Использование ресурсов технологии дополненной реальности для развития творческого мышления будущих педагогов

Е. В. СОБОЛЕВА, Т. Н. СУВОРОВА, А. В. ГРИНШКУН, Л. А. ШУНИНА

АННОТАЦИЯ

Проблема и цель. Одна из проблем высшего образования – поиск эффективных форм обучения, обладающих дидактическим потенциалом в плане развития системного, критического, творческого и других типов мышления, востребованных цифровым обществом. Авторы предлагают для формирования творческого мышления как универсального навыка, соответствующего вызовам трансформации и глобализации, использовать средства технологии искусственного интеллекта.

Цель исследования – выявить возможности взаимодействия будущих педагогов с сервисами для создания контента с элементами дополненной реальности для развития их творческого мышления.

Методы исследования. Информационное взаимодействие в AR-пространстве поддержано сервисами MyWebAR, Web-AR.Studio и реализовано на занятиях дисциплины «Теория и методика обучения информатике». Опытно-поисковая работа проведена на базе Вятского государственного университета (Российская Федерация). Задействовано 68 студентов направления подготовки – 44.03.05 Педагогическое образование, профиль «Физика и информатика». Для оценки уровня критического мышления авторами используется тест креативности Торренса (невербальная часть теста). При статистической обработке данных использован критерий χ^2-Пирсона.

Результаты. Особенность представленного варианта деятельности: с одной стороны, сервис AR является объектом изучения (возможности, шаблоны, настройки). С другой стороны, применение сервисов AR – это дополнительный ресурс для развития творческого мышления. Работа студентов экспериментальной группы организована по следующим этапам: знакомство с интерфейсом, шаблонами проектов платформы; разбор настроек проекта; изучение алгоритмов создания, добавления, группировки моделей; постановка задания по созданию собственного проекта; разбор созданных проектов, советы по их совершенствованию; демонстрация внедрений в образовательные процессы. Выявлены статистически достоверные различия в качественных изменениях, произошедших в педагогической системе (χ^2 = 9,504; p < 0,05).

Заключение. Определены факторы, влияющие на качество применения сервисов AR для развития творческого мышления педагогов: генерация и воплощение новых идей; оригинальное представление структуры решения; моделирование интерактивного информационного взаимодействия и сбора обратной связи.

КЛЮЧЕВЫЕ СЛОВА

цифровизация образования, виртуальная информационная среда, педагогическая деятельность, интерактивное взаимодействие, MyWebAR, Web-AR.Studio

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Using Augmented Reality Resources to Develop Creative Thinking in Future Teachers

E. V. SOBOLEVA, T. N. SUVOROVA, A. V. GRINSHKUN, L. A. SHUNINA

ABSTRACT

The problem and the purpose. One of the challenges in higher education is the search for effective learning formats with didactic potential for developing systemic, critical, creative, and other types of thinking demanded by the digital society. The authors propose the artificial intelligence technology to develop creative thinking as a universal skill that meets the challenges of transformation and globalization. The aim of the study is to identify opportunities for future teachers to interact with services for creating content with augmented reality elements to develop their creative thinking.

Research methods. Information interaction in the AR space was supported by the MyWebAR and Web-AR.Studio services and implemented in classes in the course "Theory and Methods of Teaching Computer Science". The experimental research was conducted at Vyatka State University (Russian Federation). The study involved 68 students majoring in 44.03.05 Pedagogical Education, majoring in Physics and Computer Science. To assess critical thinking, the authors used the Torrance Tests of Creative Thinking (non-verbal tasks). The Pearson's chi-squared test was used for statistical data processing.

Results. A distinctive feature of the presented activity: on the one hand, the AR service is the object of study (capabilities, templates, settings). On the other hand, the use of AR services is an additional resource for developing creative thinking. The work of students in the experimental group was organized according to the following stages: familiarization with the interface and platform project templates; analysis of project settings; study of algorithms for creating, adding, and grouping models; setting an assignment to create their own project; analysis of created projects, advice on their improvement; demonstration of implementation in educational processes. Statistically significant differences in the qualitative changes that occurred in the pedagogical system were revealed ($\chi^2 = 9.504$, $p < 0.05$).

Conclusion. The factors influencing the quality of AR services' application for developing teachers' creative thinking were identified. They are: generation and implementation of new ideas; original presentation of solution structures; modeling of interactive information exchange and feedback collection.

KEYWORDS

digitalization of education, virtual information environment, pedagogical activity, interactive interaction, MyWebAR, Web-AR.Studio

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INTRODUCTION

The UNESCO Creativity in Education Summit, organized in Paris in 2024, explored various ways to develop creative thinking through information technology. Case studies were also showcased, providing practical resources for empowering students [1]. As noted by T. Buzina et al., the experts were particularly interested in the practical applications of immersive technologies in stimulating innovation in education [2]. More than 200 researchers studying the theoretical and practical aspects of digitalization and globalization actively participated in the summit. They were the representatives of education ministries, experts from the UNESCO office, and educational organizations from around the world.

The Institute of Technical Education (ITE), a leading educational institution in Singapore, as described in their work by A. Lee, E. Koh, and Ch-K. Looi actively uses VR/AR application suites at various stages of the classroom [3]. This allows the institute's teachers to effectively implement educational scenarios for a wide range of systems: from large immersive rooms to mobile devices. Feedback from participants allows the organizers to note that students experience qualitative changes in their thinking and research performance. The UNESCO Institute for Information Technologies in Education and NetDragon (China) are organizing the international competition for teachers, "Teaching in the 21st Century 2.0". The goal of the competition is to actively implement digital innovations in pedagogy [4]. The event's objectives include promoting "green" education, exploring the didactic aspects of generative AI, developing creativity, and incorporating elements of gamification. Most of the objectives are expected to be addressed at the level of Russian higher education and teacher training for Russian schools. Moscow City Pedagogical University, in turn, has already demonstrated the potential of VR/AR for enhancing the educational process [5]. M. Waly argues that project-based learning integrated with ICT is a promising model for developing such in-demand skills as critical thinking, communication, collaboration, and creativity [6]. K. Lkamel and J. Assermouh define creativity in education as the ability to invent, search for, and discover new methods (ideas) [7]. According to K. Lkamel and J. Assermouh, creativity in teaching depends on many factors, including socio-demographic characteristics (gender, age, teaching experience, average class size, and educational level).

At the same time, P. Son notes that VR/AR technologies are increasingly being used in various fields, including science and education [8]. In the author's survey, teachers who implement VR/AR stated that these technologies improve the learning experience for students. The learning process itself becomes more engaging and interesting compared to traditional methods and means. For example, E. A. Mamaeva et al. are exploring the potential of AR for developing teachers' multicultural competence, which is viewed as both a general social and professional quality [9]. In the context of training mathematics, computer science, and physics teachers, AR can be used to visualize abstract concepts, improve understanding of complex processes, and provide interactive and immersive learning experiences. However, according to the findings of P. Son, noted earlier, most teachers still lack a full understanding of the potential and role of VR/AR in education [8]. This understanding is particularly relevant for the development of such personal qualities as creativity, emotional intelligence, and critical thinking. The author notes the need for comprehensive research aimed at addressing this issue.

The study hypothesis is that organizing the practical activities of future teachers with services for creating content with augmented reality elements will provide qualitatively new resources for developing their creative thinking as an important skill for in-demand specialists of the future.

The goal of the study is to identify the potential of augmented reality technology for developing the creative thinking of future teachers.

Research objectives: to clarify the challenges and potential of using services for creating content with augmented reality elements in teaching student teachers; to describe possible applications of services for creating content with augmented reality elements in teachers' work, taking into account their future job responsibilities; to identify factors influencing the quality of the use of augmented reality resources for developing the creative thinking of future teachers.

MATERIALS AND METHODS

Augmented reality technology is considered a technology that allows users to overlay digital elements onto the real world. 3D models, texts, animations, or images can be used as educational objects for study. Augmented reality resources include platforms, tools, sample applications, and resources for studying this technology. Creative thinking of a teacher is the ability to find and use innovative approaches to teaching, preparing lessons, and communicating with students.

The experiment involved 68 fourth-year students from the Faculty of Informatics, Mathematics, and Physics at Vyatka State University (Russian Federation). Their major was 44.03.05 Pedagogical Education (with two training tracks), majoring in Physics and Computer Science. The average age of the students was 22 years old (75% female, 25% male). The authors of the study used MyWebAR (https://dashboard.mywebar.com/home/) and Web-AR.Studio (https://web-ar.studio/ru/) as the applications for creating content with augmented reality elements. The choice of these services was determined by the following factors: a Russian-language interface, no requirement for advanced programming skills, browser accessibility, cross-platform compatibility, a library of ready-made templates, and support for integrating objects generated by built-in AI. The application features that were actively used in teaching and organizing information interactions aimed at developing students' creative thinking included: development of projects with multiple triggers and scenes simultaneously; publishing and personalizing projects; support for adding 3D models, music, and animation; and creation of lesson scenarios. Involving future teachers in working with AR technology services was implemented in the course "Theory and Methods of Teaching Computer Science".

In this study, the authors use the Torrance Tests of Creative Thinking (non-verbal tasks) to assess the development of creative thinking. Processing the test results involves assessing five indicators: "fluency", "originality", "elaboration", "resistance to closure", and "abstractness of names". The results were processed according to the test instructions. To formulate a conclusion about the creative thinking level of future computer science and physics teachers, a total score for all indicators was calculated. The level was recorded as follows: 30 or less – "low", 30-39 – "below average", 40-60 – "average", 61-70 – "above average", and 71 or more – "high". The interpretation is in the study program and results. A control group (34 computer science and physics teachers) and an experimental group (34 computer science and physics teachers) were formed. The Pearson's chi-squared test was used for statistical data processing.

LITERATURE REVIEW

Q. Zhang et al. note that the world is currently experiencing a key phase of digital transformation, leading to significant digitalization in education [10]. The authors' study examines how and under what circumstances educational digitalization influences student creativity. Moreover, creative self-efficacy was found to play a moderating role in this process. The study's results provide materials for educators in formulating methodological recommendations for optimizing the implementation of digital technologies in the educational environment to develop creative individuals. C. S. K. Dogbe et al. point out the crucial importance of studying the factors that contribute to teacher effectiveness and professional fulfillment [11].

R. Hassan, H. Amin, and H. Ghoneim study the interdependence of decent work and the sustainability of professional knowledge development [12]. According to the authors' conclusions, this relationship is manifested in the fact that the main conditions for the latter's equilibrium state are the ability to receive information flow and increase resources for: acquiring new knowledge and staying abreast of technological changes; developing social and labor mobility; Forecasting and preparing for the acquisition of skills for the future. N. Paziura studies the development of creativity in future designers in the context of changing labor market demands and design trends [13]. The author found that a creative educational environment best fosters creativity in future professionals. Furthermore, it has been proven that nurturing students in a creative educational environment influences their creativity and subsequent self-realization. The author concludes that it is necessary to design a creative educational environment using innovative technologies.

Q. Gao and M. Qian note that the beliefs of future teachers play a significant role in shaping their future teaching practice [14]. The authors' study explored future teachers' views on the expression of creativity in their professional work. The results showed that future teachers value professional competence and creativity. Specifically, they believe that incorporating elements of creativity leads to teaching practices that also encourage creativity in students. The findings of Q. Gao and M. Qian emphasize the need for teacher education programs to include courses that develop students' creative thinking. D. Setyawarno et al. demonstrate that the introduction of new information technology-based learning significantly impacts the development of future teachers' digital literacy skills (including creative thinking) [15].

K. Lkamel and J. Assermouh, based on the assumption that in the digital age, children grow up with constant access to computers and the internet, emphasize the need for their teachers to develop appropriate digital skills [7]. Furthermore, the authors believe that teachers proficient in ICT are, firstly, more innovative and successful. Secondly, educators proficient in technology can design lessons that foster creativity (both in themselves and in their students). A. Almukhanbetova emphasizes the importance of global trends and innovative digital technologies in education [16]. The author analyzes ways to integrate AI technologies into the educational process, taking into account the individual learning style and abilities of each student. The use of AR/VR technologies is presented as an effective solution for increasing student interest, improving their memory skills, and supporting teachers' work. The article concludes by emphasizing that teachers should utilize AR/VR resources to take the educational process to the next level.

F. Acevedo et al. consider AR as a universal technology because it has virtually no limitations in terms of content or usage [17]. Participants in an augmented reality experience can combine different temporal data, physical, and visual (augmented) objects. The results of such an experience can be tailored to the interests of each participant, providing a unique, personalized experience. A. Tiwari, K. Bhagat, and G. Lampropoulos point out that AR is one of the emerging technologies widely used in education [18].

For example, in engineering drawing, AR is being implemented to develop students' spatial abilities. D. Setyawarno et al. identify the need for and options for implementing hybrid models based on the Internet of Things and VR/AR in science education [15]. The authors' study experiment included both creative thinking tests and observation sheets. Based on the experimental data, D. Setyawarno et al. demonstrate that the creative thinking skills of students–future teachers–can be significantly improved by these digital technologies.

I. Truskavetska et al. note that the use of information technology, particularly VR/AR, is becoming a pressing issue in the professional training of science teachers [19]. I. Álvarez et al. note that improving the educational experience through immersive VR/AR is a promising direction. In particular, it has the potential to increase accessibility and engagement in learning [20]. However, one key aspect is assessing the teachers' acceptance of such environments to ensure effective didactic use of these technologies. The feedback from participants (future teachers) allowed the authors to begin formulating recommendations for integrating VR/AR tools into teacher training programs. V. Hoai et al. note that cognitive ability is a fundamental aspect of effective chemistry education [21]. AR technology is a promising tool in science education, offering immersive learning experiences that enhance students' understanding of chemical phenomena. The authors conclude that by expanding the use of AR technology to model various chemical simulations, teachers can also develop their cognitive abilities, promoting active learning and improving the overall quality of education. L. Liang, Z. Zhang, and J. Guo explore the integration of digital technologies into physical education [22]. The authors use AR tools as supporting tools to study the impact of this educational technology on learning motivation, knowledge quality, and behavior. The results of this study are as follows: first, participants in the experimental group (using AR) achieve better learning outcomes than the control group. The experimental group also experiences stronger motivation to learn and a more positive attitude toward the creative use of AR tools. L. Liang, Z. Zhang, and J. Guo formulate that AR can form the basis for an innovative teaching model that stimulates students' creativity, cognition, and motor activity.

N. Antonopoulos also examines the possibility of integrating AR into physical education teaching [23]. The author proposes this innovation with the goal of activating motor practices and developing physical skills. AR technology, with its ability to merge the real and virtual worlds, offers new perspectives on motor skill teaching, facilitating experiential and personalized learning. In this context, the study examines how AR can improve students' participation, performance, and interest in physical education. The study was based on an analysis of existing research describing the effectiveness of AR in teaching physical education and motor skills.

E. A. Mamaeva et al. examine the resources of AR technology that extend the physical world by adding layers of digital information and visual elements in real time [9]. J. Gutiérrez-Jara et al. study the impact of AR on improving the academic performance of students studying the basics of anatomy [24]. K. Oqaidi, S. Aouhassi, and K. Mansouri identify the positive impact of educational games that incorporate both immersive technologies and AI elements [25]. This class of games involves adaptability and personalization based on image recognition, human emotions, and speech to simulate the "presence" of opponents and control the difficulty of game levels and content. Ch-Y. Chung, I-H. Hsiao and others study the impact of augmented reality on verbal communication and code debugging during collaborative programming [26].

Y. Wu, Ch-H. Wu, and K-L. Peng indicate that participation in science, technology, engineering, and the arts promotes student engagement in learning and improves the quality of educational outcomes [27]. The authors examine the significance of creative thinking on the level and quality of student outcomes. Y. Wu, Ch-H. Wu, and K-L. Peng are developing a questionnaire to assess creativity by measuring students' learning motivation. Their study involved 65 students from National Taiwan University. The researchers' results showed that creativity plays a crucial role in motivation and engagement in learning. Furthermore, a direct link was found between creativity and the use of AI-based gamification.

H. Crogman et al. demonstrate that VR/AR and mixed reality have a positive impact on learning [28]. They also infuse educational paradigms with the resources of immersive and interactive environments. The authors conduct an experiment demonstrating how the integration of VR/AR technologies into the learning process enables students to overcome traditional cognitive barriers. Participants gain experience with dynamic simulations, historical reconstructions, and scientific visualizations, which enhance engagement, understanding, and retention. H. Crogman et al. highlight the revolutionary potential of mixed reality for innovation in the education system. S. Sahronih et al. explore the specifics of teaching using augmented reality-based media technologies to develop the creativity of primary school teachers [29]. D. V. Ivanov and V. K. Vlasova also use VR tools to develop the creative thinking of future primary school teachers. In their classes, the authors used VR technologies as a basis for designing virtual lesson fragments directly by the future primary school teachers themselves [30]. The authors note that the VR tools used enabled the optimal activation of creativity in future teachers. This was possible because the technology is aimed at creating originality and simulating new solutions in pedagogical practice. This means it meets the essence, fundamental elements, and conditions for the development of creative thinking. Using digital technology, future teachers can develop learning assignments, problem-solving situations, and more. E. V. Soboleva et al. examine the development of verbal creativity in future teachers using flashcards [31]. Flashcards are memory cards implemented in a virtual environment and presented to students digitally. The authors base their work on the premise that the content of verbal creativity is a factor in the development of an individual's creative thinking style. The study utilizes E. P. Torrance's methodology, which takes into account six characteristics of creativity.

The literature review allows us to objectively conclude that: the implementation of tools and services supporting AR is one of the key areas for modernizing the training of students majoring in teaching; there is a need to improve teacher training programs (including computer science and physics) on the use of AR services to develop their own creative thinking and the creativity of their future students.

RESEARCH PROGRAM

The first stage involved an analysis of literature and innovative practices on the use of augmented reality technology in teaching student teachers and developing their creativity. Various AR services and their didactic potential were considered. For example, in addition to the previously mentioned MyWebAR and Web-AR.Studio, other options included JigSpace, Google Lens, Mondly, ROAR, Mind Map AR, 8th Wall, and others. However, MyWebAR and Web-AR.Studio were ultimately selected based on the criteria in the research methodology. The content of the "Theory and Methodology of Teaching Computer Science" course was refined in terms of allocating time resources for working with AR services.

A methodology for assessing creative thinking was also selected. The authors considered the creativity tests of J. Bruner and Guilford, the Walt Disney method, and the Figural Form of the Torrance Tests of Creative Thinking. The reasons for choosing this technology were the following: time constraints within classroom instruction were taken into account, and the formal characteristics of the Torrance Tests of Creative Thinking (reliability and validity) were slightly better than those of others. The integrated indicator for formulating a conclusion about the development of creative thinking was calculated as follows subject to results in chapter "Materials and Methods". This methodology was applied before and after students worked with AR services. The essence of the levels is reflected in the study results. A control and experimental group were formed, each consisting of 34 future computer science and physics teachers.

In the second stage of the study, students studied course materials and worked with AR applications. First, according to instructions, and then completed a creative task reflecting the specifics of their training. In the third stage of the study, factors influencing the quality of the use of AR services in the development of creative thinking in future teachers were identified.

RESEARCH RESULTS

Students in the chosen program and profile study the concept and essence of AR technology in their first and second years of study, while studying the course "Digital Technologies in Education". The course "Theory and Methods of Teaching Computer Science" is studied by students, future computer science and physics teachers, in their fourth year. A sample list of topics covered includes: "Methodological System for Teaching Computer Science", "Didactic Foundations of Teaching Methods in Computer Science", "Organization of Teaching Computer Science", and "Specific Methods of Teaching Computer Science".

When studying the latter topic, the work program requires students to complete tasks such as: "Select material and develop a lesson plan for studying the basic algorithm of a processor", "Select content according to the logic of presentation of material on the topic "Computer Structure", and "Which software tool will you choose if you need to visualize an information object". Since completing the presented tasks allows for the development of creative thinking in future teachers and the use of AR services for this purpose, a decision was made to conduct a corresponding experiment.

In the presented study, student creativity in the teaching profession presumes that graduates will be able to: work with educational material, making it more accessible and understandable to the recipient when necessary; generate new ideas and propose innovative forms, methods, and teaching techniques (for example, by adding their own examples for clarification and formulating their own conclusions); creatively design the structure of an answer or solution; apply a differentiated approach to teaching; simulate various social situations, dialogue, and feedback collection.

The authors analyzed MyWebAR, JigSpace, Web-AR.Studio, Google Lens, Mondly, ROAR, Mind Map AR, 8th Wall, Blippar, and others. Of these, 8th Wall has the functionality most closely matching the resources of the selected programs. In particular, using 8th Wall with Unity is extremely simple. Simply download the SDK from the 8th Wall website, import it into your Unity projects, and add a few scripts to some objects. However, testing a simple model in AR revealed some shortcomings in its educational use. When quickly moving the phone or tilting it, the model in augmented space begins to jump erratically and shrink in size. Blippar has a more limited free template database. After determining the course placement and AR services for information interaction, the study authors developed instructions for each of the applications under study. All participants were then divided into experimental and control groups using control testing materials.

We present detailed instructions for using the MyWebAR service, which can be used to motivate students and diversify the school computer science curriculum (7th grade, "Computer Structures" section).

1.1. Go to the official website of the designer at the link: MyWebAR (https://dashboard.mywebar.com/home/). After clicking the link, you will see welcome information about our service. Next, click the "Register" button in the upper right corner and enter the required information. From the window that appears, select "For Personal Use/Freelance".

Next, you need to choose the option that best describes your role. Next, you answer whether you have experience with augmented reality. You'll be asked to choose a plan with a corresponding price. Select Sign Up For Free. Click the "Create New Project" button in the upper right corner. Select "Overlay Content on QR Code" from the options offered.

1.2. Next, the service scene opens, where you can begin creating. We recommend familiarizing yourself with the layout of the service's possible functions. Try changing the scene's position using your mouse.

1.3. To avoid any difficulties during the process, open your browser and download an image of your computer monitor. In the "Objects" section, click the plus sign next to "Image" and add the image of your computer monitor that you found and downloaded. After adding the object, observe the changes in the scene.

1.4. You can upload images from your computer, so pay attention to the downloaded images in your browser (the file type must be PNG, GIF, JPG, or JPEG, and the size must not exceed 2MB).

1.5. Similar to the computer monitor, you add objects to your scene, such as a keyboard, speakers, and a computer mouse.

1.6. By clicking on the screen, you can move the objects to achieve the desired positioning of the added objects. For more precise positioning coordinates, use the "Position and Scale" section on the right side of the screen. Here, you can set the precise coordinates along the Ox, Oy, and Oz axes, as well as rotate and scale objects.

1.7. To check the desired positioning, hold down the left mouse button and move it in different directions. You can view the objects in the scene from different angles and ensure that everything is implemented as intended.

1.8. Next, we'll make the added objects interactive. Left-click on the "Monitor" image. Next, in the upper right corner of the screen, in the "Properties" tab, select the "Add Action" button. From the list of actions provided, select "Open website on click".

1.9. Now we need to create a link that will be redirected to a specific object when clicked. To do this, open the browser and find a video on "Forming an Image on a Monitor Screen" and copy the link to the video. Go to our service and enter the link found in the "Open website on click" section.

1.10. Next, we assign a corresponding action to each object. For the "speakers" object, we'll assign the action "Play audio file on click". To do this, find information about speaker types/sound quality/classifications in the browser, copy the text found, then use a website that converts text to audio to download the resulting file to your PC, and then attach it to the "speakers" object. We'll assign the "Open website when clicked" action to the "Keyboard" object. Here, we'll add a typing tutor, which can also be found in the browser (https://typerun.top/#rus_basic).

We'll assign the "Play audio file when clicked" action to the "Computer mouse" object. To do this, find a video based on our image, copy it, and paste it into the link field, like you did with the "Monitor" object.

1.11. When finished, click the "Publish" button in the upper right corner. The notification on the website page confirms our success. Next, we point the phone camera at the QR code and click on each of the objects to view them.

Detailed instructions for using the Web-AR.Studio service are included, which can be used to motivate students and diversify the computer science curriculum (7th grade, "Personal Computer External Devices" section).

2.1. Go to the official Web-AR.Studio website (https://web-ar.studio/en/). Click "Start for free" in the upper right corner and register. You'll need to enter your first name, last name, email address (where you'll receive a confirmation message), password, and then re-enter your password. After registering, select "My Projects" on the left side of the screen, then click "Create Project" on the right.

2.2. Next, you'll see several steps for specifying your project. In step 1, select "QR Code Recognition"; in step 2, select "2D/3D Editor"; in step 3, select "AR Viewer Lite" (which is available when you first create a project, but selecting other options won't change the result). Finally, you have one final choice: choosing a project template. The service offers several categories: souvenirs, printing, advertising, and education. We need the leftmost option – a blank project – so we can start creating from scratch.

2.3. The Web-AR.Studio service offers opportunities for self-realization even for those who have never used similar services before. A brief introduction to the service's basic keys and capabilities is offered, presented in a flashcard format.

2.4. After familiarizing yourself with the service, a scene opens in front of you, where you should familiarize yourself with the service's main features. On the left side of the screen, there are scenes for designing your project; you can add them by clicking the "+" sign. There are also pre-made templates, but you can also attach your own. Above the AR scenes is a toolbar for adding videos, photos, text, 3D models, and more. The central section acts as a canvas where you'll add objects. The right section includes "scene settings": assigning click actions, transitioning between scenes, formatting text and changing its color, and more.

2.5. To start adding files, open your browser and find images of your desktop and computer. It's important to pay attention to the quality of the desktop image; the colors in the photo should contrast well so the service can recognize the objects you've attached. Next, download them to your computer. Please note that images must be in "*.png" or "*.jpg" format. The size should not exceed 3 MB.

2.6. Find "Image" on the toolbar and attach a picture of your computer. On the right side of the screen, in the "Scene Setup" section, under the "Scene Trigger" subsection, select "Edit Trigger", then "Upload New Trigger". Upload the previously downloaded desktop image. A trigger is a photo that, when hovered over, will trigger an interactive scene.

2.7. Our project will be based on clicking on each object in the main scene to navigate to a separate scene. Therefore, on the left side of the screen, in the "AR Scenes" section, click "+ Add Scene" and change its name to "Computer" using the corresponding button. Next, left-click the "Computer" object. On the right side of the screen, in the "Element Setup" section, under "Actions", select "Go to Scene" when clicked, and select the scene you just created. This way, when the user clicks on the computer, they will be taken to the new scene, where the interaction will now take place. Here you can also see what the main scene looks like with the added objects.

2.8. Some of the actions are already familiar, so it'll be easier. We'll work on the second scene, "Computer". To do this, find an image of a computer monitor in the browser. Add it to the scene using the toolbar. There's also a "Text" tool; click it. Now you can add the caption "Getting to Know Your Computer", and similarly add "Return to Room" (in other words, our main scene). Now we need to add some interaction: click on the added image and, on the right side of the screen, under "Element Settings", "Action", select "Link" when clicked. In the window that appears, paste a link to a video about a computer/PC device, which can be found on YouTube. And the final action, which will be the same on every slide, is assigning the "Return to Room" text field the action Click -> Scene -> Room.

2.9. Our main stage, "Room", will have several more objects: speakers, a flash drive, and a DVD. So we find the appropriate images in the browser, download them, and add them to the main stage using the toolbar, like on a computer. We also create a new scene for each object, bringing the total to three. And on the main stage, for each newly added object, add a click action: > Scene > Room Name.

2.10. Go to the "Speakers" stage. Add text to the stage using the toolbar. We'll write "The speakers allow you to listen to W.A. Mozart's greatest work: Symphony No. 40, Part III, Minuet", and also add a text field called "Return to Room", as we did in step 2.8.

Next, we need to download this symphony in MP3 format from the browser and add it to the right side of the screen under "Background Music".

2.11. Next, move to the "Flash Drive" scene. Add the text "Storage Media" and "Return to Room" as before. In this scene, we'll create a video that will play when the scene opens. To do this, find "Download Video Storage Media" in the browser and download it to your computer in MP4 format. Then, using the "Video" toolbar, add the downloaded material. All that's left is to adjust the dimensions, which can be done using your mouse.

2.12. The "DVD Disc" scene remains: add a "Return to Room" text field with all clicks leading to the main scene. Also, using the toolbar, add a 3D model (four circles). Here, you'll need to express your creativity and explore the service's additional features.

2.13. Once the work is nearing completion, it's important to assign a single trigger to all scenes, verify that all clicks are directed to the correct scenes and links, and then click "Publish" in the upper right corner, which typically takes 2-3 minutes. Then, click "Preview". Then we'll have the finished product ready to view.

Next, participants in the experimental group began developing their own project in the AR space. A methodological feature: they could choose any of the services they had studied. Examples of projects included a school computer lab, a laptop, the internet, a computer mouse, and virtual reality glasses. Participants in the control group also developed a project that incorporated specific learning methods used in school.

For example, "Computer Structure", "Information Security and Data Protection", and "Representation and Measurement of Information". However, the students no longer used AR services to create lesson plans. For their lesson plans, they developed an interactive presentation, using simulators and internet resources. Following the experimental work, the students were tested again to determine the teacher's level of creative thinking. To interpret the results, the following levels were defined: "low", "below average", "average", "above average", and "high".

"High level" means the student correctly follows the instructions for the AR services and independently adds their own images and explanations. They actively use previously created models to construct new objects in augmented reality. They propose new ideas for using the resulting AR objects in the teaching process and formulate them in an original way. They put forward various (differentiated) ways to incorporate AR experiences into their own activities and the creative research of others.

"Above Intermediate Level" – the student masters the functionality of AR services with minor difficulties, but makes no mistakes when adding their own images and text. They do not always use previously created models to construct new objects in augmented reality. They propose new ideas for using the resulting AR objects in the teaching process, but are unable to formulate them originally. With some assistance from their mentor, the student puts forward various ways to incorporate AR experiences into research activities.

"Intermediate Level" – the student applies the functionality of AR services in practice with one or two errors. They use the images and supporting materials suggested by the teacher. Each time, the process of creating new objects in augmented reality begins with a new project. The future teacher may not always be able to come up with new ideas for using the resulting AR objects. However, they strive to present them originally. The student suggests two or three possible ways to incorporate the AR experience.

"Below Intermediate Level" – the student has significant difficulties, but applies the functionality of AR services in practice. They use the materials suggested by the teacher. They require intensive support from the mentor both in creating new objects and in generating new ideas, as well as in formulating them. The future teacher understands the various possible uses of the resulting AR objects.

"Low Level" – the student was unable to create an AR object according to the developed instructions, even with the mentor's help. The future teacher only listened to and looked at the models of other classmates.

Table 1 presents the results of the assessment of the creative thinking level of future computer science and physics teachers before and after working with AR services.

Table 1 Assessment of the level of creative thinking of future computer science and physics teachers before and after working with AR services

Level	Groups			
	Control (34 students)		Experimental (34 students)	
	Before the experiment	After the experiment	Before the experiment	After the experiment
Low	6 (18%)	5 (15%)	6 (18%)	1 (3%)
Below Intermediate	6 (18%)	5 (15%)	6 (18%)	3 (9%)
Intermediate	9 (26%)	11 (32%)	10 (29%)	5 (15%)
Above Intermediate	10 (29%)	10 (29%)	9 (26%)	17 (50%)
High	3 (9%)	3 (9%)	3 (9%)	8 (23%)

The following hypotheses were accepted: H0: The level of creative thinking of future teachers in the experimental group is statistically equal to that in the control group; H1: The level in the experimental group is higher than that in the control group. For $\alpha = 0.05$, χ^2_{crit} is 9.488. It was determined that $\chi^2_{obs.1} < \chi^2_{crit}$ (0.105 < 9.488), and $\chi^2_{obs.2} > \chi^2_{crit}$ (9.504>9.488). Therefore, changes in the indicators of critical thinking development are not random.

Let's analyze the dynamics by training levels:

1. The greatest dynamics occurred in the experimental group at the "Above Average" level (8 students, or 24%). The smallest changes were at the "Below Average" level. This is because students significantly improved their scores on all creativity indicators, according to the Torrance Tests of Creative Thinking (non-verbal tasks).

2. In the control group, there was no change in the "Above Average" and "Average" levels. The largest changes were in the "Average" level (2 students, or 6%).

Thus, working with AR services contributed to the development of key components of creativity (originality, fluency, flexibility, and thoroughness of development), and therefore, the development of creative thinking in future teachers.

DISCUSSION

In presenting the research materials, the authors took into account the findings of experts from UNESCO [1], the Institute of Technical Education [4], and the Moscow City Pedagogical University regarding the importance of developing teachers' creative thinking for the sustainable development of society [5]. We believe that the study confirmed M. Waly's conclusion that working on an ICT-based educational project will contribute to the development of communication skills and creativity [6]. Furthermore, it expands on the ideas of D. V. Ivanov and V. K. Vlasov that VR/AR tools create opportunities for developing the creative thinking of future teachers – not just elementary school teachers [30], but computer science and physics teachers. The presented materials continue the earlier research of E. V. Soboleva et al., which emphasized the need to specifically explore the possibilities of integrating AR into the disciplines that form the foundation of training programs for in-demand teachers in digital society [31]. Further directions for refining the findings include: incorporating other training profiles (e.g., history and mathematics teachers) into the training; development of materials for the creation of a separate discipline adapted for students of pedagogical specialties.

CONCLUSION

Thus, teachers' work with AR services contributes to the improvement of the learning process and the development of creative thinking in students majoring in teaching. Furthermore, the organization of information interaction between digital school mentors and AR applications creates qualitatively new conditions for the development of their creative thinking, as students apply them at the following stages: algorithms (from registration to the start of using the platform); familiarization with the platform's project templates; creating 2D objects for a project using graphics editor programs; analysis of project settings and built-in analytics data; study of the processes of creating, adding, and grouping models in the designer; demonstration of the implementation of augmented reality in educational processes; setting a practical assignment for creating their own project; project analysis, advice on design, functionality, and project improvement.

Participants in the pilot study identified the following factors influencing the effectiveness of AR services in developing their creative thinking: the ability to process educational material in an AR environment, making it more accessible and visual; tools for generating and implementing new ideas (forms, methods, and teaching techniques); resources for original presentation of the structure of an answer or solution; opportunities for various practical applications of the acquired AR experience; modeling interactive information exchange and feedback collection in a virtual environment.

Limitations when using AR services in the didactic process include: technical difficulties (the need for stable, high-quality internet access and additional accessories); lighting and contrast conditions; intellectual property protection and information security. These results can be used to improve training programs for future teachers to master AR tools that will enable digital school mentors to make the learning process more interactive, engaging, and stimulating.

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Авторы

Соболева Елена Витальевна
(Россия, Киров)
Кандидат педагогических наук,
доцент кафедры цифровых технологий в образовании
Вятский государственный университет
E-mail: sobolevaelv@yandex.ru
ORCID ID: 0000-0002-3977-1246

Суворова Татьяна Николаевна
(Россия, Москва)
Доктор педагогических наук, заведующий лабораторией развития цифровой образовательной среды
Центр развития образования
Федеральное государственное бюджетное учреждение «Российская академия образования»
***
Профессор кафедры прикладного искусственного интеллекта, факультет искусственного интеллекта
Российский университет дружбы народов имени Патриса Лумумбы
E-mail: suvorovatn@mail.ru
ORCID ID: 0000-0003-3628-129X

Гриншкун Александр Вадимович
(Россия, Москва)
Кандидат педагогических наук
Начальник департамента информатизации образования
Институт цифрового образования
Московский городской педагогический университет
E-mail: aleksandr@grinshkun.ru
ORCID ID: 0000-0003-3882-2010

Шунина Любовь Андреевна
(Россия, Москва)
Доцент, кандидат педагогических наук,
заведующий кафедрой информатики и информационно-коммуникационных технологий факультета информационных технологий
Университет "Синергия"
E-mail: shunina.mgpu@gmail.com
ORCID ID: 0000-0002-6952-000X

Authors

Elena V. Soboleva
(Russia, Kirov)
Cand. Sci. (Educ.),
Associate Professor of the Department of Digital Technologies in Education
Vyatka State University
E-mail: sobolevaelv@yandex.ru
ORCID ID: 0000-0002-3977-1246

Tatyana N. Suvorova
(Russia, Moscow)
Dr. Sci. (Educ.), Head of the laboratory of Development of Digital Education Environment
Education Development Center «The Russian Academy of Education»
***
Professor of the Department of Applied Artificial Intelligence, Faculty of Artificial Intelligence
Peoples' Friendship University of Russia
E-mail: suvorovatn@mail.ru
ORCID ID: 0000-0003-3628-129X

Aleksandr V. Grinshkun
(Russia, Moscow)
Cand. Sci. (Educ.),
Head of the Department of Informatization of Education
Institute of Digital Education
Moscow City University
E-mail: aleksandr@grinshkun.ru
ORCID ID: 0000-0003-3882-2010

Liubov A. Shunina
(Russia, Moscow)
Cand. Sci. (Educ.), Associate Professor,
Head of the Department of Computer Science and Information and Communication Technologies of The Faculty of Information Technology
Synergy University
E-mail: shunina.mgpu@gmail.com
ORCID ID: 0000-0002-6952-000X

Вклад авторов

Соболева Е. В.: концептуализация, методология, создание рукописи и ее редактирование, руководство исследованием, администрирование проекта
Суворова Т. Н.: верификация данных, проведение исследования, создание черновика рукописи
Гриншкун А. В.: ресурсы, программное обеспечение, проведение исследования
Шунина Л. А.: формальный анализ, проведение исследования, визуализация

Authors contribution

Elena V. Soboleva: Conceptualization, Methodology, Writing - Review & Editing, Supervision, Project administration
Tatyana N. Suvorova: Validation, Investigation, Writing - Original Draft
Aleksandr V. Grinshkun: Software, Investigation, Resources
Liubov A. Shunina: Formal analysis, Investigation, Visualization

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