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Effectiveness Of Using Digital Simulations In Molecular Physics Classes

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Abstract: This article highlights the didactic possibilities of using digital simulations in teaching the molecular physics section, their impact on students' knowledge acquisition, and the advantages of an interactive environment. In the course of the study, the results of traditional education and education based on digital simulations were compared, and the effectiveness of the digital educational environment was substantiated with statistical data.

Keywords: Molecular physics, digital simulation, virtual laboratory, digital educational environment, effectiveness of the educational process, interactive teaching technologies, digitalization of education.

Introduction: Molecular physics is a branch of science that studies the motion of atoms and molecules, their interactions, and their thermodynamic properties, and it requires students to master many abstract concepts. In traditional classes, these concepts are often presented through mathematical formulas and theoretical explanations. However, the frequent lack of visual representation of theoretical knowledge makes it difficult for students to understand the subject [1]. Therefore, the use of digital simulations and interactive laboratories in molecular physics classes helps to effectively improve students' knowledge [2].

With the help of digital simulations, students can observe the motion of molecules, the kinetic properties of gases and liquids, phase transition processes, conduct experiments, and analyze the results. This makes it possible to reinforce theoretical knowledge through practical experience [3].

METHODOLOGY

In recent years, the pedagogical effectiveness of digital simulations and virtual laboratories in teaching the molecular physics section has been widely studied.

In their 2025 article entitled "Solving Graphical Problems in Physics Using Digital Technologies on the Example of the Molecular Physics Section" published in the journal Science and Education, D. Esanboyev, D. Malikova, and N. Toshmurodov present examples of solving graphical problems using the Python programming language [4]. As they emphasize, solving graphical problems with digital tools helps students to reinforce theoretical knowledge in a visual form.

G. Rakhmatullayeva, in her article entitled "Experience of Teaching Molecular Physics and Thermodynamics Based on a Digital Platform", published in 2025 at the international scientific and practical conference "Modern Approaches in Teaching Exact and Natural Sciences: Challenges and Solutions", analyzes the experience of conducting classes using a digital platform and demonstrates that virtual laboratory work and interactive tests are effective in increasing students' knowledge levels and developing independent learning skills. At the same time, the platform provides students with the opportunity to manage the learning process and increases their motivation [5].

In their 2025 article entitled "Simulators as an Innovative Strategy in the Teaching of Physics in Higher Education" published in the journal Education Sciences, Mexican scholars Alvarez Siordia, F. M., Merino Soto, C., Rosas Melendez, S. A., Perez Diaz, M., and Chans, G. M. analyze the effectiveness of digital simulations in teaching physics in higher education. The analysis shows that simulations help strengthen students' conceptual understanding and increase their interest and engagement in lessons [6]. The authors recommend using simulations together with problem-based tasks and analytical assignments for effective implementation. Thus, simulations become a useful tool for teaching molecular physics and other physics topics in an interactive and comprehensible manner.

In a comprehensive study published in the journal Physical Review Physics Education Research (2021), the effectiveness of PhET digital simulations in physics education was analyzed [7]. Based on more than 80 scientific studies, it was shown that the use of simulations helps learners gain a much deeper understanding of abstract physical processes, in particular molecular physics concepts such as the random motion of molecules, the pressure–temperature relationship, and heat transfer. Simulations create a visual environment close to real experiments, making complex processes observable and controllable.

The teaching methodology for using digital simulations in molecular physics classes was developed on the basis of systemic-didactic, competency-oriented, and digital learning environment principles. This methodology was formulated by taking into account the complexity of processes at the molecular level and the limitations of fully demonstrating them under real laboratory conditions (Figure 1).

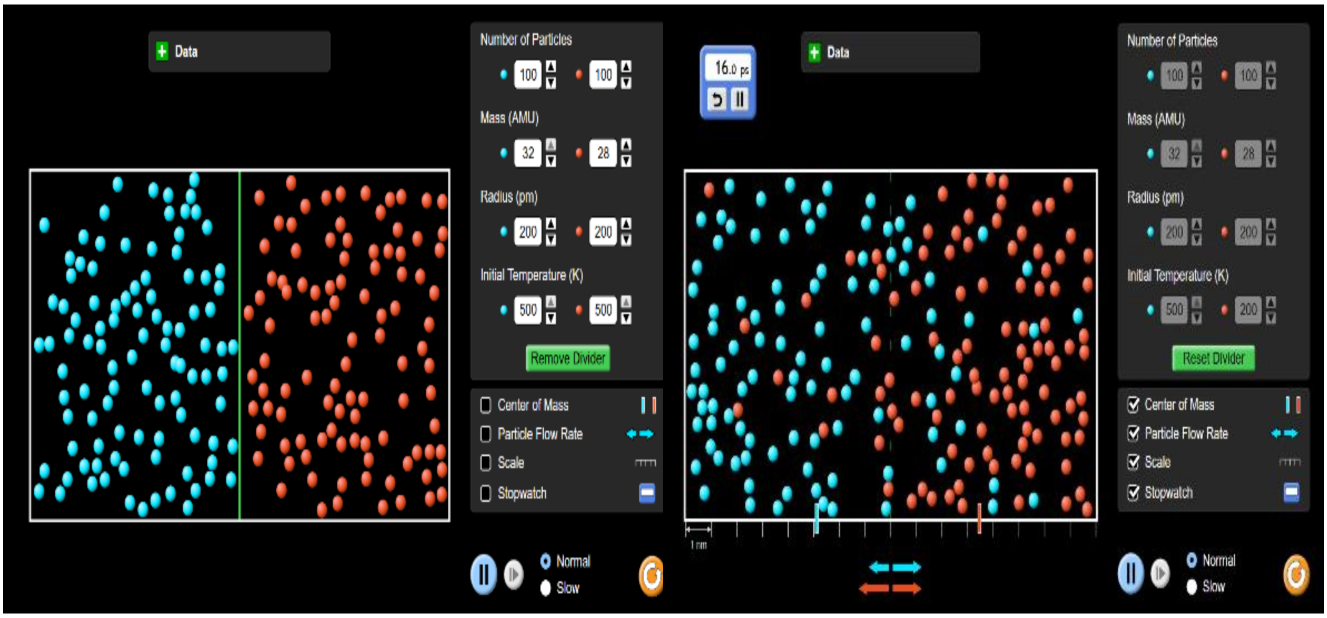

Figure 1. Simulation of the Diffusion Process in Gases (PhET)

This study was conducted based on pedagogical experimental testing, comparative analysis, and methods of mathematical and statistical data processing. During the research process, the impact of using digital simulations in teaching the molecular physics section on the learning process was examined through a consistent methodological approach. In this context, the process of integrating digital simulations into lesson content, students' knowledge levels, analytical thinking skills, and changes in learning activity were analyzed in a comprehensive manner. The obtained results were evaluated through comparative analysis, and their reliability and scientific validity were ensured by means of statistical processing.

The methodological model shown in Figure 2 reflects a sequential pedagogical process aimed at the effective organization of molecular physics classes in a digital environment. First, students' existing knowledge levels are identified and their readiness for the topic is established. At the next stage, complex molecular processes are demonstrated in a visual form through interactive models, allowing the studied phenomena to be observed dynamically. Subsequently, the obtained results are subjected to logical analysis, their physical meaning is determined, and they are linked to theoretical laws. In the final stage, the acquired knowledge is generalized, analyzed, and assessed, and then reinforced through independent activities. This approach serves to enhance the effectiveness of the learning process through the use of digital technologies.

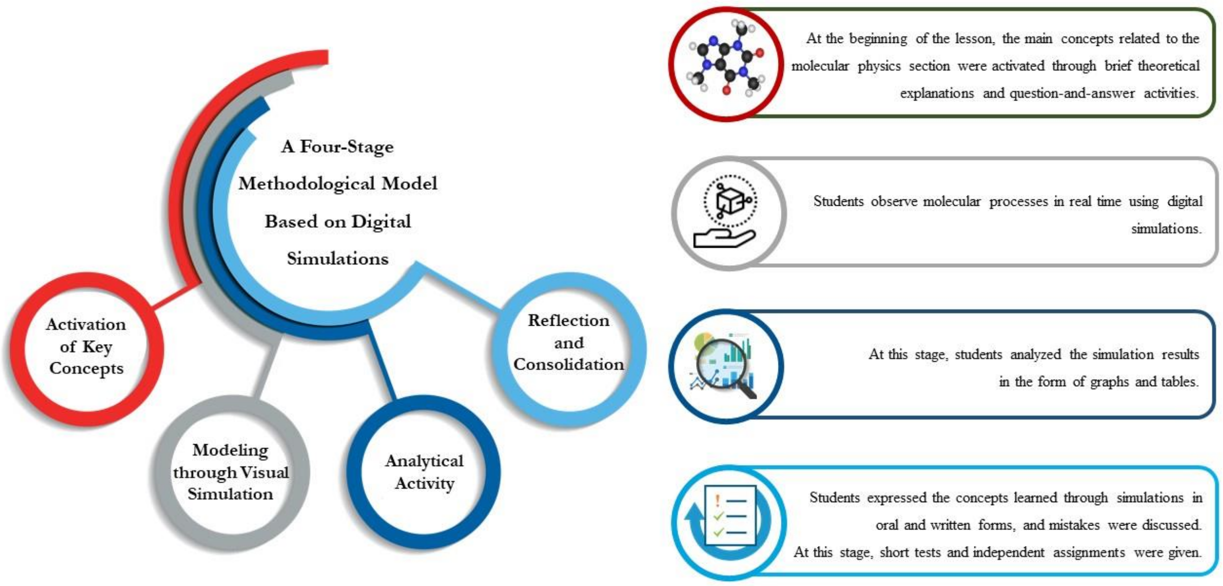

Figure 2. A Methodological Model Based on Digital Simulations for Molecular Physics Classes

RESULTS AND DISCUSSION

The research design belongs to the quasi-experimental type, in which learning outcomes between the control and experimental groups were compared. In both groups, the curriculum, number of instructional hours, and assessment criteria were identical, and the difference was observed only in the teaching technology.

The experimental work was conducted among undergraduate students majoring in physics at Bukhara State University. The total number of participants was 150, who were randomly divided into two groups: the experimental group – 75 students, and the control group – 75 students.

Before the start of the experiment, the initial level of knowledge related to the molecular physics section in both groups was determined using a special diagnostic test. Statistical analysis showed that there was no significant difference between the indicators of the two groups, which ensured the objectivity of the experimental results.

Digital simulations develop not only knowledge but also ways of thinking. Therefore, the following aspects were assessed: correct interpretation of graphs, identification of cause–effect relationships, explanation of the differences between models and real processes, and justification of physical conclusions. Assessment methods included tests, practical tasks, oral questions, and written analysis.

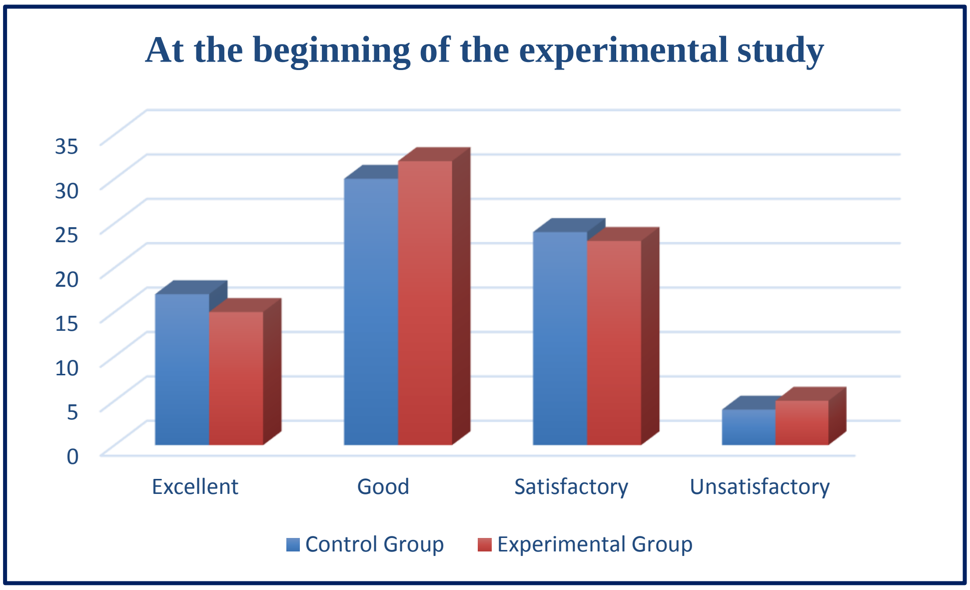

Figure 3. Indicators at the Beginning of the Experimental Study

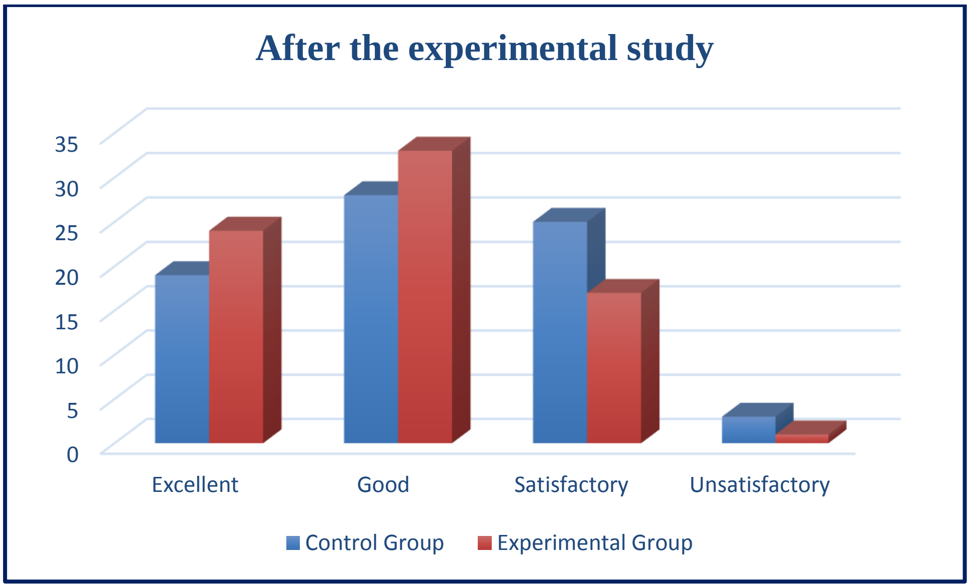

Figure 4. Indicators After the Experimental Study

The analysis of the results yielded the following indicators: the average achievement score of the experimental group was 82.42%, while the average achievement score of the control group was 75.81%. A graphical representation of the results is presented in Figures 3–4.

CONCLUSION

The results of the conducted pedagogical experimental study showed that the use of digital simulations in teaching the molecular physics section increases the effectiveness of the learning process. It was determined that the level of knowledge acquisition of students in the experimental group was 6.61% higher than that of the control group. This result is explained by the fact that lessons organized on the basis of digital simulations facilitate students' understanding of complex and abstract molecular concepts.

During the research, the opportunities created by digital simulations—such as visual modeling of molecular processes, independent modification of parameters, and real-time analysis of processes—contributed to the development of students' analytical thinking and scientific reasoning skills. As a result, a stable, statistically reliable, and pedagogically grounded growth in knowledge was ensured.

In addition, the experimental results showed that integrating digital simulations with traditional teaching methods improves the methodological quality of molecular physics classes. This methodology can be recommended for implementation in the teaching process of the molecular physics section in higher education institutions and serves to develop the professional and digital competencies of future physics teachers.

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