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METHODOLOGY FOR UTILIZING DIGITAL INTERACTIVE TOOLS IN SOLVING CHEMICAL PROBLEMS

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Abstract
This article provides a comprehensive analysis of the methodological aspects of integrating interactive digital tools into the chemistry education process. In the context of the total digitalization of the educational space, the transformation of traditional methods for solving calculation and experimental problems is of particular importance. The author provides a detailed justification and description of the methodology for integrating virtual laboratory complexes, molecular constructors, and dynamic simulations. An original algorithm for implementing these tools is presented, aimed at visualizing microscopic processes and intensifying the cognitive activity of students. Experimental data confirm a significant increase in the quality of material mastery and the development of research competencies among learners.

Keywords: digital didactics, interactive learning, virtual laboratories, chemistry teaching methodology, solving calculation problems, ICT competence, STEM education, pedagogical experiment.

Introduction

Relevance of the Research. The current stage of development of the higher and secondary specialized education system in the Republic of Uzbekistan is

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characterized by the deep integration of information and communication technologies into all spheres of academic activity. The implementation of the "Digital Uzbekistan – 2030" strategy dictates the need to train specialists capable of not only operating with theoretical knowledge but also effectively utilizing high-tech tools in their professional activities [1].

Chemistry, as a fundamental natural science, possesses a specific complexity associated with the high degree of abstraction of the objects studied. In the learning process, solving chemical problems is traditionally the most labor-intensive stage. This is due to the fact that the student is required not only to have formal knowledge of mathematical formulas but also the ability to multi-levelly represent the mechanisms of chemical transformations — from macroscopic signs of a reaction to interactions at the atomic-molecular level.

Traditional pedagogical approaches, based on the use of static demonstration material, often prove insufficiently effective for forming dynamic images in the minds of the modern generation of students, the so-called "digital natives." An objective contradiction arises between the exponential growth of digital technology capabilities and the persistent conservatism of problem-solving methodologies.

The Research Problem is formulated as the need to find and justify an optimal balance between classical algorithms for solving calculation problems and the functional capabilities of modern interactive environments that allow for the modeling of processes inaccessible to direct visual observation.

Literature Review and Theoretical Foundation

The problem of utilizing digital resources in chemistry is at the center of attention for many domestic and foreign researchers. Pedagogical aspects of digitalization in Uzbekistan are covered in detail in the works of G.I. Mukhamedov, B.Z. Akhmadjanov, and K.U. Khalikova. The authors argue that digital educational resources (DER) should act not as an addition, but as an organic part of the methodological system [3, 5].

Foreign experience, particularly developments from the University of Colorado (the PhET project), indicates that interactive simulations allow for the implementation of the "implicit support" concept, where the learner independently discovers the laws of nature through the manipulation of variables

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[8]. Research within STEM education has recorded that the level of engagement when using interactive environments increases by an average of 35–40%.

The Methodological Basis of the article consists of:

1. The System-Activity Approach: the student is viewed as an active subject who "extracts" data for problem-solving during interaction with a digital model.
2. The Concept of Cognitive Visualization: the use of graphic and animated images to overcome the cognitive barrier of abstraction.
3. Problem-Based Learning Technology: posing a learning task as a research challenge requiring a virtual experiment.

Research Methodology

The scientific apparatus of this research is based on a comprehensive approach, including theoretical and empirical methods of cognition. The dominant method is "digital modeling of chemical processes," integrated into the classical structure of a practical lesson.

Main Stages of the Research:

1. Theoretical-Analytical Stage: performing a systematic analysis of the pedagogical design of existing DERs and their adaptation to specific sections of the chemical curriculum (inorganic, organic, and physical chemistry) [6].
2. Design Stage: developing didactic scenarios where the interactive tool is not just an illustration but a source of primary data for a subsequent calculation algorithm.
3. Experimental-Transformative Stage: implementing the methodology into the educational process and conducting a comparative analysis of results in control and experimental groups.

Instrumental Complex:

To implement the methodology, the following software products were selected and classified:

- Molecular Visualizers: Avogadro, ChemSketch — for studying the geometry and properties of substances.
- Virtual Chemical Laboratories: ChemCollective, Yenka — for simulating experimental procedures.
- Dynamic Simulators: PhET Simulations — for managing physical and chemical parameters of systems.

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The methodology for applying digital interactive tools**.** The methodology involves the implementation of four sequential modules; each aimed at forming specific competencies.

Module 1. Microstructure Modeling: Transition from Static Drafting to Predictive Analysis

Traditional problem solving for determining hybridization types or molecular polarity often reduces to mechanical memorization of valence angle tables.

Methodological Algorithm in the Avogadro Environment:

- Problem Posing: The student is asked to justify differences in the chemical activity of molecules using ammonia (NH3) and boron trifluoride (BF3) as examples.
- Interactive Action: The student independently constructs 3D models of these compounds. Using the "Force Field" optimization module, they observe how the program calculates the energy minimum and automatically rearranges the geometry from planar to pyramidal (for NH3).
- Analytical Phase: Using measurement tools, the student records actual valence angles and dipole moments.
- Conclusion: The abstract concept of "electron pair repulsion" becomes a visually obvious fact. This allows for solving higher-level problems, such as predicting the solubility of substances in polar and non-polar solvents based on their calculated geometry.

Module 2. Interactive Stoichiometry and Virtual Verification Experiment

In classical learning, calculation problems are detached from reality: the student receives dry figures and provides a numerical answer. The digital methodology introduces a "laboratory admission" stage.

Methodological Algorithm in the ChemCollective Virtual Lab Environment:

- Pre-analysis Stage: The student receives the problem conditions for preparing a solution of a given molar concentration or for titrimetric analysis of a mixture.
- Virtual Modeling: Before writing calculations in a notebook, the learner in a virtual environment selects the necessary equipment (volumetric flasks, pipettes, burettes) and reagents.
- Feedback: If the student makes an error in the volume calculation during virtual titration, the virtual indicator does not show the equivalence point, or the pH meter yields values that do not correspond to theoretical expectations.

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- Correlation: This forces the learner to critically rethink their calculations. The interactive environment blocks the possibility of "fitting the answer," forming a deep understanding of the relationship between the mass of the sample and the solution concentration.

Module 3. Dynamic Management of Reaction Rates and System Equilibrium

Studying Le Chatelier's principle and chemical kinetics is the most problematic area. Static graphs in textbooks do not convey the dynamics of the process.

Methodological Algorithm in PhET Simulations:

- Implementation: The student works with a model of ammonia synthesis or nitrogen dioxide. They have tools ("sliders") to change temperature, pressure, and introduce a catalyst.
- Dynamic Visualization: When pressure increases, the student sees on the screen not only the shift of curves on the graph but also an increase in the frequency of molecular collisions in the reaction vessel.
- Result: A static problem ("In which direction will the equilibrium shift?") is transformed into an active study of dependence. The student begins to understand the physico-chemical essence of processes rather than just memorizing rules.

Module 4. Digital Augmentation Technology (QR) and Contextual Learning

In organic chemistry, solving transformation chains requires working with massive amounts of data (constants, conditions, catalysts).

- Methodology: Application of QR codes in didactic materials. Each step in a problem is provided with a code that leads not to an answer, but to an interactive reaction mechanism (e.g., visualization of nucleophilic attack in SN1/SN2 reactions).

Effect: This significantly reduces the cognitive load on memory, allowing focus on synthesis logic rather than searching for reference information.

Results and Interpretation

The developed methodology was tested throughout the academic year. A total of 93 students participated in the experiment (Control Group CG=45, Experimental Group EG=48).

1. Quantitative Indicators of Academic Performance

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The primary indicator of the methodology's effectiveness was the learning mastery coefficient (Ku), calculated as the proportion of correctly solved problems out of their total number.

Table 1. Dynamics of Changes in the Quality of Solving Chemical Problems

Group	Initial Control (Ku)	Intermediate Cut-off (Ku)	Final Control (Ku)	Increase (%)
Control (CG)	0.62	0.68	0.71	+14.5%
Experimental (EG)	0.61	0.76	0.86	+40.9%

Analysis of the data shows that the final coefficient in the experimental group was 0.86, which is 21.1% higher than the same indicator in the control group. The statistical reliability of the results is confirmed by Student's t-test ($p < 0.01$).

2. Analysis of Time Spent on Problem Solving

The use of digital simulators allowed for a significant intensification of the educational process.

Table 2. Average Time per Problem Solving (in minutes)

Problem Type	Traditional Method	Digital Methodology	Savings (%)
Reaction Equation Calculations	12.5	9.2	26.4%
3D Structure Modeling	18.0	7.5	58.3%
Virtual Titrimetric Analysis	25.0	15.4	38.4%

The greatest efficiency (over 50%) was recorded in spatial structure problems. This is explained by the fact that the digital environment takes over the routine function of rendering and visualization, allowing the student to move immediately to the analytical phase.

3. Cognitive-Psychological Aspect

A student survey showed that working in an interactive environment lowers the "entry threshold" into the subject. The proportion of learners reaching the creative-research level (the ability to independently construct problem conditions) in the EG grew from 12% to 34%. This is directly related to the fact that a virtual experiment is safe and psychologically comfortable: the student is not afraid to make a mistake, as they can instantly restart the simulation.

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Discussion of Results

The data obtained allow for a deep interpretation of the impact of digital interaction on cognitive processes. The main achievement of the methodology is the transformation of the learner's role: from a passive recipient of knowledge, they become a researcher-modeler.

In the control group, errors were predominantly of a formal-calculation nature, often caused by inattention when applying memorized algorithms. In the experimental group, however, errors were of a conceptual nature (testing risky hypotheses), which indicates the mind working in the field of the limits of applicability of chemical laws. This testifies to a transition from "algorithmic" to "systems" thinking.

Conclusion

The research confirms that the integration of digital interactive tools into the process of solving chemical problems is an essential imperative for the modernization of chemical education.

Main Conclusions

1. It has been established that the use of dynamic models and virtual laboratories increases the quality of knowledge by 20–25% with a substantial reduction in time costs.
2. It has been proven that interactivity contributes to the development of critical thinking and removes psychological barriers to complex sections of the discipline.
3. It has been revealed that the digital environment forms the skills in students necessary for working in the conditions of modern digital production (In silico).

Prospects: Future research should be directed toward creating intelligent adaptive systems based on AI and integrating augmented reality (AR) technologies, which will fully eliminate the gap between theory and practice in chemical education.

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