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Augmented Reality as an Aid to Collaborative and Autonomous Learning in Engineering Education

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Many years of experience in teaching pneumatic control have pointed out numerous problems in understanding the logic of pneumatic control. Therefore, this paper focuses on describing the effect of Augmented Reality (AR) applications developed for engineering students to enhance collaborative and autonomous learning and understanding of pneumatic control schemes. Also, a new version of workbook was introduced. In order to monitor the results of using AR applications, an evaluation was conducted among students for the original and upgraded versions of AR applications. Through the evaluation, the students expressed their impressions about the innovative teaching process and the use of AR technologies in the learning process. AR is emerging as the very good technology to complement and enhance the traditional learning process. The AR applications have a significant contribution to the understanding of pneumatic schemes and a strong impact on students' knowledge that helps them achieve the desired learning outcomes faster.

Keywords: Digital technologies, Educational methods, Industrial digitization, Pneumatic

Introduction

Education, as a condition for the progress of society, should follow modern trends in the era of digitalization that is underway. Understanding teaching materials exclusively from printed literature is becoming an increasing problem for newer generations of students who have grown up watching short digital forms such as music videos, TikTok videos, YouTube videos, Facebook and Instagram posts, etc. As a result, standard educational methods, such as learning from books, are often being improved by some form of digital content as additional educational material, such as different types of simulations, video clips, dedicated software, online, virtual or remote laboratories[1] and the increasingly popular Augmented Reality (AR).[2,3]

In addition, during the previous years, the world was hit by the COVID-19 pandemic, which remarkably changed the traditional way of life, business, and education. The previously known teaching process, which includes the use of blackboard and chalk, has now been partially or completely replaced by an online teaching process. In order to ensure the continuity and quality of the teaching process in the changed circumstances, universities have started to apply new methods in their learning processes. Among these methods are the AR applications[4–8] in order to transform higher education. AR technology combines different digital information with the user's view of the real physical world. Today, there is a trend of increasing occurrence of AR applications in educational processes.[9–15]

All those who teach courses dealing with energy flows or signal flows know how challenging it is to convey to students the logic of thinking about flows within a system. This challenge has become even greater with the transition to online or combined teaching models. Teachers and researchers have determined that virtual and remote labs are not suitable for teaching students because they actually deprive students of practical work. Thus, a blended approach to learning by combining virtual and real laboratory equipment gives better results. The use of AR applications makes it easier for students to understand the subject, and encourages students' independent work because they strengthen their digital competencies in this area.[16–19] In this way, students are empowered to independently actively use the latest technologies in their own work, which is a key competence for lifelong learning.[20] In this sense,

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AR appears as a very good technology to supplement and improve the traditional learning process.

In order to meet the current trends in the use of digital technologies in education and to ensure the quality of the teaching and learning process, this paper has a double goal: to present the implementation of AR technologies in the teaching process in the field of automation control and to evaluate the usefulness and functionality of the presented AR solution. For the purpose of using AR technologies to facilitate understanding, the workbooks[21,22] and the accompanying AR applications[23,24] have been developed. The developed application does not require investments in additional, expensive smartphones or tablets.

In order to monitor the results of using AR applications, an evaluation was conducted among students. The focus of this survey was to determine whether and in what way the learning process was facilitated with the use of AR applications and what could potentially be improved in terms of AR applications, to make the learning process even more efficient.

Materials and Methods for Implementation of AR in Teaching

Teaching in the field of pneumatic work process automation and control in the study programs Mechatronics and Industrial Engineering at the Faculty of Technical Sciences in Novi Sad is performed in two courses, basic course named Components of Technological Systems (CTS) in study program Mechatronics or Automation of Work Processes 1 in study program Industrial Engineering, and advanced course named Automation of Work Processes (AWP) in study program Mechatronics or Automation of Work Processes 2 in study program Industrial Engineering.

The goal of basic CTS course is to acquire knowledge of basic components used in pneumatic control systems (mechanical, pneumatic and mechatronic components), assemblies of elementary components, actuating elements of technical systems (pneumatic cylinders and motors, pneumatic grippers), regulators, pneumatically controlled valves and other valve types. The advanced AWP course deals with the topics of complex control techniques used in pneumatic systems, in order to master the skills of control and regulation, control signals, selection of appropriate automation techniques, etc.

Based on many years of experience in teaching these courses, and on the basis of student feedback, the most common problems faced by students are related to understanding the process that takes place within pneumatic components and to a systematic approach to solving complex control tasks. This is often due to the fact that the traditional literature offers 2D illustration as a means of explaining the principle of operation of pneumatic components. Some students find it difficult to visualize which parts are moving and what is happening inside the pneumatic component when it is supplied with compressed air. Moreover, understanding the flow of compressed air through the entire pneumatic control system, as well as the sequential activation of pneumatic components, step by step, can also be confusing for them.

Therefore, the developed AR applications work on the principle of scanning 2D illustrations from the workbook via a smartphone (cross-sections of pneumatic components and illustrations of devices) or QR codes assigned to the pneumatic control schemes. After recognizing the illustration or the QR code, the smartphone screen displays a 2D or a 3D animation of the component, device or pneumatic control scheme. In this way, the user gets a clear idea of the principle of operation of pneumatic components. It is possible to understand which parts inside the pneumatic component are moving and what happens in the pneumatic system once it is supplied with compressed air. Also, the user always has a clear view of which parts of the pneumatic system are supplied with compressed air.

In order to prevent any inappropriate use of digital content, the AR applications can only be downloaded and used by authorized users (students enrolled in the listed courses). This encourages a responsible attitude towards intellectual property and responsible use of developed digital learning tools.

Unity and Vuforia SDK (Software Development Kit) programs were used in the application development process. These programs were chosen because of their availability and simple user environment.

The First Version of the AR Implementation

The first AR implementation involved the use of existing workbook and the development of an AR applications for smartphones (on the Android platform) intended to expand the workbook tasks with appropriate digital information.

The user (student) only needs to install and run the appropriate AR application, find the desired image in the workbook[21] and scan it with a smartphone/tablet. All images are stored in the applications databasis.[23,24] As soon as the used AR application recognizes the image, additional information is automatically displayed and remains on the screen as long as the scanned image is in the focus of the smartphone camera. Three types of images can be identified and three types of information are displayed in the first version of the AR applications, as shown in Table 1.

The use of AR applications with three-dimensional or animation display improves the perception of the functioning and movement of parts of pneumatic components and systems, as well as a better understanding of the relationship of elements within the pneumatic system.[25]

Using the AR applications is extremely simple and intuitive. For example, the user scans a graphical representation of workbook task[21] and the corresponding 3D computer-aided design (CAD) model appears on the smartphone screen. Moving the workbook or rotating the phone around the model in the workbook, which must be the focus of the camera, causes the AR application model to move and rotate.

If the user brings his smartphone closer to the workbook, the model will look bigger and vice versa. In this way, the user has a better and more detailed overview of the model compared to the printed image in the workbook.

The Second Version of the AR Implementation

Based on some image recognition problems that have occurred among students who have older phones with weaker cameras and because of some images in the existing workbook that are made up of a large number of thin lines and text the unreliable operation of AR applications occur.

This problem was solved by developing the second (improved) version of AR applications that offered a better method for scanning the image of the task in the new version of the workbook.[22] As recommended by Vuforia's library for AR, the focus mode *continuous auto* option was selected in a written focus script, but after some additional testing it was decided to return the focus to standard mode. Other improvements made in the second version of the AR applications include the implementation of QR codes next to the pneumatic schemes, as well as the addition of smartphone icon next to the elements that provide digital content in existing workbook, which indicates that scanning an image would show the animation on the phone. Recognition of QR code gives higher reliability to the applications. In addition, based on some student comments and suggestions animations of 3D CAD models have been improved. This means that in the second version of the AR implementation, both, the workbook and the AR applications have been upgraded. Two examples of improved versions of workbook and AR applications are presented below.

One example of a CTS course is shown in Fig. 1. The Fig. 1(a) shows a photograph of a smartphone while displaying the AR animation of the switching device, which is described in detail in the workbook.[22] The user can clearly see which elements are moving inside the device and thus visualize the defined task. The animation of the pneumatic “AND” valve (Fig. 1(b)) shows the movement of its internal elements as well as the flow of compressed air, i.e. which combination of inlets is needed to produce one outlet.

The solution in the form of a developed pneumatic control scheme of the defined task is shown in Fig. 2(a). The AR application reproduces the animation (Fig. 2(b)) of the corresponding simulation, where the pneumatic components in the control scheme begin to change their positions in accordance with the task description. Students encounter certain difficulties in

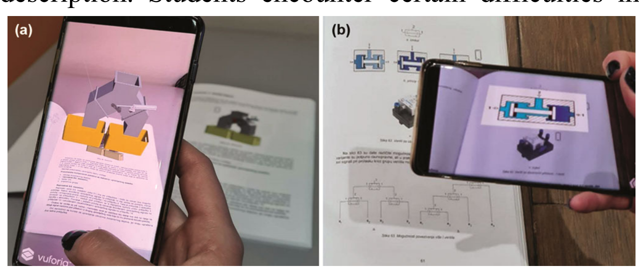

Fig. 1 — (a) AR animation of the switching device and (b) “AND” valve when scanning 2D illustrations from a workbook

Table 1 — Displayed digital content based on the scanned image in the AR application

Basic CTS course		Advanced AWP course	
Scan image	Type of additional digital information	Scan image	Type of additional digital information
Graphical representation of the task (device)	3D CAD model	Graphical representation of the task (device)	3D CAD model
Cross section of a pneumatic component	Animation of component operation	Displacement-step diagram	Animation of displacement-step diagram operations
Schematic solution of the task	Simulation of task solution	Schematic solution of the task	Simulation of task solution

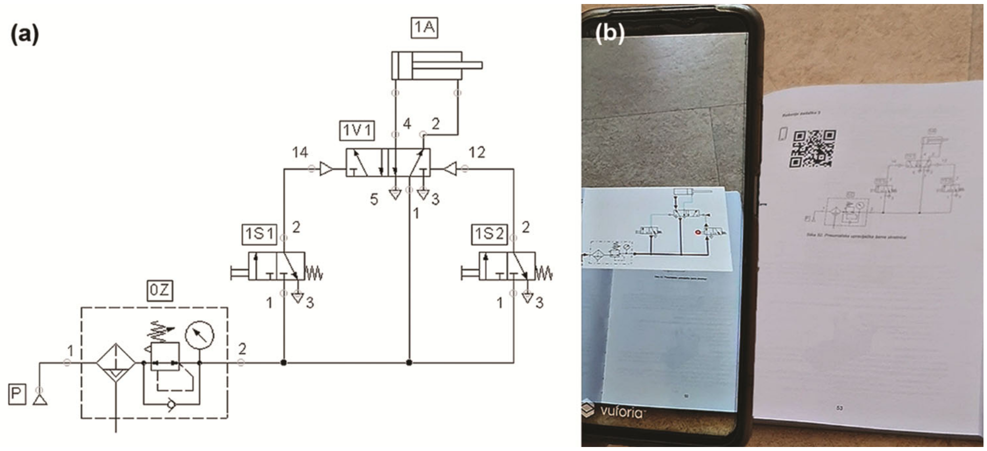

Fig. 2 — (a) Pneumatic control scheme and (b) pneumatic control scheme simulation in the AR application

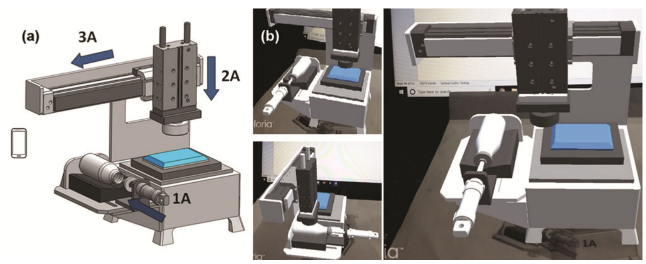

Fig. 3 — (a) 3D model of the painting device and (b) views of the device from different angles using AR application

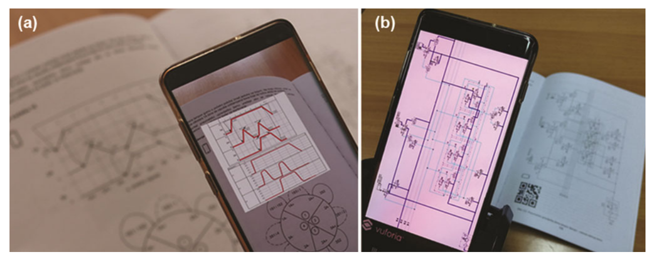

Fig. 4 — (a) One frame of displacement-step diagram and (b) pneumatic control scheme from the AR application

studying this topic: understanding the working principles of pneumatic components and visualizing which parts of these pneumatic components are moving and which are not. In addition, it is difficult for them to follow the paths of compressed air flow within the components and through the entire pneumatic system. AR animations provide useful visualization and facilitate understanding of the revealed problems among students.

An example of an assignment from AWP course is given in Fig. 3(a) and represents a painting device. After recognizing the image of the device, a "moving" 3D model appears on the phone screen, giving the impression of standing on a flat surface. This model performs the task defined in the workbook and gives the user an animated representation of the working principle of the device. As the model is related to the given image, changing the position of the camera in relation to the focused image changes the viewing angles of the digital model, which can be seen in Fig. 3(b).

The next step in solving the task is to create a displacement-step diagram. The workbook also contains solutions to all students' tasks. After scanning the image representing the displacement-step diagram with the AR application, a real-time simulation of cylinders' motion (Fig. 4(a)) appears. Immediately after reaching one of its end positions (extracted or retracted), the cylinder activates the corresponding mechanically or magnetically actuated valve. This is shown in the displacement-step diagram in the form of a short appearance of a red circle. The same thing happens when one of the sensors is activated. The red circle appearance only gives an information on what condition is, or should be met, in order to continue the execution of the program. The last step is to create a pneumatic control scheme (Fig. 4(b)). Using the AR application, the static control scheme becomes "live", i.e. instead of a static image, a simulation of the operation of a given pneumatic control scheme is displayed. AR application has a crucial contribution to the understanding of such schemes and the main impact on students' knowledge.

Results and Discussion

In order to assess the usefulness and functionality of the developed applications, a survey[2–4] was conducted among the bachelor students of Mechatronics, at the

Table 2 — Results of students' evaluation for the Components of Technological Systems course (CTS)

		Average grade			
		Live	On line		
		First version	First version	Second version	Overall
1	I have received adequate explanations on how to use the application before using it.	4.79	4.58	4.94	4.77
	Application usefulness for learning				
2	The application helped me to learn the theoretical foundations in a shorter time.	4.06	3.95	4.13	4.05
3	Using the application gave me a better understanding of the operation of pneumatic components.	4.42	4.25	4.38	4.35
4	Animations of the operation of pneumatic components that the application displays are useful and adequate.	4.7	4.67	4.56	4.64
5	Using the application gave me a better understanding of pneumatic control schemes.	4.53	4.42	4.37	4.44
6	Simulations of the operation of pneumatic control schemes presented by the application are useful and adequate.	4.7	4.83	4.69	4.74
	Average for usefulness	4.48	4.42	4.43	4.44
	Application functionality				
7	The application is easy to use.	4.62	4.67	4.56	4.62
8	The speed of the application is satisfactory.	3.5	3.33	4.12	3.65
9	The quality of the visual display is satisfactory.	4.28	4.08	4.49	4.28
10	I would like to use similar applications in other subjects.	4.94	4.83	4.62	4.80
	Average for functionality	4.34	4.23	4.45	4.34
	Overall average	4.42	4.34	4.44	4.38

Faculty of Technical Sciences. The evaluation questionnaire was filled out by exactly 169 respondents, which is approximately 60% of the total number of students who attended courses where AR applications were introduced. A large part of them, i.e. 120 students from three different generations, used the applications within the course Components of Technological Systems (CTS) at the third year of study. Nearly half of them, i.e. 52, used the first version (FV) of the application during regular classes, 36 of them used the first version (FV) of the application during online classes, and 32 of them used the second version (SV) of application during online classes. Results of students' evaluation for the course Components of Technological Systems are shown in the Table 2.

The remaining 49 students used applications in the course Automation of Work Processes (AWP) in the fourth year of study during online classes. Two generations of students used applications in this course, 25 of them used the first version (FV), and 24 of them used the second version (SV) of the application. The results of students' evaluation for the course Automation of Work Processes are presented in the Table 3.

Student answers in the presented tables correspond to a five point Likert Scale, where 1 means "Completely Disagree", 2 – "Mostly Disagree", 3 – "Partly Agree", 4 – "Mostly Agree" and 5 – "Completely Agree". The applied statistical methods are descriptive and the results are presented as the mean value for the given question.

Application Usefulness for Learning

According to the obtained data, overall score for application usefulness for understanding and learning is 4.44 for CTS course and 3.87 for AWP course, which can be considered as a good result. A difference of 14.5% between these two scores is evident, may be the reason that there is a significant difference in the answers to the first question about the received instructions on how to use the application between the courses, from 3.9 for AWP course to 4.77 for CTS course. Based on this, it can be concluded that it is necessary to pay special attention in preparing students for using the application in order to use the full potential of the application as an aid for teaching and learning.

Simulations of the operation of pneumatic control schemes and animations of the operation of pneumatic components shown by the application have the highest scores for usefulness at CTS course, followed

Table 3 — Results of students' evaluation for the Automation of Work Processes course (AWP)

		Average grade			
		First version	Second version	Overall	Difference %
1	I have received adequate explanations on how to use the application before using it.	3.8	4	3. 9	5.26
	Application usefulness for learning				
2	The application helped me to learn the theoretical foundations in a shorter time.	3.2	3.3	3.25	3.12
3	Using the application allowed me to better understand the operation of pneumatic systems by using a displacement-step diagram.	3.5	3.3	3.40	− 5.71
4	System animations using the displacement-step diagram that the application displays are useful and adequate.	4.4	4.6	4.50	4.55
5	Using the application gave me a better understanding of the operation of pneumatic control schemes.	3.7	3.9	3.80	5.41
6	Simulations of the operation of pneumatic control schemes presented by the application are useful and adequate.	4.2	4	4.10	−4.76
7	Animations of pneumatic systems (machines) are useful and adequate.	4.2	4.1	4.15	−2.38
	Average for usefulness	3.87	3.87	3.87	
	Application functionality				
8	The application is easy to use.	4.6	4.8	4.70	4.35
9	The speed of the application is satisfactory.	4.1	4.6	4.34	12.20
10	The quality of the visual display is satisfactory.	3.9	4.3	4.10	10.26
11	I would like to use similar applications in other subjects	4.1	4.1	4.10	0.00
	Average for functionality	4.18	4.45	4.31	6.59
Overall average		3.99	4.10	4.04	

by animations of the operation of pneumatic components (Table 2). System animations of the displacement-step diagram have the highest scores at AWP course, followed by simulations of the operation of pneumatic control schemes (Table 3). This indicates that the visual display is very important for students, as visuals tend to be more concrete and easier to recall. Visual stimulation can keep students more engaged and has become a necessity.[8] It is interesting that in both courses, students rated the contribution of the application in shortening learning time the lowest, although the overall result for shortening learning time is 3.65 which is definitely a good result. There are slight differences of up to 4.56% for CTS course (Table 4), and up to 5.71% for AWP course (Table 3) in student responses to questions regarding the application usefulness for learning between the two versions of the application. These differences have a variable sign and it is difficult to draw any conclusions based on them.

According to the obtained results for CTS course (Table 4) it can be noticed that there are no significant differences between the application at regular - live course and online courses. This indicates that the application is suitable for use in both teaching models, which is certainly a very important finding.

Application Functionality

According to the obtained data overall score for application functionality is 4.31 for AWP course and 4.34 for CTS course, which again can be considered a good result. But, if specific questions are considered, significant differences between the two versions of the application can be seen. For AWP course students rated the second version of the application 12.2% better for speed and 10.26% better for visual display quality than the first version (Table 3) and for on line CTS course students rated the second version 23.72% better for speed and 10.05% better for visual quality than the first version (Table 4). This clearly shows that the students recognized the improvements in speed and visual quality for the second version of the application which indicates that these two parameters are very important and students are sensitive to them. The importance of visual representation has already been mentioned in application usefulness for learning.

The top rated app functionality statement for the CTS course is: "I would like to use similar applications in other subjects", with a score of 4.80.

Table 4 — Students evaluation differences for the Components of Technological Systems Course (CTS)

	Average grade			Difference %	
	Live	On line			
	First version	First version	Second version	Live *vs* on line	First *vs* second on line
Application usefulness for learning					
The application helped me to learn the theoretical foundations in a shorter time.	4.06	3.95	4.13	2.78	4.56
Using the application gave me a better understanding of the operation of pneumatic components	4.42	4.25	4.38	4.00	3.06
Animations of the operation of pneumatic components that the application displays are useful and adequate.	4.7	4.67	4.56	0.64	−2.36
Using the application gave me a better understanding of pneumatic control schemes.	4.53	4.42	4.37	2.49	−1.13
Simulations of the operation of pneumatic control schemes presented by the application are useful and adequate.	4.7	4.83	4.69	−2.69	−2.90
Application functionality					
The application is easy to use.	4.62	4.67	4.56	− 1.07	− 2.36
The speed of the application is satisfactory.	3.5	3.33	4.12	5.11	23.72
The quality of the visual display is satisfactory.	4.28	4.08	4.49	4.90	10.05
I would like to use similar applications in other subjects	4.94	4.83	4.62	2.28	− 4.35

The top rated app functionality statement for the AWP course is: “The application is easy to use”, with a score of 4.7. Overall, this unequivocally indicates the need to develop new AR applications with high visual quality that are fast and easy to use.

Devices and Main Features of AR Applications

During the survey, the developed applications were used on more than 80 different devices of various price categories, from phones introduced in 2016 with Android Marshmallow operating system to phones introduced in 2021 with Android 11 operating system. The applications were also used on several tablets. The applications worked on all used devices, although a difference in speed could be noticed. The general impression is that for the normal operation of the developed application, a device with a minimum of 2GB of RAM memory is required. The ability of apps to recognize images also varied between devices. In addition to the quality of the camera itself, image recognition depended on the presence of light, as well as the angle and distance of the device from the image in the textbook.

Certain problems that appeared with image recognition in the first version of the applications on some devices have already been mentioned as one of the reasons for improving the applications and implementing QR codes and the smartphone icon in the workbook. However, it should be noted that the second version of the applications was developed a year and a half later and was therefore used on newer, more capable devices, which all together significantly contributed to the much better results for speed and image recognition in the second version of the application.

Improving the first version of the AR applications included upgrading three features that are according to our findings crucial in order to exploit the full potential of AR technology in education:

(1) *Reliability:* Improvements in this area have been made in the workbook itself by adding QR code beside the pneumatic control schemes, the recognition of which gives greater reliability to the application. By reading the QR code, instead of the pneumatic scheme (as realized in the first version), the speed of object identification is increased, and thus the speed of displaying the animation. In this way, errors in image recognition due to thin and light lines, which were present, have been eliminated. Also, QR codes are a clear association to mobile tagging and are intuitive for Generation Z, but also for other users of digital technologies.

(2) *Quality of the Visual Display:* The second version of the applications contains animations that have much better quality of the visual display. Firstly, the 3D models of the devices have been improved and students really appreciate how realistic and clear the videos are. Secondly, all moving parts of the devices and components are really moving, even in the most

obvious and simplest items. Thirdly, pneumatic schemes are created so that by changing the distance/focus of the camera, they change the size. By changing the distance of the camera, you can see an enlarged view of the specific part of the scheme.

(3) *Speed:* Keeping in mind that speed is key, significant changes have been made to make the applications faster. The increase in speed was achieved by changing the 3D model and the way of creating animations. All this affected the smaller amount of data in the database, the application is smaller and consumes less resources.

Conclusions

The necessary conditions for using the developed AR solutions described in this paper are very easy to achieve because today's students have the necessary devices. Apart from students, the workbook and AR applications are intended for all those who want to get to know and further improve and apply in practice the knowledge about the pneumatic systems control.

With the implementation of the AR applications, a new version of workbook/practicum was developed that helps to achieve the planned learning outcomes faster. Students/users are not only passive readers of professional literature, but also active and independent participants in the learning process.

Evaluation of the second version of the applications, as well as conversations with colleagues who are not IT experts, but experts in the field of pneumatics, electro-pneumatics, hydraulics and related fields, revealed opportunities for further improvement, which will certainly be discussed in the next version. The main areas for improvement are: lack of user interface; allowing the user to control the application (start, pause, stop, zoom in, zoom out, etc.); setting the animation display speed (slow down, speed up); offer users more content through the application; provides information about components during animation; enabling the use of smart glasses; the possibility of application on different operating systems, etc.

References

1 Reeves S M & Crippen K J, Virtual laboratories in undergraduate science and engineering courses: a systematic review, 2009–2019, *J Sci Educ Technol*, **30(1)** (2021) 16−30, doi: 10.1007/s10956-020-09866-0.

2 Nadeem M, Chandra A, Livirya A & Beryozkina S, AR-LaBOR: Design and assessment of an augmented reality application for lab orientation, *Educ Sci*, **10(1)** (2020) 316, doi: 10.3390/educsci10110316.

3 Andújar J M, Mejias A & Marquez M A, Augmented reality for the improvement of remote laboratories: An augmented remote laboratory, *IEEE Trans Educ*, **54(3)** (2011) 492−500, doi: 10.1109/TE.2010.2085047.

4 Criollo-C S, Abad-Vásquez D, Martic-Nieto M, Velásquez-G F A, Pérez-Medina J L & Luján-Mora S, Towards a new learning experience through a mobile application with augmented reality in engineering education, *Appl Sci*, **11(11)** (2021) 4921, doi: 10.3390/app11114921.

5 Gurevych R, Silveistr A, Mokliuk M, Shaposhnikova I, Gordiichuk G & Saiapina S, Using augmented reality technology in higher education institutions, *Postmod Openings*, **12(2)** (2021) 109−132, doi: 10.18662/po/12.2/299.

6 Bos A S, Herpich F, Kuhn I, Guarese R, Tarouco L, Zaro M A, Pizzato M & Wives L, Educational technology and its contributions in students' focus and attention regarding augmented reality environments and the use of sensors, *J Educ Comput Res*, **57(7)** (2019) 1832–1848, doi: 10.1177/0735633119854033.

7 Sahin D & Yilmaz R M, The effect of augmented reality technology on middle school students' achievements and attitudes towards science education, *Comput Educ*, **144** (2020) 103710, doi: 10.1016/j.compedu.2019.103710.

8 Chang H Y, Hsu Y S, Wu H K & Tsai C C, Students' development of socio-scientific reasoning in a mobile augmented reality learning environment, *Int J Sci Educ*, **40(12)** (2018) 1410−1431, doi: 10.1080/09500693. 2018.1480075.

9 Tomara M & Gouscos D, A case study: visualizing coulomb forces with the aid of augmented reality, *J Educ Comput Res*, **57(9)** (2019) 1626−1642, doi: 10.1177/0735633119854023.

10 Karagozlu D, Kosarenko N N, Efimova O V & Zubov V V, Identifying students' attitudes regarding augmented reality applications in science classes, *Int J Emerg Technol Learn*, **14(22)** (2019) 45−55, doi: 10.3991/ijet.v14i22.11750.

11 Jamaluddin A A, Rusli N, Yoke L L & Hoh G T L, Assessment of augmented reality mobile application for educational purposes, *Built Environ J*, **17(3)** (2020) 29−42, doi: 10.24191/bej.v17isi.11742.

12 Tashko R & Elena R, Augmented reality as a teaching tool in higher education, *Int J Cogn Res Sci Eng Educ*, **3(1)** (2015) 7−15, doi: 10.23947/2334-8496-2015-3-1-7-15.

13 Bazarov S E, Kholodilin I Y, Nesterov A S & Sokhina A V, Applying augmented reality in practical classes for engineering students, *Earth Environ Sci*, **87** (2017) 032004, doi :10.1088/1755-1315/87/3/032004.

14 Lucas P, Vaca D, Dominguez F & Ochoa X, Virtual circuits: an augmented reality circuit simulator for engineering students, in *IEEE 18th Int Conf Adv Learn Technol* (IEEE) 2018, 380−384, doi: 10.1109/ICALT.2018.00097.

15 Singh G, Mantri A, Sharma O, Dutta R & Kaur R, Evaluating the impact of the augmented reality learning environment on electronics laboratory skills of engineering students, *Comput Appl Eng Educ*, **27** (2019) 1361–1375, doi: https://doi.org/10.1002/cae.22156.

16 Martín-Gutiérrez J, Fabiani P, Benesova W, Meneses M D & Mora C E, Augmented reality to promote collaborative and autonomous learning in higher education, *Comput Human Behav*, **51** (2015) 752–761, doi: 10.1016/j.chb.2014.11.093.

17 Kaur D P, Mantri A & Horan B, Enhancing student motivation with use of augmented reality for interactive

learning in engineering education, *Procedia Comput Sci*, **172(2019)** (2020) 881–885, doi: 10.1016/ j.procs.2020.05.127.

18 Karagozlu D & Ozdamli F, Student opinions on mobile augmented reality application and developed content in science class, *TEM J*, **6(4)** (2017) 660, doi: 10.18421/TEM64-03.

19 Elford D, Lancaster S J & Jones G A, Exploring the effect of augmented reality on cognitive load, attitude, spatial ability, and stereochemical perception, *J Sci Educ Technol*, **31** (2022) 322–339, doi: 10.1007/s10956-022-09957-0.

20 Arici F, Yildirim P, Caliklar Ş & Yilmaz R M, Research trends in the use of augmented reality in science education: content and bibliometric mapping analysis, *Comput Educ*, **142** (2019) 103647, doi: 10.1016/j.compedu.2019.103647.

21 Dudić S, Šešlija D, Milenković I, Šulc J, Reljić V & Bajči B, *Zbirka Rešenih Zadataka sa Teorijskim Osnovama iz Pneumatskog Upravljanja* (Novi Sad: Fakultet tehničkih nauka) (In Serbian) 2021.

22 Bajci B, Seslija D, Reljic V, Milenkovic I, Dudic S & Sulc J, Augmented reality as an advanced learning tool for pneumatic control, in *5th Exp Int Conf* (IEEE) 2019, 415–418, doi: 10.1109/EXPAT.2019.8876552.

23 Bajči B, Reljić V, Šulc J, Dudić S, Milenković I, Šešlija D & Smajić H, Work-in-progress: development of augmented reality application for learning pneumatic control, in *Cyber-Physical Systems and Digital Twins: Proc 16th Int Conf Remote Eng Virtual Instrum* (Springer International Publishing) 2020, 711-718, doi: 10.1007/978-3-030-23162-0_64.

24 Spencer S, Drescher T, Sears J, Scruggs A F & Schreffler J, Comparing the efficacy of virtual simulation to traditional classroom role-play, *J Educ Comput Res*, **57(7)** (2019) 1772–1785, doi: 10.1177/0735633119855613.

25 Baabdullah A M, Alsulaimani A A, Allamnakhrah A, Alalwan A A, Dwivedi Y K & Rana N P, Usage of augmented reality (AR) and development of e-learning outcomes: An empirical evaluation of students' e-learning experience, *Comput Educ*, **177** (2022) 104383, doi: 10.1016/j.compedu.2021.104383.