DIDACTIC POTENTIAL OF AUGMENTED AND VIRTUAL REALITY TECHNOLOGIES IN TEACHING TECHNICAL DISCIPLINES

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Annotation: The article analyses the didactic potential of augmented reality (AR) and virtual reality (VR) technologies as means of visualization in the teaching of technical disciplines. On the basis of systematic reviews of international research, the main advantages of these technologies are summarised, including the visualization of invisible processes, the development of spatial abilities and increased learning motivation, together with the challenges associated with usability, cognitive overload, cost and teacher preparedness. The relationship between virtual and physical laboratories is examined, and safety issues are considered. A staged model for integrating AR and VR into the educational process of higher education institutions of Uzbekistan is proposed in the context of the "Digital Uzbekistan – 2030" strategy.

Keywords: augmented reality, virtual reality, virtual laboratory, technical disciplines, visualization, spatial abilities, digital transformation, TPACK.

The digital transformation of the economy and society sets new requirements for the training of engineers, who will work with digital twins, computer-aided design systems and automated production lines. The "Digital Uzbekistan – 2030" strategy defines the development of digital infrastructure and the wide introduction of information technologies in education as strategic directions of state policy [1]. Higher technical education must respond to these requirements not only by teaching digital technologies as a subject, but also by using them as didactic tools. Among such tools, augmented and virtual reality occupy a special place, since they offer new forms of visualization that go beyond the possibilities of a printed drawing, a slide or even a computer animation displayed on a flat screen.

Augmented reality is usually understood as a technology that superimposes computer-generated virtual objects on the user's view of the real environment in real time, so that real and virtual elements coexist and can be interacted with. Virtual reality, by contrast, places the user in a fully computer-generated environment, which in its immersive form is experienced through a head-mounted display and tracking of the user's movements. In the review by Wu and colleagues it is emphasised that AR should be considered as a concept rather than a particular type of device, and that its educational value lies in affordances such as the presentation of learning content in three-dimensional perspectives, the visualization of invisible concepts and events, and the connection of formal and informal learning [2]. This conceptual view is important for technical education: the question is not which headset to buy, but which learning difficulties can be overcome through the joint presentation of real and virtual information.

The content of technical disciplines provides numerous situations in which such joint presentation is useful. In the course of machine elements, a student can direct the camera of a tablet at a real gearbox or at a printed assembly drawing and see a virtual exploded view of the shafts, bearings and gears, with labels indicating their names, materials and functions. In engineering graphics, an AR marker placed on a worksheet can generate a three-dimensional model of the part shown in orthographic projections, allowing the student to rotate it and compare its views with the projections on paper. In electrical engineering, an overlay on a laboratory stand can display the direction and magnitude of currents in the branches of a real circuit, making visible what is normally available only as instrument readings. In strength of materials, a virtual stress field can be superimposed on a specimen in a testing machine, linking the abstract concept of stress distribution with a physical object. In all these cases AR acts as a bridge between the concrete object and its abstract model.

Virtual reality opens other possibilities. Immersive environments allow students to enter spaces that are inaccessible, dangerous or too expensive to reproduce: the interior of a power substation, the engine room of a ship, an operating boiler of a thermal power plant or the workspace of an industrial robot. The systematic review by Radianti and co-authors shows that immersive VR applications in higher education have been developed in a wide range of domains, with engineering among those most frequently represented, and that they are used for purposes such as procedural and practical knowledge, declarative knowledge and the analysis of complex systems [3]. At the same time the authors note that many applications are not explicitly grounded in learning theories and that their evaluation often focuses on usability rather than on learning outcomes [3]. This observation is significant for the didactics of technical disciplines: the technical sophistication of a VR environment does not by itself ensure its pedagogical effectiveness.

A central issue in the use of these technologies is the relationship between virtual and physical laboratories. Laboratory work has always been an essential component of engineering training, yet physical laboratories require expensive equipment, consumables and safety measures, and the number of workstations is limited. Virtual laboratories remove many of these constraints. De Jong, Linn and Zacharia, analysing research in science and engineering education, argue that virtual and physical laboratories have distinct affordances and that the choice between them should depend on the learning objectives [4]. Virtual laboratories can simplify reality, make unobservable phenomena visible, and allow a large number of experiments to be performed quickly, while physical laboratories develop practical skills of handling real equipment and confront students with measurement errors and the imperfections of real materials. The authors conclude that the two forms can be combined to complement each other [4]. For teaching technical disciplines this means that a VR laboratory should not replace, for example, a real tensile test, but can precede it as

preparation, during which students rehearse the procedure, or follow it as an extension, during which they vary parameters that cannot be changed in the physical setup.

The advantages of AR identified in the research literature are substantial. The systematic review by Akçayır and Akçayır groups the reported advantages into categories related to learner outcomes, pedagogical contributions and interaction; among them are enhanced learning achievement, increased motivation and positive attitudes, improved understanding of content and support for spatial abilities [5]. The last point is particularly relevant to engineering, where spatial visualization is a prerequisite for success in engineering graphics, mechanics and design. Sorby's research has demonstrated that spatial skills of engineering students can be developed through targeted training and that such development is associated with improved success and retention in engineering programmes [6]. AR and VR, which enable direct manipulation of three-dimensional models, create favourable conditions for such training, provided that tasks are designed to require mental operations rather than passive observation.

The same reviews draw attention to significant challenges. Akçayır and Akçayır report that AR applications may be difficult for students to use, that technical problems occur, and that some studies indicate cognitive overload [5]. Wu and colleagues likewise point out that the large amount of information, multiple technological devices and complex tasks in AR environments can overload learners, and that the pedagogical design of AR activities requires careful attention [2]. For technical disciplines, where the content itself already imposes a high intrinsic load, this risk is serious: a student who struggles to keep an AR marker in the camera's field of view or to navigate a VR menu has fewer resources left for understanding the kinematics of a mechanism.

Safety and health considerations constitute another group of challenges. Prolonged use of head-mounted displays can cause discomfort, fatigue or symptoms of simulator sickness in some users, and immersion reduces awareness of the physical

environment. Therefore, VR sessions should be limited in duration, conducted in a cleared area and accompanied by instructions on what to do in case of discomfort. Paradoxically, VR also contributes to safety: training in a virtual electrical installation or at a virtual lathe allows students to make and analyse errors that would be dangerous in reality. Issues of data protection must also be taken into account, since many applications collect information about users' actions.

Economic factors are equally important. Although mobile AR applications can run on students' own smartphones, high-quality immersive VR requires headsets, sufficiently powerful computers and licensed software, as well as the development or adaptation of content in the language of instruction. For many higher education institutions the most realistic path is a combination of low-cost mobile AR for mass use and a limited number of VR workstations organised as a shared laboratory.

The decisive factor, however, is the readiness of teachers. The TPACK framework proposed by Mishra and Koehler shows that effective use of technology in teaching requires not separate knowledge of technology, pedagogy and content, but an integrated understanding of how a specific technology can represent specific content and support specific pedagogical approaches [7]. A teacher of theoretical mechanics who knows how to operate a VR headset but does not understand which concepts of the course are most difficult for students to visualize will not be able to use it meaningfully. Consequently, professional development programmes for teachers of technical disciplines should combine technical training with methodological workshops on the design of AR and VR learning activities, building on the national experience of introducing innovative educational technologies [8].

Taking into account the above, a staged model for integrating AR and VR into the teaching of technical disciplines in higher education institutions of Uzbekistan can be proposed. The first stage is diagnostic: teachers of each department identify topics where students systematically experience difficulties connected with spatial

imagination or with invisible processes, such as the stress state of a body, the magnetic field of an electrical machine or the operation of an assembly. The second stage involves selecting the technology that corresponds to the identified difficulty: mobile AR for linking drawings and real objects, desktop simulations for parametric exploration, and immersive VR only for situations where presence and scale are essential. The third stage consists of methodological design, in which each AR or VR episode is embedded into a lesson with a clear objective, preparatory explanation, tasks requiring active manipulation and a subsequent discussion. The fourth stage is the organisation of infrastructure and teacher training, including shared VR laboratories and the creation of content in Uzbek. The fifth stage is evaluation, in which the effects of the technology on learning outcomes, motivation and spatial abilities are examined by means of appropriate pedagogical research rather than assumed in advance.

In conclusion, augmented and virtual reality possess considerable didactic potential for teaching technical disciplines, primarily as tools for visualizing three-dimensional structures and invisible processes, for safe rehearsal of laboratory and production procedures, and for developing spatial abilities. At the same time, international reviews warn against technological enthusiasm that is not supported by pedagogical design. The realisation of this potential in Uzbek higher education, within the framework of the “Digital Uzbekistan – 2030” strategy, depends on a balanced combination of virtual and physical laboratory work, on attention to cognitive load, safety and cost, and above all on the preparation of teachers capable of integrating these technologies with the content of their disciplines.

FOYDALANILGAN ADABIYOTLAR RO‘YXATI

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