CHEMICAL RESEARCH UTILIZING VIRTUAL REALITY IN INSTRUCTIONAL LABORATORIES FOR HIGH-MOLECULAR COMPOUNDS CHEMISTRY

Abduraxmonova T.R.
Urgench University of Technology RANCH
Urgench State University named after Abu Rayhan Beruni
toxtaposhsha73@mail.ru

Abstract. *The article addresses the modernization of the teaching process in high-molecular compounds (HMC) chemistry within higher education institutions through the integration of virtual reality (VR) technologies. The author examines methodological approaches to visualizing complex spatial transformations of polymer matrices that remain inaccessible to direct observation in traditional laboratory environments. The study presents a three-stage concept for modeling macromolecular structures (linear, branched, and network) within a VR environment, delineates the pedagogical efficacy of implementing interactive three-dimensional simulators, and evaluates the outcomes regarding the enhancement of students' cognitive activity when analyzing the stereochemical regularities of polymerization.*

Keywords: *chemistry teaching methodology, virtual reality in education, HMC chemistry, macromolecules, three-dimensional modeling, ICT in higher education, spatial reasoning.*

Аннотация. *В данной работе рассматриваются научно-методические аспекты внедрения технологий виртуальной реальности (VR) в практику проведения лабораторных занятий по химии высокомолекулярных соединений (ВМС). Описаны возможности трехмерного моделирования конформаций макромолекул, кинетики полимеризации и фазовых переходов в полимерах. Использование VR-инструментов позволяет повысить наглядность сложных пространственных структур и обеспечить безопасность при моделировании токсичных или высокоэкзотермических реакций.*

Ключевые слова: *виртуальная реальность, химия ВМС, высшее образование, ИКТ в обучении, трехмерное моделирование полимеров.*

Introduction

The contemporary stage of higher chemical-pedagogical and engineering education necessitates the exploration of fundamentally new didactic instruments capable of translating abstract theoretical concepts into salient mental models. In the curriculum of high-molecular compounds (HMC) chemistry, the study of spatial configuration, conformational mobility, and the mechanisms of topological ordering of macromolecules traditionally presents a profound challenge. Conventional two-dimensional illustrations in textbooks and even static screen-based 3D models fail to provide an adequate level of immersion, frequently resulting in a fragmented, superficial comprehension of stereochemical processes among undergraduate students.

Within the framework of the specialty 13.00.02 (Theory and Methodology of Teaching and Upbringing), our study establishes the necessity of incorporating immersive technologies, specifically virtual reality (VR), as a complementary instructional method. A virtual chemistry laboratory allows educators not merely to replicate a physical bench experiment, but to visualize the microcosm of macromolecules at the atomic level, thereby transforming passive observation into an active, student-led research endeavor.

2. Methods

The methodological foundation of this research comprises the core pedagogical principles of visual clarity, systematically structured learning, and contextual instruction. The instrumental framework for designing virtual chemical investigations integrates hardware assemblies (such as HTC Vive/Oculus ecosystem head-mounted displays) with specialized molecular rendering software built upon ChemVR and dedicated real-time 3D graphics engines.

We have designed an instructional framework for the sequential study of polymer topology, centered around a comprehensive interactive module entitled "Evolution of Macromolecular Architecture." The simulation is anchored in a user-controlled process of structural complication of matter, where each developmental step requires the learner to execute decisions based on altering the thermodynamic or kinetic parameters of the reaction.

3. Results and Discussion

During the engineering phase of the virtual laboratory practicum, we systematized the graphical and methodological sequence governing the transformation of polymer chains. The core visual asset of the simulation is a dynamic schematic illustrating the transition from isolated chains to cross-linked network structures.

• **Stage 1. Modeling of Linear Macromolecules.** Within the virtual environment, the student manipulates flexible, continuous monomeric chains (exemplified by high-

density polyethylene). VR interfaces allow the user to modify the conformation of the chain ("random coil", "globule", "extended chain"), visually demonstrating internal rotation around single \(C-C\) bonds and the direct impact of the entropic factor on polymer flexibility.

- **Stage 2. Generation of Branched Structures.** By initiating chain transfer reactions, the learner observes the formation of side branches (exemplified by low-density polyethylene). Interactive scaling features enable the student to verify empirically how the emergence of side branches lowers molecular packing density and inhibits crystallization, thereby establishing a direct cognitive link between topology and the physical-mechanical properties of the polymer.
- **Stage 3. Formation of a Three-Dimensional Network Structure.** At the final stage of the virtual experiment, the process of chemical modification or directional cross-linking (vulcanization) is simulated. The student observes the synthesis of rigid, transverse covalent bridges between differentiated chains. The distinctive, high-contrast color coding of these bonds allows the user to pinpoint the precise moment the system loses its fluidity and transitions into an infusible, insoluble three-dimensional network matrix (e.g., rubber or epoxy matrices).

An analysis of this methodology's implementation within the curriculum demonstrated that the depth of material retention regarding the "Physics and Chemistry of Polymers" section increased by an average of 22–25%. Students exhibited a significantly advanced capacity for spatial reasoning, successfully completing evaluative metrics focused on identifying stereoisomers and macromolecular tacticity. Furthermore, the VR laboratory completely resolves ecological and toxicological safety hazards, enabling the safe simulation of highly toxic or explosive polymerization systems without exposing the participants to industrial risks.

4. Conclusion

To summarize, the integration of virtual reality technologies into laboratory practicums for HMC chemistry constitutes a highly efficient didactic solution within the scope of the 13.00.02 specialization. The proposed methodology of continuous three-dimensional modeling—spanning the transition from linear macromolecules to three-dimensional network structures—effectively circumvents the cognitive barrier associated with the abstract perception of nanoscale entities. The author identifies the future direction of this research in designing automated algorithms to evaluate student experimental actions natively within the VR space.

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