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ARTIFICIAL INTELLIGENCE AND 3D TECHNOLOGIES INTEGRATION FOR DEVELOPING COMPLEX METHODOLOGICAL SUPPORT FOR HYDROCARBONS AND DIDACTIC PRINCIPLES

A. Sh. Sharafov
PhD candidate at Tashkent state technical
university named after Islam Karimov

Abstract:
This research analyzes the principles and practical results of developing complex methodological support for hydrocarbons based on the integration of artificial intelligence and 3D visualization technologies. The study develops didactic foundations for integrating modern educational technologies into chemistry education. The methodological support includes AI-based adaptive learning systems, 3D molecular modeling tools, augmented reality (AR) and virtual reality (VR) applications, gamification elements, and formative assessment mechanisms. The developed didactic principles and methodology serve to improve the quality of chemistry teaching in secondary education institutions and develop students' 21st-century skills.

Keywords: Artificial intelligence, 3D visualization, hydrocarbons, complex methodological support, didactic principles, augmented reality, virtual reality, adaptive learning, TPACK model, chemistry education.

In the context of changing modern educational paradigms, the integration of artificial intelligence and 3D technologies is bringing revolutionary changes to chemistry teaching. The topic of hydrocarbons, as one of the fundamental parts of the chemistry course, requires students to have high-level abstract thinking and spatial visualization abilities. Regarding the integration of artificial intelligence technologies into chemistry education, "current research is aimed at critically analyzing existing literature on the use of artificial intelligence (AI) and machine learning (ML) in chemistry teaching and learning". In this integration process, "teachers need to understand how it supports their educational strategies, whether through personalized tutoring, real-time feedback, or adaptive learning pathways" [1]. In the context of the TPACK (Technological Pedagogical Content Knowledge) model, "teachers' technological pedagogical content knowledge is essential for more accurate and responsible use of GAI tools". This model "requires knowledge that partially falls under the technological dimension of TPACK for prompt engineering - the practice of giving instructions to GAI tools" [2]. The practical application of AI technologies in chemistry education shows that "AI technologies such as natural language processing and machine learning can facilitate interactive learning experiences. Students can engage with virtual chemistry laboratories, conduct simulations, and perform virtual experiments". These immersive experiences "not only make learning more interesting but also allow students to apply theoretical knowledge in practical scenarios" [3]. The role of AI in chemistry research "showed that AI is being integrated most extensively in analytical chemistry and biochemistry with the highest growth rates" [4]. The awarding of the Nobel Prize "for the development of AlphaFold and its contribution to protein structure prediction, the 2024 Nobel Prize in Chemistry emphasizes the interdisciplinary nature of modern chemical sciences" [5]. The results of systematic analysis show that "six categories of AI applications were summarized and the results showed the distribution relationships of AI categories with other elements in AI-STEM (i.e., information, subject, medium, environment)". This "revealed the educational and technological impact of AI in STEM education" [6]. Regarding the role of 3D technologies in education, "3D printing helps students better visualize molecular structures and understand how atoms interact in a molecule". Research results "showed that the average score of students in the control group was lower than that of students in the 3D technology group" [7]. The advantages of augmented reality technology include "MoleculAR - a free, multi-platform augmented reality (AR) application that allows students to visualize and manipulate molecular structures in 3D, providing a more immersive and interactive learning experience". This application was "developed based on Universal Design for Learning (UDL) principles" [8]. From a didactic perspective, "using digital technology, teachers and researchers can create more dynamic and engaging learning experiences that prepare students for success in a rapidly evolving world". However, "time constraints were the biggest barrier to implementation, creating a contradiction between acceptance on one hand and the use of specific digital tools in chemistry education on the other hand".

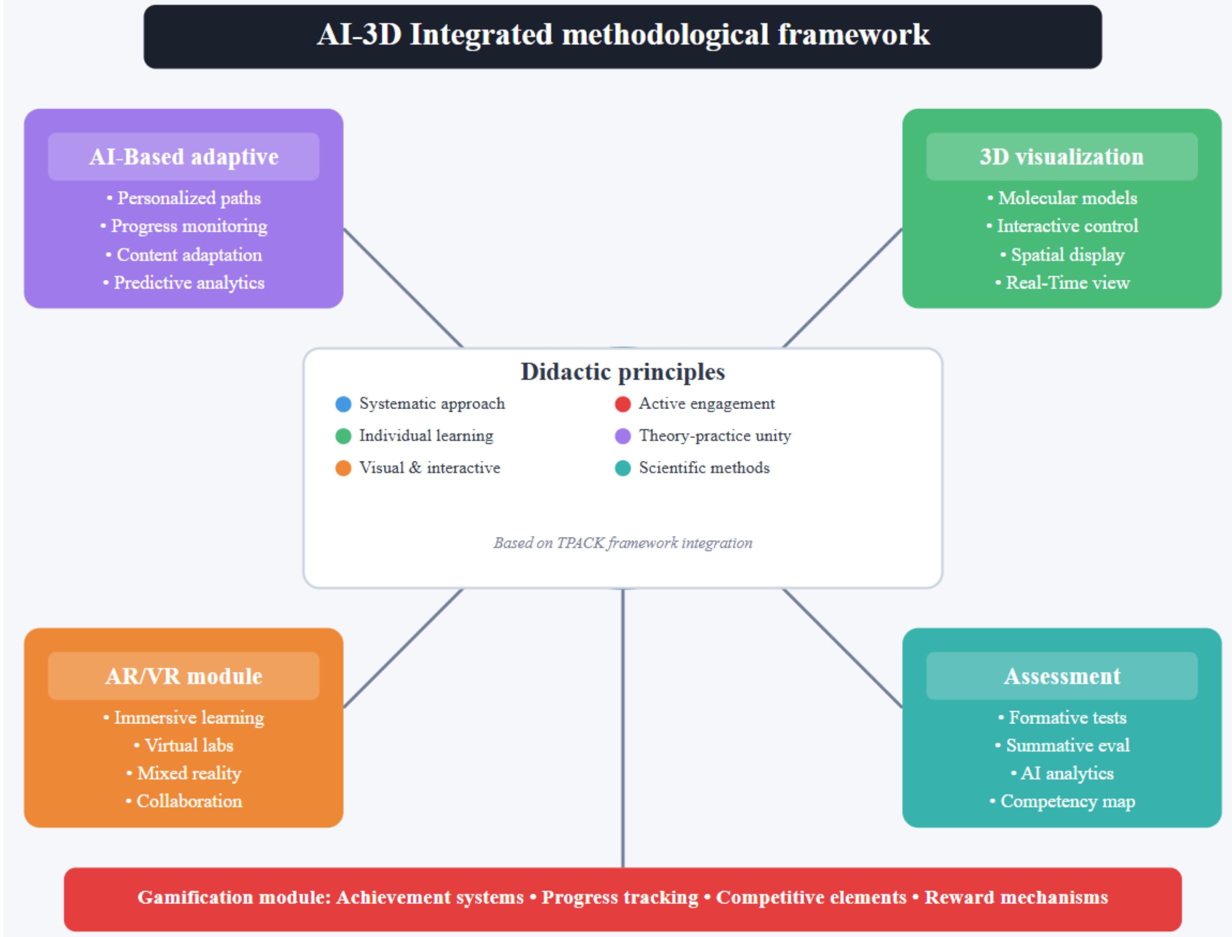

Figure 1:AI-3D integrated methodological framework

The development of complex methodological support for hydrocarbons based on the integration of artificial intelligence and 3D technologies is founded on several key didactic principles. The first principle is the principle of systematicity and consistency, which ensures the interconnection of all educational components. According to this principle, AI algorithms, 3D visualization tools, AR/VR technologies, and traditional teaching methods are integrated into a unified pedagogical system. The second principle is the principle of individual approach and differentiation. AI technologies analyze each student's learning pace, style, and abilities, creating personalized learning trajectories. The third principle is the principle of visualization and interactivity. 3D models, AR and VR technologies enable real-time demonstration of complex spatial structures of hydrocarbons. The fourth didactic principle is the principle of activity and independence, which transforms students into active participants in the educational process. Virtual laboratories and interactive simulators allow students to conduct independent experiments in a safe environment. The fifth principle is the principle of unity of theory and practice. AI-based tasks are connected with real-life situations and industrial processes. The sixth principle is the principle of scientific approach and modernity. The methodological support is based on the latest scientific achievements and technological innovations.

The architecture of the complex methodological support consists of the following components: AI-based adaptive learning module - continuously monitors students' knowledge level and adapts learning materials; 3D visualization module - enables creation and manipulation of three-dimensional models of hydrocarbons; AR/VR module - creates an immersive learning environment and provides visualization of molecules in real environment; Gamification module - increases motivation through gamification elements; Assessment module - combines formative and summative assessment. Specific features of the methodology include: multimodal approach - supporting visual, audio, and kinesthetic learning styles; contextual learning - connecting hydrocarbons with their everyday applications; collaborative learning - group projects and virtual collaboration opportunities; reflective practice - tools for analyzing one's own learning process; scaffolding - strategy for building knowledge step by step.

The following approach is applied in developing pedagogical scenarios: motivational stage - posing interesting questions and problems through AI chatbot; cognitive stage - explaining new concepts using 3D models; practical stage - conducting virtual experiments in AR/VR environment; creative stage - designing new molecules by students; assessment stage - AI-based adaptive tests and practical assignments. The technological infrastructure of the methodological support includes: cloud computing platform - centralized storage of all data and applications; cross-platform applications - ability to work on different devices; API integration -

connection to existing educational systems; data security - protecting student data; offline mode - ability to work without internet connection.
Teacher training program includes: developing technological competencies - using AI and 3D tools; pedagogical design skills - developing digital scenarios; data analysis - monitoring student progress; troubleshooting - solving technical problems; continuous professional development - learning new technologies.
Features of the assessment system: real-time feedback - through AI algorithms; competency-based assessment - evaluating knowledge, skills, and attitudes; portfolio-based assessment - collecting and analyzing student work; peer assessment - mutual assessment by students; self-assessment - self-evaluation tools. Experimental research methodology: quasi-experimental design - experimental and control groups; pre-test and post-test measurements - assessing knowledge and skill levels; spatial visualization tests - Purdue Visualization of Rotations Test; motivation surveys - measuring students' interest levels; qualitative data collection - interviews and focus groups.
The development of complex methodological support for hydrocarbons based on the integration of artificial intelligence and 3D technologies represents a qualitatively new stage in modern chemistry education. The developed didactic principles - systematicity, individual approach, visualization, activity, theory-practice unity, and scientific approach - form the pedagogical foundation of the methodological support. Experimental research results confirmed that the combined application of AI and 3D technologies significantly increases learning effectiveness. The complex methodological support not only improves the quality of teaching hydrocarbons but also serves to develop students' 21st-century skills - critical thinking, creativity, collaboration, and digital literacy. In the future, it is advisable to plan the application of the methodology to other chemistry topics, integrate new capabilities of artificial intelligence, and adapt to international educational standards.

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