Using augmented reality technologies to create interactive educational digital content

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Abstract

The article reveals the possibilities of using augmented reality technologies to create interactive educational digital content. Based on the analysis of scientific literature and the needs of modern education, the need to provide the educational process with interactive digital content that can be used in various forms of organizing learning has been established. Such needs can be met through the introduction of immersive technologies into the educational process. In this context, augmented reality technologies deserve special attention, as they contribute to the development of students' critical thinking, creativity, and cooperation skills, and help to explain abstract concepts easily. The need to select means of creating digital interactive content based on AR applications has been established, taking into account the various capabilities of educational institutions to provide them with technical and software tools. Based on the results of expert evaluation of the most popular applications, we have established that the Merge Cube software is appropriate for implementation in the educational process today, according to the most important criteria. The technology of using the Merge Cube to create interactive educational content has been disclosed. The significant advantages of this software are: a large library of interactive objects and tasks; playback of video, text, animation, and audio information; the ability to download original 3D models and create collections; integration of Merge Cube with virtual reality glasses. A pedagogical experiment was conducted, which allowed us to ascertain the pedagogical feasibility of using Merge Cube to create interactive educational digital content. The results of the pedagogical study prove that the use of the Merge Cube platform contributes to increasing cognitive interest and ensures the implementation of flexible, personalized, and interactive learning.

Keywords

augmented reality technologies, immersive technologies, interactive content, Merge Cube, educational process

1. Introduction

Modern processes of digital globalization require the implementation and adaptation of digital technologies in all spheres of human activity [1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11]. In turn, digital transformation in society requires the introduction of innovations in the use of digital technologies in the educational process [12, 13, 14, 15, 16, 17]. This will help to increase students' motivation and cognitive interest. The low level of cognitive interest of students leads to their passive participation in educational activities and, as a result, an unsatisfactory level of formation of professional competences, particularly with regard to the use of modern digital tools in professional activities [18].

This problem requires rethinking approaches to creating educational content to develop students' critical thinking, creativity, and independence. Studies show that the use of digital content in the educational process, which is formed based on visual modeling and interactive multimedia content, increases students' activity and improves their creative approach to learning, which allows them to increase their interest in learning material [19, 20, 21]. The use of virtual, augmented and mixed reality technologies contributes to the growth of students' cognitive interest, their motivation and the effectiveness of their educational activities [22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34].

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Thus, there is a pressing need to provide the educational process with interactive digital content based on the use of immersive technologies that can be used in various forms of organizing learning.

Methodological aspects of implementing interactive digital content into educational resources are considered in the research of many scientists from the global community, which is due to the multifaceted nature of this problem, including in the context of the use of AR technologies [35, 36, 37, 38, 39, 40, 41]. According to experts from different countries, the development of such resources as basic from the point of view of smart education should take into account both technological aspects and ethical issues that affect the formation of learning outcomes [42, 43]. Researchers emphasize the need to develop innovative educational resources taking into account the capabilities of immersive technologies for the implementation of interactive content according to the content of the academic discipline [44, 45, 46, 47, 48, 49, 50]. Under such conditions, it is important to analyze the perception of the academic community of the use of these approaches and technologies in the educational process [51, 52, 53]. In particular, noting the advantages and disadvantages of the impact of the implementation of these technologies on the educational process, the researchers argue that their further integration into the educational space is unconditional [54]. This ensures the flexibility of the educational process and compliance of the proposed technologies with modern requirements. First of all, this is due to the fact that the use of interactive tools as educational tools allows increasing the interest of students and improving the learning results [55]. As noted by Tărîţă [56], an interactive approach that combines education and entertainment promotes brain training, is able to stimulate cognitive processes and motivate students.

In this context, augmented reality technologies deserve special attention, which contribute to the active involvement of students through the creation of interactive learning environments [57]. This makes it possible to personalize learning to the individual needs of each student and promotes the development of students' critical thinking, creativity, and collaboration skills, and helps to explain abstract concepts easily [51].

The purpose of the study is to reveal the possibilities of using augmented reality technologies to create interactive educational digital content and to verify the feasibility of their implementation in the educational process.

2. Results of the study

2.1. Augmented reality technologies and their possibilities in education

Augmented reality technologies allow the physical and virtual worlds to be combined with constant user control, enabling immersive and interactive learning [58].

The unique capabilities of augmented reality, such as 3D rendering of virtual information and interaction functions, allow students to develop critical thinking and problem solving skills by conducting original investigations of physical phenomena. With the help of AR, objects and data that are usually absent can be integrated into the real environment, creating educational scenes [59]. Visualization in 3D format makes objects more understandable and exciting to study, allowing interaction with virtual objects that are rarely available in real life.

The use of AR in education improves learning abilities and creates a comfortable learning atmosphere. Thanks to interactivity, AR training programs help to better understand the material through visualization of complex processes and interaction with objects, providing the opportunity to view them from different angles. In addition, the use of AR models eliminates the need to use large stands and other demonstration materials, increasing efficiency and making the educational process interesting and exciting. Thus, AR technology plays a crucial role in creating an interactive hybrid learning environment and developing digital skills.

Thus, the use of augmented reality technologies in the educational process ensures the implementation of:

- creates a sense of reality;

- increases attention and involvement in learning;
- contributes to a better understanding of the material;
- stimulates creative thinking;
- provides flexibility to the educational process;
- provides experience that is difficult to access in real life;
- saves space and time;
- creates a safe environment for learning.

It should be noted that the use of this tool in the educational process does not allow one to completely replace traditional teaching methods that have been used for many years, but it can significantly supplement them.

However, as noted by Kiv et al. [60], when developing methodological support for the use of augmented reality technologies, careful attention is required when choosing software, taking into account the target audience and providing the necessary technical means. It should be borne in mind that different educational institutions have different opportunities to provide technical and software means. This creates inequality of access to modern digital content, which requires solving the problem of selecting appropriate digital means. Therefore, we consider it necessary to determine those means of creating digital interactive content based on AR applications that are most accessible to the educational industry.

2.2. Analysis of the capabilities of AR applications for creating interactive educational content

The scientific literature identifies a number of varieties of augmented reality visualization technologies. We agree with Semerikov et al. [61] who classify AR applications according to the technology of their functioning. Therefore, we have identified the following main types of augmented reality:

- projection AR (technology of user interaction with the projection based on a change in the projection display);
- markerless AR (using GPS, compass, gyroscope, and accelerometer to provide data on the user's basic locations);
- marker AR (scanning a special visual object (QR code, special character, image, logo, etc.) with the gadget's camera).

AR based on layering (full or partial replacement of the original image with a spatial object of augmented reality).

Let's analyse the most popular AR applications that are advisable to integrate into the educational process to create interactive educational digital content. All applications differ in that they are used in different application areas and have different functionalities. Since the goal of our research is to integrate augmented reality technologies into education, we conducted a comparative analysis of software that can be used in the process of studying various disciplines.

Cleto et al. [62], Yildiz [63], Ivanytska et al. [64], Gasmi and Benlamri [65], Voštinár and Ferianc [66] analyzed the capabilities of the most popular AR applications for education, including: ARLOOPA, Panoform, ARitize, Merge Cube, Augment, etc. The ARLOOPA application is primarily intended for visualizing models during the study of natural sciences in the secondary and higher education system. However, the limited content in the free version is a significant disadvantage of this software [63]. The Panoform application is intended for use when studying creative disciplines (art, language) and promotes the development of spatial thinking [64]. However, this software does not allow interactive interaction between participants in the educational process, only viewing AR content. A feature of the ARitize platform for 3D visualization is an online designer [65] for adding AR to websites, educational presentations, and online courses. The disadvantage is that the application is focused mainly on business, and less on classical education. Therefore, many features are available only in the paid version.

The Merge Cube platform is supported by mobile applications Merge Explorer, Object Viewer, HoloGlobe, etc., which "animate" 3D objects on the surface of the AR cube [66]. A functional feature of the platform is collections of interactive content for studying natural processes, technical disciplines, history, architecture, etc. A feature of the platform is the need for a printed Merge Cube model. However, free printable templates are offered for their production [66].

To describe the quality of the software taking into account the most important parameters, based on the ISO/IEC 25002:2024 standard (Systems and software Quality Requirements and Evaluation (SQuaRE) — Quality model overview and usage) [67], a software rating was determined. It is worth noting that the analyzed software uses different content visualization technologies: markerless, marker, and the nesting method.

According to the standard, the software quality model consists of nine characteristics related to their quality properties. Each characteristic is described by several attributes, where for each attribute a set of metrics is defined that allow it to be evaluated. Characteristics and subcharacteristics provide a reference model for the quality of the product to be defined, measured and evaluated.

In the context of this study, the most important criteria were identified:

1. Accessibility.
2. Functionality.
3. Flexibility.
4. Productivity.
5. Modifiability (number of libraries).
6. Cross-platform.
7. Interoperability (availability of virtual classes).

Since the quality criteria have different significance, different coefficients are set for them according to the standard method of expert assessments. Therefore, for determining the availability of software, the evaluation coefficient is 0.5, for functionality, flexibility and cross-platform – 0.7, for performance and modifiability – 1.0, and the possibility of interaction is determined by its presence or absence (+ or –). The overall rating score is equal to the average score for each criterion multiplied by the corresponding coefficient.

A software rating was formed based on the analysis of the most significant quality characteristics of software according to the ISO/IEC 25002:2024 standard, scientific literature, personal experience using AR applications, surveys, and subjective judgments of specialists on the research problem (table 1).

Table 1
Software rating table.

Software name	Software evaluation criteria							Total score
	1	2	3	4	5	6	7	
ARLOOPA	4.5	6.4	7.2	6.6	7.8	4.9	+	37.4 +
Panoform	4.4	6.8	6.7	6.5	8.9	5.0	–	38.3 –
ARitize	4.0	7.6	6.6	7.1	8.5	4.8	–	38.6 –
Merge Cube	4.5	8.7	7.5	8.5	9.6	5.0	+	43.8 +
Augment	4.2	8.1	7.1	6.7	9.1	4.8	–	40.0 –

Thus, based on the results of expert evaluation of the most popular applications, we have determined that Merge Cube software is the most appropriate for integration into the educational process according to the most significant criteria. Therefore, we will analyse in more detail the features of using this technology.

2.3. Technology for reproducing interactive educational content using Merge Cube

The development of cloud-based systems singles out one of the promising areas – the development of digital educational content using augmented reality technology. One of the popular platforms for

implementing augmented reality is Merge Cube, which allows you to display and interact with 3D objects while literally holding them in your hands [68]. The model layering looks like a Cube with unique markers on its surfaces (figure 1) that activate various virtual scenes and objects through applications on a smartphone or tablet.

Figure 1: Merge Cube.

Using Merge Cube allows you to create an interactive learning process in which students can interact with three-dimensional models and virtual objects [69]. This platform offers over 100 different interactive lessons that cover key topics from a range of disciplines. Merge Cube is compatible with Google Classroom and Microsoft Teams learning platforms, making it easier to manage classes and conduct lessons in distance education. It is also worth noting that the content of the Merge Cube active learning platform is aligned with the NGSS standard, which makes it possible to use libraries of teaching aids with augmented reality technology. This makes it popular in educational institutions due to its convenience and interactivity.

The Cube integrates with the cloud-based Merge EDU system (figure 2), which includes a variety of educational applications aimed at studying science, technology, mathematics, and other disciplines. A significant advantage of Merge EDU is a large thematic collection of 3D objects and integration with other similar services. Merge Cube can be used in distance education settings, as most of its applications are compatible with smartphones and tablets, as well as for conducting research in classrooms [69]. With Merge Cube, students can conduct experiments in a virtual environment, avoiding real-world risks.

To view each of the 3D objects, you don't need a separate marker or plugin. All the necessary information is contained on the key image Cube. To visualize the object, the smartphone or tablet camera scans a QR code on each side of the Cube, which allows the application to overlay 3D objects and models on the Cube in augmented reality. The user feels like he is holding various virtual objects in his hands, which can be rotated and explored from all sides (figure 3).

For example in figure 3 shows an example of using the Merge Cube in studying the basics of robotics. In particular, the platform was used to familiarize students with a model of a robotic complex, which allows for a visual representation of the structure and layout of the system.

This augmented reality technology allows not only to visualize 3D objects, but also to play video, text, animation, and audio, which expands the opportunities for students to better absorb educational material. The application also allows students to complete interactive tasks or quests, and solve problems

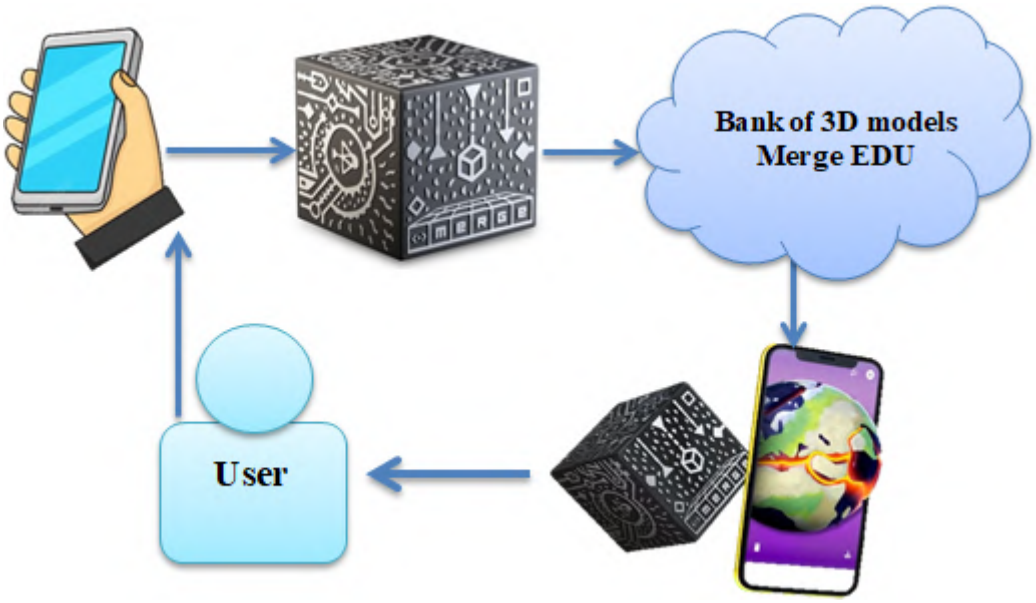

Figure 2: Cloud-oriented Merge EDU system.

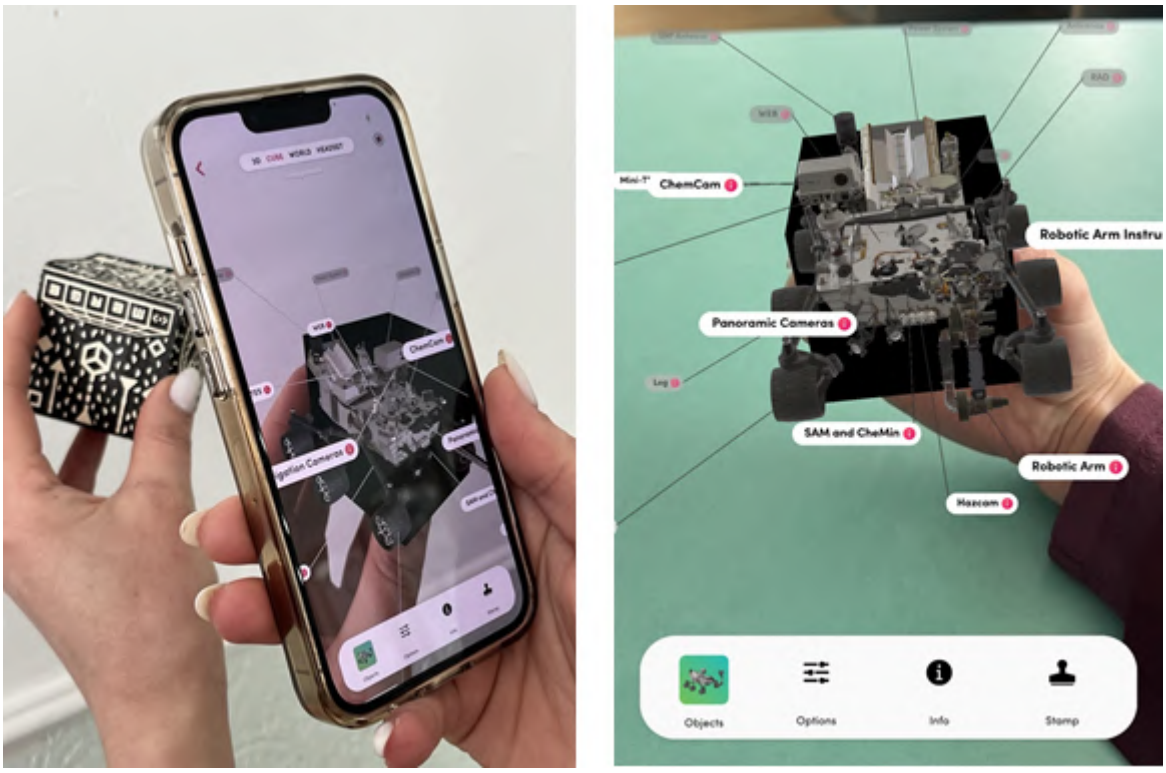

Figure 3: Example of using the Merge Cube application.

related to AR content.

AR content of this technology meets the following criteria:

- virtual additions, correspond to the content of the lesson or the topic being studied;
- sound effects emphasize artistic or other content;
- video fragments demonstrate processes, events or video instructions in content;
- the reproduction of the AR object is simple, intuitive;
- the AR reproduction process is technically stable;

- the font is dynamic (increases or decreases according to the user's needs);
- 3D images are clear;
- different operating systems are supported.

Investigating the capabilities of this technology, it was found that the Merge EDU platform also allows users to upload their own 3D models and create collections (figure 4). that meet the educational needs of students, the specific requirements of an academic discipline or a separate project. Uploading your own models allows you to combine standard content with individual developments. This is especially important for specialized disciplines that require detailing, understanding of physical processes, principles of operation of individual mechanisms, etc. Using your own 3D models in Merge EDU allows you to integrate the latest innovations in AR/VR technologies into the educational process, making it more dynamic and relevant. This allows you to integrate materials that are most consistent with the course content and its objectives, and therefore opens up new prospects for personalizing the educational process and a creative approach to learning.

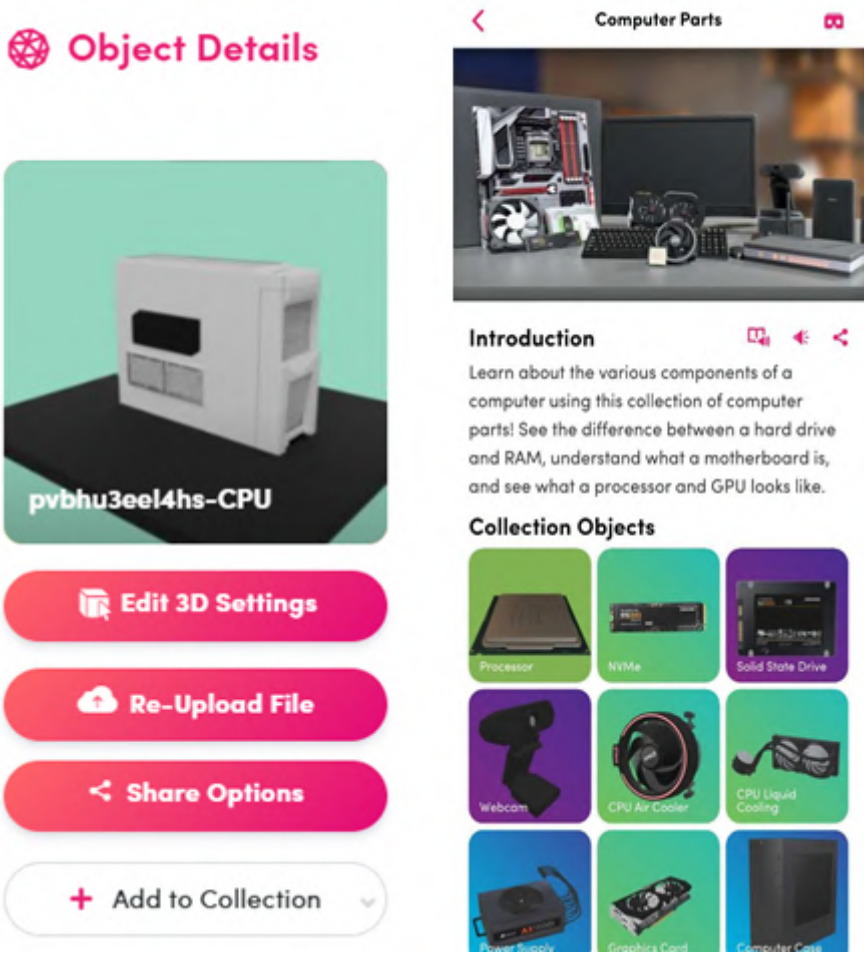

Figure 4: Uploading your own 3D model and creating a collection PC Building.

Another significant advantage of this development is the possibility of using Merge Cube in combination with virtual reality glasses (figure 5 a). To do this, you need to connect a special headset, in which the application scans the surface of the Cube and images are projected through the lenses of the headset. Thus, it also allows you to use another type of immersive technology – mixed reality.

The user, while wearing the headset, can still see the real environment around the Cube. The Cube itself is visualized by various 3D objects. Due to the fact that the objects are visualized against the background of the real world, they look realistic (figure 5 b).

Figure 5 shows an example of using Merge Cube in combination with virtual reality glasses, which

a b

Figure 5: Integration of Merge Cube with virtual reality glasses.

allows to demonstrate the process of operation of a hydraulic turbine in dynamics. This provides the opportunity to visually represent physical and technological processes when studying technical disciplines.

Therefore, Merge Cube makes it possible to use this technology to update basic knowledge, conduct laboratory and practical work, during independent or individual work, use it as a reference interactive summary of basic concepts and terms, as well as to test students' knowledge.

2.4. Analysis of the results of the pedagogical experiment

During the study of the problem of using augmented reality technologies to create interactive educational digital content, a pedagogical experiment was conducted. To allow students to study various educational materials on the operation of individual technical mechanisms, physical processes, the architecture of personal computers, the construction of working nodes of robotic systems, etc., we used the capabilities of Merge Cube to visualize complex educational materials. The pedagogical experiment was conducted at the Ternopil Volodymyr Hnatiuk National Pedagogical University in the process of training students of the specialty 015 Professional Education with a specialization in Digital Technologies. The Merge Cube platform was tested within the following academic disciplines: "Personal Computer Architecture", "Fundamentals of Robotics", "PC Repair and Modernization", "Digital Technologies and Learning Tools". The study lasted for one academic year, which involved 146 students of different years of study and 8 qualified teachers.

After the pedagogical experiment, an online survey was conducted using Google Forms. The questionnaire included questions that allow for a comprehensive assessment of the pedagogical feasibility of using the application, as well as the level of student satisfaction with the use of Merge Cube in the educational process.

Having analyzed the results of the questionnaire, we can state that the respondents are motivated to implement innovative technologies for creating interactive digital content (figure 6). The survey also confirmed the intensification of students' educational activities through interactive tasks. The convenience of the application, its visual appeal and the usefulness of the content made it possible to state the pedagogical feasibility of using augmented reality technologies in education, in particular the use of Merge Cube.

The intuitive interface, the simplicity of Merge Cube and its compatibility with various devices (smartphones, VR glasses) contribute to the convenient use of applications by students of various

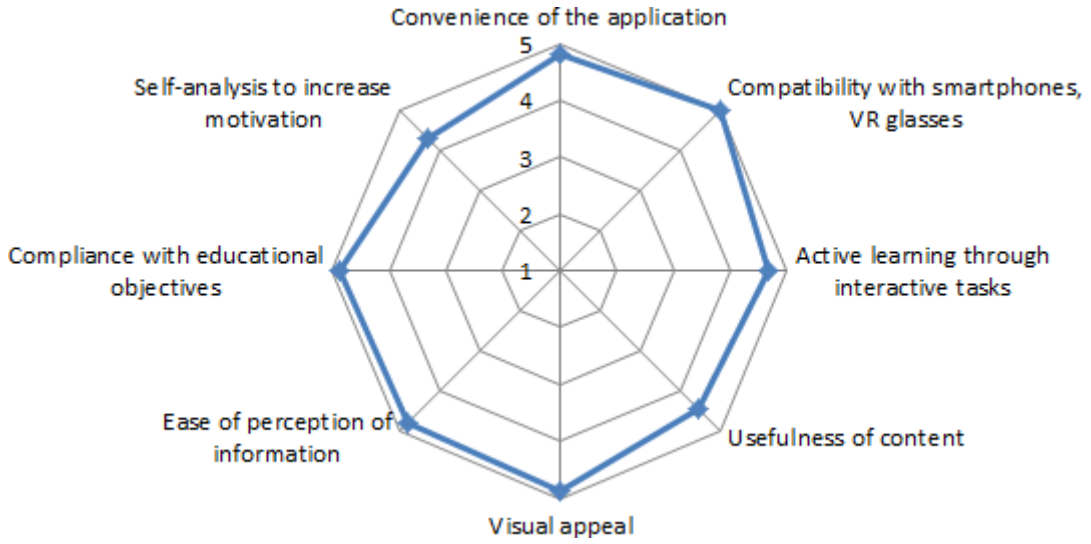

Figure 6: Level of student satisfaction with the use of Merge Cube.

specialties (technical, humanitarian, natural sciences, etc.) and age groups.

It should also be noted the high level of user interaction with 3D models and the ability to use interactive tasks for the active participation of students in the educational process. Therefore, we conclude that the use of augmented reality technologies helps to stimulate creative activity and independent search for knowledge by students.

Also among the questions of the questionnaire was an open question on the analysis of the general impressions of each student after using the Merge Cube augmented reality in education. Based on the results of short answers, a "word cloud" was formed, which allows to understand the key impressions of the respondents (figure 7).

Figure 7: Key impressions of respondents (in the original language).

Analysis of the survey results made it possible to state that students are interested in using the latest learning tools that allow them to develop spatial thinking, design skills, and understanding of processes. Students noted that using the Merge Cube platform provides conditions for flexible, personalized, and interactive learning, and also contributes to a deeper understanding and assimilation of the material.

3. Conclusions and discussions

In the context of digitalization of the educational space, mass technologization of the pedagogical process, AR technologies are an innovative tool that has great potential for: updating basic knowledge, conducting laboratory and practical work, organizing independent or individual work, developing interactive summaries of basic concepts and terms, testing students' knowledge. Analysis of the experience of using AR technologies indicates the need for further methodological developments in this direction to increase student motivation and the professional level of teachers [51, 52, 53].

As a basic software tool for implementing AR technologies, we selected Merge Cube as the most appropriate for implementation in the educational process. The choice was justified on the basis of the defined software quality criteria according to the ISO/IEC 25002:2024 standard based on the results of expert analysis among the most popular AR applications.

The technology of reproducing interactive educational content by layering an object on Merge Cube is disclosed, which has a number of advantages that contribute to improving the visibility of educational materials. The described capabilities and examples can be used in the development of didactic interactive tasks that can provide a deeper understanding and assimilation of educational material.

We conducted a survey among future professionals of vocational education on the basis of a pedagogical university. The survey shows that the proposed AR application allows you to create exciting, visual and accessible interactive educational content. In addition, the use of the Merge Cube platform in the implementation of teaching methods allows you to increase student motivation and also meets the requirements of flexible, personalized and interactive learning. The survey showed that students are interested in using the latest learning tools that give them the opportunity to develop spatial thinking, design skills, and understanding of technological processes.

Considering the need and interest of students in an innovative approach to learning, which also includes the introduction of augmented reality technologies to create interactive digital content, we see prospects for further research in the creation of methodological materials for teachers, taking into account the specifics of professional training, as well as the organization and conduct of relevant training seminars.

Declaration on Generative AI

The authors have not employed any generative AI tools.

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