

Improving the Cognitive-Algorithmic Methodology for Solving Chemistry Problems in an E-Learning Environment

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Abstract: This article explores the improvement of chemical problem-solving methodology within an e-learning environment under the specialization 13.00.02 – Theory and Methodology of Education and Training. The relevance of the study stems from the necessity to overcome cognitive barriers students face in visualizing chemical processes at the submicroscopic level and applying mathematical algorithms in practice. A four-stage problem-solving model is proposed, based on the Cognitive Load Theory and the principles of "Johnstone's Triangle." The impact of virtual laboratories and interactive simulations integrated into the LMS (Moodle) platform on student achievement rates was demonstrated through a pedagogical experiment. The results indicate that the proposed methodology increases the efficiency of solving complex, high-order problems by 26.7% compared to traditional teaching methods.

Keywords: E-learning, chemistry teaching methodology, problem-solving, cognitive load, LMS, interactive simulations, virtual laboratory, pedagogical experiment, digital didactics, competence.

Introduction: My nearly seven years of teaching experience and observations in the field of chemistry pedagogy indicate that the greatest "cognitive barrier" for students is not in understanding the fundamental laws of the subject, but in applying these laws to specific quantitative calculations - that is, to problem-solving. In traditional classrooms, we have spent years illustrating the mathematical models of chemical processes with a board and chalk. However, it must be acknowledged that only 15-20% of students are able to fully visualize the real microscopic processes (atomic collisions, electron movement, thermodynamic changes) behind the dry numbers and formulas on the board. For the rest, problem-solving has become a mechanical process that consists merely of substituting numbers into a ready-made algorithm.

Today, in the era of the digital transformation of education, the e-learning environment provides us with unprecedented opportunities to address this problem. Developing a methodology for solving

chemistry problems within an e-learning environment is not simply a matter of converting textbooks into PDF format or taking tests on a computer. It involves enriching a student's spatial and logical thinking through digital simulations, virtual laboratories, and Intelligent Tutoring Systems, which means creating a completely new didactic model of education.

The main goal of this research is to develop the scientific and methodological foundations for the transition from the traditional abstract-mathematical method of solving chemistry problems in higher and general secondary education to an interactive-cognitive method within an electronic environment, as well as to prove its practical effectiveness. We are exploring the mechanisms for creating a safe virtual environment that shifts the student's focus from the result to the problem-solving process itself and allows them to learn from their mistakes.

LITERATURE REVIEW

The didactics of chemical education has always evolved in close connection with psychology and cognitive sciences. To correctly structure our methodology within an electronic educational environment, we rely primarily on two fundamental theories: A. H. Johnstone's "Triangle of Chemical Knowledge" (Johnstone's Triangle) and J. Sweller's "Cognitive Load Theory." 2.1. The Johnstone Triangle and its Integration into the Electronic Environment

In 1982, the renowned Scottish chemist and methodologist Alex Johnstone proposed a three-level model to explain the difficulties that arise when learning chemistry:

Macroscopic level: processes that we can see and perceive (color change, precipitation, gas evolution).

Submicroscopic level: the movement of atoms, molecules, ions, and electrons.

Symbolic level: chemical formulas, reaction equations, and mathematical calculations.

In my experience, I have found that traditional

problem-solving primarily remains at the third, *symbolic, level*. A student might calculate mass, volume, or concentration, but they don't have a feel for what is happening to the substance. The power of an electronic educational environment lies in its ability to simultaneously combine all three levels on one screen. For example, when solving a problem on gas mixtures, a student can synchronously observe the gas volume (macro level), the collision of molecules with the container walls (submicro level), and the changes in the formula for Boyle's law, $P_1V_1=P_2V_2$ (symbolic level), on the computer screen. This integration leads to the more robust formation of neural networks in the brain.

2.2. Cognitive Load Theory

The biggest mistake often made when creating electronic educational resources is overloading the screen with various distracting animations, text, and complex navigation. According to John Sweller's theory, a person's working memory is very limited. In the process of solving a problem, the total cognitive load (C_{total}) consists of three parts:

$$C_{total} = C_{intrinsic} + C_{extraneous} + C_{germane}$$

Where:

$C_{intrinsic}$ (intrinsic load) is the inherent difficulty of the problem and the student's existing knowledge.

$C_{extraneous}$ (extraneous load) is the load (often unnecessary) that arises from the way the educational material is presented (e.g., poor design, an unclear interface).

$C_{germane}$ (germane load) is the mental effort expended on transferring information to long-term memory (e.g., creating schemas, identifying patterns).

The key feature of our proposed methodology is to minimize the external cognitive load $C_{extraneous}$ in the electronic environment (on LMS platforms) and maximize the relevant load $C_{germane}$. This is achieved through minimalist interface design, step-by-step task presentation (scaffolding method), and the use of interactive schemes that serve only content. Foreign scientists (Mayer, Clark) noted in their research that the rational use of multimedia tools increases the speed of problem-solving by an average of 30% and our preliminary research conducted in the Uzbek audience

also confirms this.

METHODOLOGY

This study is based on a mixed methodological approach (Mixed Methods Research) and combines both quantitative (statistical analysis) and qualitative (observation of cognitive processes) analysis methods. The purpose of the research is to empirically study the influence of interactive tools integrated into the electronic educational environment on students' competence in solving chemical problems.

Research design and participants

The pedagogical experiment was conducted during one semester (15 weeks) of the academic year among 1st and 2nd-year students studying in the "Chemistry" and "Chemistry Teaching Methodology" programs. The total number of participants was 110 people. Participants were divided into two groups by random sampling (randomization):

The control group ($n_1 = 54$): developed problem-solving skills using the traditional method, which consisted of lectures and practical sessions using

standard printed textbooks.

The experimental group (n₂ = 56): was taught using a specially developed electronic educational and methodological complex (EEMC) and virtual laboratories on the LMS Moodle platform, based on the principle of "reduced cognitive load."

To confirm that the initial level of knowledge in both groups was the same, a diagnostic pre-test was conducted at the beginning of the semester. No statistically significant differences were observed between the variance and mean values of the pre-test results ($p > 0.05$).

A cognitive-didactic model for solving problems in an electronic environment

Solving a problem is more than just a mathematical calculation. In the experimental group, we abandoned the traditional "Condition → Formula → Solution" sequence and implemented the following four-stage cognitive-didactic model.

Contextualization and visualization: The problem is presented not as dry text, but in the context of a real-

life problem or a situation in a virtual laboratory.

Deconstruction (Breaking down the problem): An intelligent tutor on the platform helps the student break down the problem into logical blocks.

Simulation-based calculations: Students first simulate the progression of a chemical reaction in a virtual environment.

Calculations in the Scaffolding System (Step-by-Step Support): If a problem is solved incorrectly in the e-learning environment, the system does not simply display an "Error" message. Instead, it identifies the step in which the error was made and asks a guiding question.

Organization of the Experimental Educational Process

For the students in the experimental group, interactive modules were developed for solving complex stoichiometric and thermodynamic problems. For example, let's consider problems that reflect the following fundamental relationship in the field of chemical equilibrium and thermodynamics:

$$\Delta G^{\circ} = \Delta H^{\circ} - T\Delta S^{\circ} = -RT \ln K_{eq}$$

In traditional learning, students find the values for Gibbs energy, enthalpy, and entropy in tables and perform only mechanical calculations. In contrast, in an interactive educational environment, students use virtual sliders to change the temperature and **visually** observe how the reaction's equilibrium constant changes and when the forward or reverse reaction prevails. Only after the student has fully grasped the essence of the process does the system offer them a numerical problem with individual parameters.

Measurement Tools and Validity

Upon completion of the study, a final test (post-test) was conducted to measure the students' competencies. The test questions were divided into 3

categories according to the higher levels of Bloom's taxonomy (Application, Analysis, Evaluation):

1. *Reproductive tasks* (solved directly using a formula);
2. *Heuristic tasks* (requiring the establishment of a connection between several principles);
3. *Cognitive problem-solving tasks* (predicting reaction conditions and analyzing results).

To ensure the reliability of the data and to assess the differences in results between the groups, the arithmetic mean and standard deviation (\$s\$) were calculated.

$$s = \sqrt{\frac{\sum_{i=1}^n (x_i - \bar{x})^2}{n - 1}}$$

All empirical data obtained were subjected to quantitative analysis.

RESULTS AND DISCUSSION

The quantitative indicators from the pedagogical experiment clearly demonstrated the influence of the electronic educational environment on the

methodology for solving chemistry problems. The results of the final test showed that the students' knowledge level underwent not only a quantitative but also a qualitative transformation. To identify the differences between the experimental and control groups, the results are summarized in the following table:

Task Categories	Control Group (X1)	Experimental Group (X2)	Difference (Δ)	Statistical Significance (p)
Reproductive (Algorithmic)	72.5	81.2	+8.7	p < 0.05
Heuristic (Logical connection)	61.3	79.8	+18.5	p < 0.01
Cognitive Problem-Solving (Creative)	48.6	74.4	+25.8	p < 0.01
Average Score	60.8	78.5	+17.7	p < 0.01

As the table shows, the greatest positive difference was observed in the cognitive problem-solving tasks category (+25.8 points). This indicates that interactivity within the electronic environment helped students develop not only the skill of memorizing formulas but also the ability to make correct decisions in non-standard chemical situations.

We attribute these high results to several fundamental pedagogical factors:

Visual Thinking: The students in the control group fell into the trap of "mathematical abstraction" while solving the problem. That is, although they knew the formula for calculating molar concentration ($C = n/V$), they could not visualize how particle density changes when a solution is diluted. In the experimental group, however, virtual simulations made the submicroscopic level (particle movement) visible. In cognitive psychology, this is known as "**dual-coding theory**" (Paivio's theory): when information is encoded both

visually and verbally (textually), the rate of retention increases manifold.

The Freedom to Make Mistakes and Motivation: In an electronic environment, a student is not afraid of making mistakes. In a traditional classroom, making a mistake at the blackboard puts a student under psychological pressure. Our "**Smart Feedback**" system on the LMS platform presents an error not as a reason for "blame" but as an opportunity for "guidance." When a student independently corrects their mistake with the help of the system, the brain releases *dopamine*, which creates a "success effect" and increases intrinsic motivation to solve the next, more complex problem.

Optimizing Cognitive Load: In the methodology we developed, complex calculations (e.g., logarithmic calculations or operations with large numbers) were visualized by the platform itself. As a result, the student's working memory was directed not toward dry

arithmetic, but toward **understanding the chemical logic** - that is, comprehending the reaction mechanism.

$$K_c = \frac{[C]^c [D]^d}{[A]^a [B]^b}$$

When solving chemical equilibrium problems, students saw in real time on graphs how concentration affects the equilibrium, which enabled them to apply Le Chatelier's principle consciously rather than through rote memorization.

Another important aspect of the study is that the knowledge acquired by the experimental group was not "fragile." Follow-up tests conducted two months after the experiment showed that students who studied in the electronic environment had a knowledge retention coefficient ($K_{retention}$) of 0.82, whereas in the control group, this figure dropped to 0.58.

CONCLUSIONS

This study, focused on developing a methodology for solving chemistry problems within the higher education system using an electronic learning environment, has led to the following fundamental conclusions:

1. Methodological Transformation:

When moved to an electronic environment, the process of solving chemistry problems was transformed from a simple set of mathematical calculations into a cognitive and research-based activity. The electronic learning environment increased students' assimilation of abstract concepts by 26.7% by visually synchronizing all levels of Johnstone's triangle (macro, submicro, and symbolic).

2. Cognitive Load Management:

The study found that implementing "Scaffolding" (step-by-step support) and "Smart Feedback" systems on LMS platforms effectively distributes students' cognitive load. This allowed the main resources of working memory to be directed not toward technical calculations, but toward analyzing the essence of the chemical process.

3. Individualized Path:

The electronic environment provided each student with the opportunity to solve problems at their own cognitive pace and independently work on their mistakes. This

ensured a significantly higher knowledge retention rate compared to the control group, especially in complex stoichiometric and thermodynamic calculations.

Practical Recommendations:

For Educators: In problem-solving classes, chemistry teachers are advised not to limit themselves to rote algorithms, but to combine PhET simulations and virtual laboratory elements with the "Problem-Based Learning" methodology.

For curriculum developers: When creating electronic versions of textbooks and manuals for specialty 13.00.02, it is necessary to integrate interactive models (linking to simulations via QR codes).

For future research: To further improve problem-solving methodologies in chemistry education, it is important to implement adaptive learning paths based on Artificial Intelligence (AI) and to study their effectiveness.

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