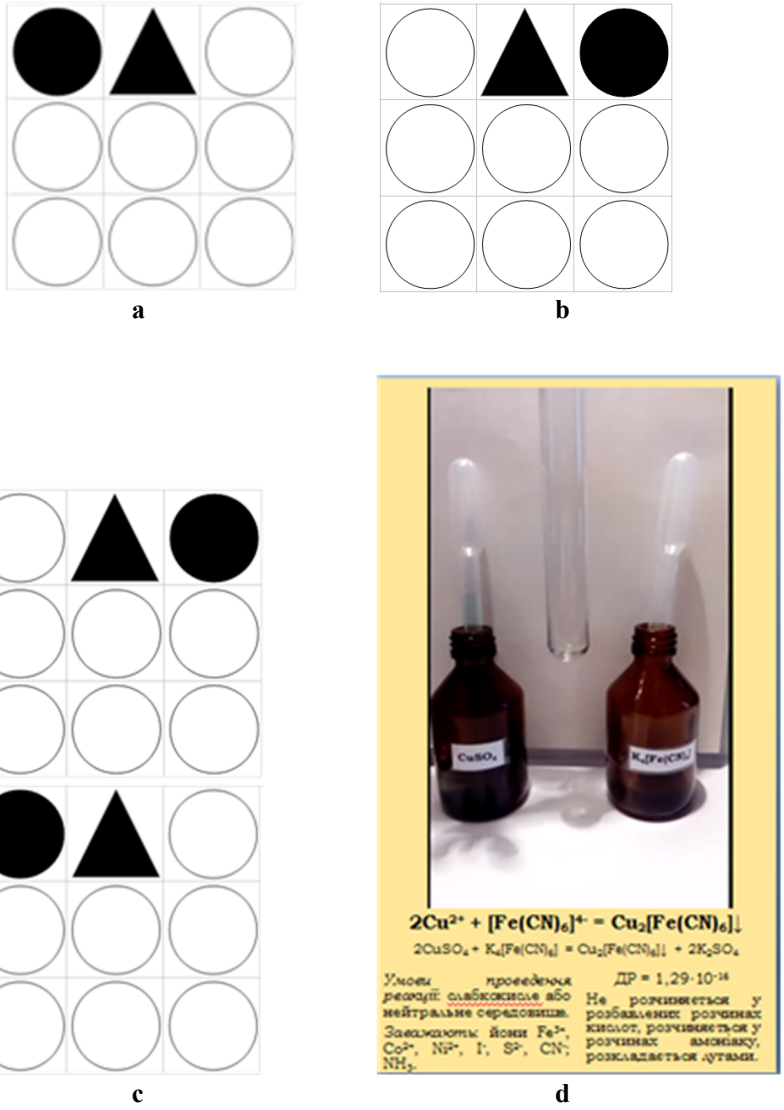

Fig. 2. Markers work scheme of in a virtual chemical laboratory for qualitative chemical analysis: a) is a marker encoded with a Cu^{2+} cation, b) is a marker encoded by an anion $[Fe(CN)_6]^{4-}$, c) is a marker corresponding to the aura showing the course of the reaction between the solutions containing Cu^{2+} and $[Fe(CN)_6]^{4-}$, d) is the aura displayed on the gadget screen.

Access to these educational resources is carried out through the web-page of the Department of Chemistry and its teaching methods at the official website of the Kryvy Rih State Pedagogical University.

3 Conclusions and directions of further research

The application of AR-technologies in chemistry teaching both institutions high and secondary schools, in our opinion, has enormous methodological potential and determines a new level in the creation and use of visibility tools.

Compliance with modern educational standards is important for Ukrainian education system. Therefore, the development of AR-technologies for chemistry training is one of the priority directions of the ICTs introduction in educational process.

When creating training resources with the elements of the augmented reality for study of chemistry, it is necessary to maximize the benefits of AR-technologies: accessibility, visibility, interactivity, ability to provide opportunities for holistic perception of study objects.

Educational and methodological materials on chemistry using the augmented reality developed and implemented at Kryvyi Rih State Pedagogical University are intended primarily to improve the quality and efficiency of independent work of students, to create opportunities for distance and continuous training.

Further areas of work and research are related to the improvement and expansion of the created resources of teaching chemistry with the AR-elements, checking their effectiveness and impact on the quality of student learning, as well as expanding the target audience of these resources at the expense of students from schools engaged in research activities, prepare for chemical competitions and contests, are interested in chemistry and want to study it in depth.

References

1. Buzko, V.L., Bonk, A.V., Tron, V.V.: Implementation of Gamification and Elements of Augmented Reality During the Binary Lessons in a Secondary School. 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**, 53–60. http://ceur-ws.org/Vol-2257/paper06.pdf (2018). Accessed 30 Nov 2018
2. Di Serio, A., Blanca Ibáñez, Delgado Kloos, C.: Impact of an augmented reality system on students' motivation for a visual art course. Computers & Education **68**, 586–596 (2013). doi:10.1016/j.compedu.2012.03.002
3. Dunleavy, M., Dede, C.: Augmented Reality Teaching and Learning. In: Spector, M.J., Merrill, D.M., Elen, J., Bishop, J.M. (eds.) Handbook of Research on Educational Communications and Technology, pp. 735–745. Springer New, York (2014). doi:10.1007/978-1-4614-3185-5_59
4. HP: HP Reveal. https://www.hpreveal.com (2018). Accessed 25 Oct 2019
5. Hruntova, T.V., Yechkalo, Yu.V., Striuk, A.M., Pikilnyak, A.V.: Augmented Reality Tools in Physics Training at Higher Technical Educational Institutions. 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**, 33–40. http://ceur-ws.org/Vol-2257/paper04.pdf (2018). Accessed 30 Nov 2018
6. Kiv, A.E., Soloviev, V.N., Semerikov, S.O.: CTE 2018 – How cloud technologies

continues to transform education. 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**, 1–19. http://ceur-ws.org/Vol-2433/paper00.pdf (2019). Accessed 10 Sep 2019

7. Kolomoiets, T.H., Kassim, D.A.: Using the Augmented Reality to Teach of Global Reading of Preschoolers with Autism Spectrum Disorders. 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**, 237–246. http://ceur-ws.org/Vol-2257/paper24.pdf (2018). Accessed 30 Nov 2018
8. Lin, T.-J., Been-Lirn Duh, H., Li, N., Wang, H.-Y., Tsai, C.C.: An investigation of learners' collaborative knowledge construction performances and behavior patterns in an augmented reality simulation system. Computers & Education **68**, 314–321 (2013). doi:10.1016/j.compedu.2013.05.011
9. Lvov, M.S., Popova, H.V.: Simulation technologies of virtual reality usage in the training of future ship navigators. 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-WS.org, online (2020, in press)
10. Markova, O.M., Semerikov, S.O., Striuk, A.M., Shalatska, H.M., Nechypurenko, P.P., Tron, V.V.: Implementation of cloud service models in training of future information technology specialists. 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**, 499–515. http://ceur-ws.org/Vol-2433/paper34.pdf (2019). Accessed 10 Sep 2019
11. Merzlykin, O.V., Topolova, I.Yu., Tron, V.V.: Developing of Key Competencies by Means of Augmented Reality at CLIL Lessons. 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**, 41–52. http://ceur-ws.org/Vol-2257/paper05.pdf (2018). Accessed 30 Nov 2018
12. Mintii, I.S., Soloviev, V.N.: Augmented Reality: Ukrainian Present Business and Future Education. 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**, 227–231. http://ceur-ws.org/Vol-2257/paper22.pdf (2018). Accessed 30 Nov 2018
13. Modlo, Ye.O., Semerikov, S.O., Bondarevskyi, S.L., Tolmachev, S.T., Markova, O.M., Nechypurenko, P.P.: Methods of using mobile Internet devices in the formation of the general scientific component of bachelor in electromechanics competency in modeling of technical objects. 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-WS.org, online (2020, in press)
14. Modlo, Ye.O., Semerikov, S.O., Shmeltzer, E.O.: Modernization of Professional Training of Electromechanics Bachelors: ICT-based Competence Approach. 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**, 148–172. http://ceur-ws.org/Vol-2257/paper15.pdf (2018). Accessed 21 Mar 2019
15. Modlo, Ye.O., Semerikov, S.O.: Xcos on Web as a promising learning tool for Bachelor's of Electromechanics modeling of technical objects. In: Semerikov, S.O., Shyshkina, M.P. (eds.) Proceedings of the 5th Workshop on Cloud Technologies in Education (CTE 2017), Kryvyi Rih, Ukraine, April 28, 2017. CEUR Workshop Proceedings **2168**, 34–41. http://ceur-ws.org/Vol-2168/paper6.pdf (2018). Accessed 21 Mar 2019
16. Nechypurenko, P.P., Soloviev, V.N.: Using ICT as the Tools of Forming the Senior Pupils' Research Competencies in the Profile Chemistry Learning of Elective Course "Basics of

Quantitative Chemical Analysis". 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**, 1–14. http://ceur-ws.org/Vol-2257/paper01.pdf (2018). Accessed 30 Nov 2018

17. Nechypurenko, P.P., Starova, T.V., Selivanova, T.V., Tomilina, A.O., Uchitel, A.D.: Use of Augmented Reality in Chemistry Education. 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**, 15–23. http://ceur-ws.org/Vol-2257/paper02.pdf (2018). Accessed 30 Nov 2018
18. Popel, M.V., Shyshkina, M.P.: The Cloud Technologies and Augmented Reality: the Prospects of Use. 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**, 232–236. http://ceur-ws.org/Vol-2257/paper23.pdf (2018). Accessed 30 Nov 2018
19. 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 30 Nov 2018
20. Raspopovic, M., Cvetanovic, S., Jankulovic, A.: Challenges of Transitioning to e-learning System with Learning Objects Capabilities. The International Review of Research in Open and Distributed Learning **17**(1), 123–147 (2016)
21. Shapovalov, Ye.B., Bilyk, Zh.I., Atamas, A.I., Shapovalov, V.B., Uchitel, A.D.: The Potential of Using Google Expeditions and Google Lens Tools under STEM-education in Ukraine. 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**, 66–74. http://ceur-ws.org/Vol-2257/paper08.pdf (2018). Accessed 30 Nov 2018
22. Shyshkina, M.P., Marienko, M.V.: Augmented reality as a tool for open science platform by research collaboration in virtual teams. 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-WS.org, online (2020, in press)
23. Stoliarenko, V.H.: Perspektyvy vykorystannia AR-tekhnolohii u protsesi vyvchennia khimichnykh dystsyplin (Prospects for the use of AR - technologies in the process study of chemical disciplines). In: Starova, T.V. (ed.) Zbirnyk tez dopovidei Vseukrainskoi naukovo-praktychnoi internet-konferentsii "Tekhnolohii navchannia khimii u shkoli ta ZVO", November 30, 2018, Kryvyi Rih State Pedagogical University, pp. 28–31. KDPU, Kryvyi Rih (2018)
24. Striuk, A.M., Rassovytska, M.V., Shokaliuk, S.V.: Using Blippar Augmented Reality Browser in the Practical Training of Mechanical Engineers. In: Ermolayev, V., Suárez-Figueroa, M.C., Yakovyna, V., Kharchenko, V., Kobets, V., Kravtsov, H., Peschanenko, V., Prytula, Ya., Nikitchenko, M., Spivakovsky A. (eds.) Proceedings of the 14th International Conference on ICT in Education, Research and Industrial Applications. Integration, Harmonization and Knowledge Transfer (ICTERI, 2018), Kyiv, Ukraine, 14-17 May 2018, vol. II: Workshops. CEUR Workshop Proceedings **2104**, 412–419. http://ceur-ws.org/Vol-2104/paper_223.pdf (2018). Accessed 30 Nov 2018
25. 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 2019
26. Taçgin, Z., Uluçay, N., Özüağ, E.: Designing and Developing an Augmented Reality Application: A Sample of Chemistry Education. Turkiye Kimya Dernegi Dergisi Kisim C: Kimya Egitimi **1**(1), 147–164. https://dergipark.org.tr/en/pub/jotcsc/issue/30533/330316 (2016). Accessed 21 Mar 2019
27. Tkachuk, V.V., Yechkalo, Yu.V., Markova, O.M.: Augmented reality in education of students with special educational needs. In: Semerikov, S.O., Shyshkina, M.P. (eds.) Proceedings of the 5th Workshop on Cloud Technologies in Education (CTE 2017), Kryvyi Rih, Ukraine, April 28, 2017. CEUR Workshop Proceedings **2168**, 66–71. http://ceur-ws.org/Vol-2168/paper9.pdf (2018). Accessed 21 Mar 2019
28. Yechkalo, Yu.V., Tkachuk, V.V., Hruntova, T.V., Brovko, D.V., Tron, V.V.: Augmented Reality in Training Engineering Students: Teaching Techniques. In: Ermolayev, V., Mallet, F., Yakovyna, V., Kharchenko, V., Kobets, V., Korniłowicz, A., Kravtsov, H., Nikitchenko, M., Semerikov, S., Spivakovsky, A. (eds.) Proceedings of the 15th International Conference on ICT in Education, Research and Industrial Applications. Integration, Harmonization and Knowledge Transfer (ICTERI, 2019), Kherson, Ukraine, June 12-15 2019, vol. II: Workshops. CEUR Workshop Proceedings **2393**, 952–959. http://ceur-ws.org/Vol-2393/paper_337.pdf (2019). Accessed 30 Jun 2019
29. Zelinska, S.O., Azaryan, A.A., Azaryan, V.A.: Investigation of Opportunities of the Practical Application of the Augmented Reality Technologies in the Information and Educative Environment for Mining Engineers Training in the Higher Education Establishment. 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**, 204–214. http://ceur-ws.org/Vol-2257/paper20.pdf (2018). Accessed 30 Nov 2018