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THE ROLE OF "VR", "AR", "MR", AND "3D" TECHNOLOGIES IN PREPARING CHEMISTRY TEACHERS FOR INTERNATIONAL TALIS STUDIES

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Abstract

This article examines the role of VR (Virtual Reality), AR (Augmented Reality), MR (Mixed Reality), and 3D technologies in preparing chemistry teachers for participation in international TALIS (Teaching and Learning International Survey) studies. The research highlights the importance of integrating immersive and interactive digital technologies into chemistry teacher professional development to enhance pedagogical competence, digital literacy, and innovative teaching practices. Particular attention is paid to the potential of VR, AR, MR, and 3D technologies to support visualization of abstract chemical concepts, virtual laboratory experiments, and simulation-based learning environments. The article argues that the systematic use of these technologies contributes to the development of teachers' reflective practice, classroom management skills, and readiness for international assessment frameworks such as TALIS. The findings emphasize that technology-enhanced training not only improves the quality of chemistry education but also aligns national teacher preparation systems with global educational standards and trends.

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Keywords: Chemistry teachers, TALIS international study, virtual reality (VR), augmented reality (AR), mixed reality (MR), 3D technologies, digital competence, innovative pedagogy, professional development.

Introduction

President Shavkat Mirziyoyev has emphasized that the interim objectives of the idea of the Third Renaissance in our country should be clearly defined. In particular, it is necessary to determine what level of gross domestic product per capita Uzbekistan is expected to achieve by 2030 and 2040–2050, and approximately what positions the country will reach in global rankings. Clear benchmarks must also be set for the achievements to be attained in the fields of education, culture, and science. Only in this case will the mobilizing impact of this idea be concrete and strong.

However, these targets should not be illusory or based solely on abstract numerical indicators. Tasks related to the development of new information and communication technologies, nanotechnologies, biotechnologies, artificial intelligence, and similar advanced areas should not be overlooked. Any great plans and great ideas acquire real meaning and practical value only when they are directly connected with human needs, the improvement of living standards, the expansion of freedoms, and spiritual development. Otherwise, they risk remaining nothing more than unrealistic aspirations.

Taking these considerations into account, the widespread use of information and communication technologies (ICT) in today's education and training process has become a global trend in world development. At present, the creation of an interactive learning environment, the improvement of innovative methods and technologies aimed at developing students' thinking and worldview, and the enhancement of education through electronic textbooks and resources, educational software, automated knowledge assessment systems, and training simulators, supported by interactive software tools, are recognized as urgent and important tasks.

In chemistry education at the general secondary school level, students' understanding of matter and substances, the periodic system of elements, chemical formulas, and atomic–molecular concepts remain limited. One of the

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main reasons for this is the absence of probabilistic and statistical representations in existing electronic educational programs. In practice, when studying atomic–molecular theory within the school chemistry curriculum, dynamic visualizations play not only an introductory but a central role. They are crucial for shaping students' scientific worldview, enabling the observation and analysis of molecular phenomena and processes that cannot be perceived directly by the human eye.

Nevertheless, the effective use of new innovative software technologies in teaching chemistry can, to a certain extent, address the above-mentioned problem. Currently, in foreign education systems, talented young specialists and research scientists have developed and implemented new types of VR (Virtual Reality), AR (Augmented Reality), and MR (Mixed Reality) software related to subject-specific topics and integrated them into the teaching process. In contrast, in our educational practice, instruction is still largely limited to the use of electronic manuals, slides, multimedia, and animations. This indicates that the level of effectiveness envisioned for the development of the education system has not yet been fully achieved [1].

We should no longer limit the teaching–learning process to the use of slides, multimedia materials, videos, and animations alone. Instead, by integrating new technologies such as VR (Virtual Reality) [Figure 1], AR (Augmented Reality), MR (Mixed Reality), and 3D technologies, it becomes possible to enhance the formation and acquisition of students' chemical knowledge through dynamic visual representations. These technologies enable learners to study processes that cannot be directly observed with the naked eye—such as the motion of microparticles—thereby fostering a higher level of independent and analytical thinking.

Furthermore, the development and application of relevant software tools contribute to the advancement of the teaching process, the establishment of collaborative partnerships with foreign educators and qualified researchers, and the exchange of professional experience. When innovative and pedagogical technologies are applied in an integrated manner in education, students gain the opportunity not only to hear and see, but also to form independent mental representations based on what they observe, which significantly enhances the effectiveness of learning.

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Figure 1. The use of virtual reality in forming students' conceptual understanding of molecules in chemistry.

Further improving the continuous education system, expanding access to high-quality educational services, and consistently pursuing a policy of training highly qualified specialists in line with the modern demands of the labor market are among the key priorities of today. A fundamental improvement in the quality of general secondary education, the in-depth study of foreign languages, informatics, as well as other highly demanded core subjects such as mathematics, physics, chemistry, and biology, and the introduction of international standards for assessing the quality of education and teaching are essential for enhancing the effectiveness and efficiency of general secondary education institutions.

At the same time, stimulating research and innovation activities, creating effective mechanisms for transferring scientific and innovative achievements into practice, and establishing specialized scientific and experimental laboratories, high-technology centers, and technoparks under higher education institutions and research institutes constitute one of the main tasks aimed at the development of the education and science sectors in the current context.

The establishment of a modern education system is closely linked to the integration of achievements in information technologies into the teaching–learning process. This is particularly relevant to new forms and tools of instruction based on information and telecommunication technologies. Therefore, today it is not sufficient to train prospective teachers merely to use ready-made electronic learning materials; rather, it is equally important to teach them the

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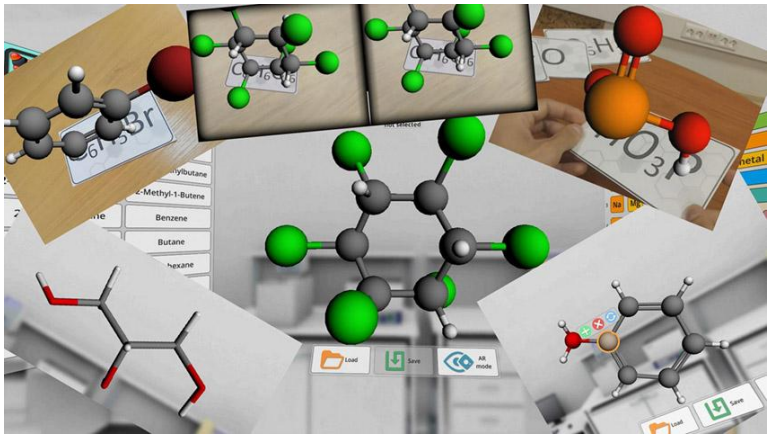
methods, approaches, and tools for using and developing innovative technologies in new formats.

A contemporary teacher should be a well-rounded professional, a master of their subject, capable of working in harmony with the demands of the time, familiar with modern teaching methods, continuously improving their knowledge and skills, proficient in the use of innovative technologies, and open to collaboration with qualified foreign educators. One of the key directions in improving educational content is the creation of favorable conditions for the development and expansion of educational and information resources, which serve as essential tools for students' independent learning.

Scientific research indicates that, in general secondary school chemistry education, students' understanding of matter and substances and atomic–molecular concepts remain insufficient. One of the main reasons for this is the absence of probabilistic and statistical representations in existing electronic educational programs.



At the same time, in foreign education systems, new types of educational software, such as 3D, VR (Virtual Reality), AR (Augmented Reality), and MR (Mixed Reality) applications, developed by talented young specialists and research scientists, are being actively created and integrated into the teaching process across subject-specific domains.

After that, a rapid question-and-answer activity was conducted in which each student was asked to identify which chemical element corresponded to the formula on the card, its position in the periodic table, and its atomic mass. Subsequently, through AR technology, students were instructed to bring the

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various markers in their hands in front of the camera of a specially installed smartphone—"General Mobile," manufactured in Uzbekistan. It was explained that the images of the elements encoded in these markers would be transformed into live 3D visualizations via the camera, activating their spatial representations. As a result, it was observed that the majority of students demonstrated an increased interest in chemistry. Their understanding of the spatial structure of elements, the movement of nuclei and electrons, and the distribution of electrons across energy levels was significantly enriched.

Sources devoted to studying the effectiveness of using VR (Virtual Reality), AR (Augmented Reality), and MR (Mixed Reality) technologies in teaching the school chemistry curriculum are increasingly being developed in the form of 3D objects. In particular, when teaching the topic "Atomic–Molecular Theory," the application of VR, AR, and MR technologies to visualize the planetary models of elements in the periodic table during lessons [4, pp. 174–178]:

- significantly increases students' interest in chemistry;
- gradually familiarizes learners with the use of the latest information and communication technologies (ICT);
- helps form accurate conceptual understandings of chemical substances, their structure, and properties through the application of new ICT tools;
- promotes the scientific organization of instructional labor in chemistry teaching by enabling the acquisition of large amounts of information within a short time span.

In this regard, mobile applications developed abroad—such as *RAPP Chemistry* by Creating Ware and *Chemistry VR – Cardboard* by ARLOOPA Inc—can be cited as illustrative examples. The *RAPP Chemistry* application enables users to view interactive 3D models of each element in the periodic table using AR technology. *Chemistry VR – Cardboard* is designed as a game-based learning environment created on the basis of VR technology. Its main objective is to require students to search for elements hidden in virtual rooms and place them into designated slots displayed on the screen in order to construct substances such as water, salt, and other compounds [2, pp. 516–523].

These technologies may appear similar at first glance; however, their functional capabilities differ significantly. VR (Virtual Reality) is a technology in which a

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user enters a fully immersive virtual environment through special devices such as VR headsets or helmets. In this mode, the user is completely isolated from the real world and cannot see what is happening in the surrounding physical environment. As a result, the individual experiences a strong sense of presence, feeling as if they have been transferred into an entirely different reality.

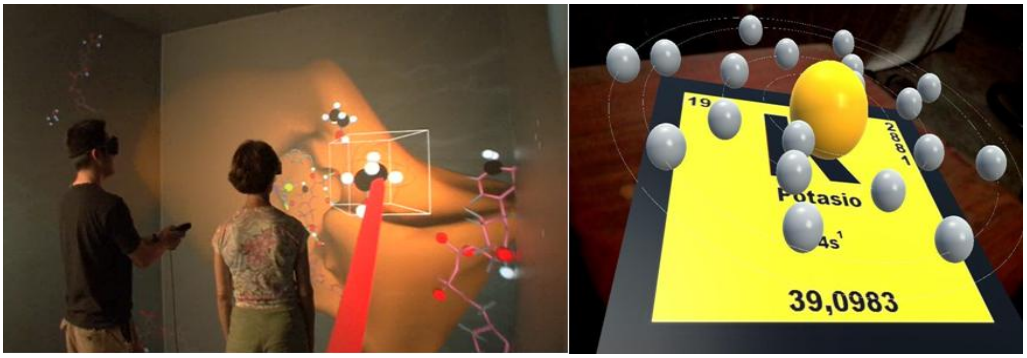

Figure 2. Immersion in a virtual environment using Virtual Reality (VR) technology

We also focus specifically on the application of virtualization in chemistry education. In order to demonstrate the importance of chemistry in human life, it should be noted that, compared to many other disciplines, chemistry is considered a relatively complex subject to master. However, the integration of 3D technologies into the learning process significantly facilitates the comprehension of chemical concepts.

The study begins with learning the periodic table of chemical elements, for which a "Virtual Journey into the World of Elements" is organized [6, pp. 180–189]. When a specially developed software application is installed onto the periodic table created by us, the elements become animated and, through audio-visual narration, provide information about their significance, applications in everyday life, and the areas of human activity in which they are used.

This environment is created on the basis of the real-world context and is characterized by the coexistence of real and virtual objects. In this case, virtual objects appear visually identical to real ones, leading users to perceive them as actual physical entities. Examples include a virtual painting hanging on a wall, a virtual sofa, or a furnished empty room. The essence of this technology lies in

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ensuring that virtual objects are perceived as realistically as possible, to the extent that they are accepted by users as real.

Figure 3. *A virtual journey into the periodic table using 3D and virtual technologies in chemistry education.*

In conclusion, it should be emphasized that in teaching the school chemistry curriculum—particularly the topics "Atomic–Molecular Theory and the Reality (Existence) of Atoms and Molecules" and "The Periodic Law and the Periodic Table of Chemical Elements"—educational effectiveness can be significantly enhanced if the following conditions are met:

- a teaching methodology based on the use of new 3D, VR, AR, and MR technologies is developed;
- new Uzbek-language applications and software are created specifically for these technologies;
- the teaching process is integrated with VR, AR, and MR technologies alongside conventional computer-based instruction;
- a methodology for the use of electronic educational tools in teaching certain topics of the school chemistry curriculum is designed;

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- furthermore, if "innovative technology classrooms" are established in general education schools and equipped with VR, AR, and MR technologies, allowing not only chemistry but also selected topics in biology, geography, and physics to be taught in such environments, the overall effectiveness of education will increase substantially.

3D Studio MAX represents a new stage in three-dimensional modeling and visual demonstration (visualization). Using this software, it is possible to create high-quality animations and three-dimensional models at a professional level. The program supports both two-dimensional and three-dimensional objects, enabling rich and realistic visual representations for educational purposes. The software is developed by Autodesk.

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