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## THE POSSIBILITIES OF USING ARTIFICIAL INTELLIGENCE TO IMPROVE THE EFFECTIVENESS OF CHEMISTRY LESSONS

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The article examines the potential of artificial intelligence (AI) tools—virtual laboratories, generative neural networks, and adaptive learning platforms—for improving the quality of chemistry teaching in secondary schools in Kazakhstan. In a quasi-experimental study, 42 ninth-grade students from the A.Navoi School No. 13 (Shymkent) were randomly assigned to an experimental group (AI-integrated program,  $n = 21$ ) and a control group (traditional instruction,  $n = 21$ ). Before and after the six-week course, students completed a 40-item test aligned with the state curriculum standards and a learning-motivation questionnaire. Following the course completion, the experimental group demonstrated test results 25% higher than those of the control group ( $d = 0.82$ ;  $p < 0.001$ ) and a higher engagement level (85% vs. 55%). A two-way ANOVA revealed a significant Group  $\times$  Time interaction ( $F(1, 38) = 12.54$ ;  $\eta^2 = 0.21$ ). Additionally, a 30% increase in learning independence and more substantive discussions of organic chemistry topics were observed. The findings indicate that AI enables safe and resource-efficient experimentation, individualizes the learning pace, and reduces students' cognitive load. Methodological recommendations—including 30–45-minute VR laboratory sessions, generative reaction visualization, adaptive diagnostics, estimated implementation costs, and a teacher-training model for large-scale adoption—are proposed. Further longitudinal research is required to evaluate long-term effects and implementation in rural schools.

**Key words:** chemistry, teaching, virtual laboratory, artificial intelligence, educational technologies, adaptive training, efficiency.

## ХИМИЯ САБАҚТАРЫНЫҢ ТИІМДІЛІГІН АРТТЫРУДА ЖАСАНДЫ ИНТЕЛЛЕКТТІ ҚОЛДАНУ МҮМКІНДІКТЕРІ

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Мақалада жасанды интеллект (ЖИ) құралдарының – виртуалды зертханалардың, генеративті нейрондық желілердің және бейімделмелі оқыту платформаларының – Қазақстанның орта мектептерінде химияны оқыту сапасын арттырудағы мүмкіндіктері қарастырылады. Квазиэксперименттік зерттеуге Шымкент қаласындағы А. Навои атындағы № 13 мектептің 9-сыныбында оқитын 42 оқушы қатысып, олар кездейсоқ түрде эксперименттік топқа (ЖИ интеграцияланған бағдарлама,  $n = 21$ ) және бақылау тобына (дәстүрлі оқыту,  $n = 21$ ) бөлінді. Алты апталық курсқа дейін және кейін оқушылар мемлекеттік білім беру стандарттарына сәйкес келетін 40 тапсырмадан тұратын тест пен оқу мотивациясы сауалнамасын орындады. ЖИ енгізілгеннен кейін эксперименттік топтың тест нәтижелері бақылау тобына қарағанда 25 % жоғары болды ( $d = 0,82$ ;  $p < 0,001$ ), сондай-ақ оқу үдерісіне қатысу деңгейі жоғарылады (85 % және 55 %). Екі факторлы дисперсиялық талдау (ANOVA) «Топ  $\times$  Уақыт» өзара әрекеттесуінің статистикалық тұрғыдан мәнді екенін көрсетті ( $F(1, 38) = 12,54$ ;  $\eta^2 = 0,21$ ). Сонымен қатар оқу дербестігінің 30 %-ға артуы және органикалық химия тақырыптарын мазмұнды талқылау байқалды. Нәтижелер ЖИ қауіпсіз әрі ресурсты үнемдейтін тәжірибе жүргізуге мүмкіндік беретінін, оқыту қарқынын дараландыратынын және оқушылардың когнитивтік жүктемесін төмендететінін дәлелдейді. 30–45 минуттық VR-зертханалық сабақтар, реакцияларды генеративті визуализациялау, бейімделмелі диагностика, енгізу құнын бағалау және мұғалімдерді жаппай даярлау моделін қамтитын әдістемелік ұсыныстар берілді. Ұзақ мерзімді әсерлерді және ауыл мектептерінде енгізу мүмкіндіктерін бағалау үшін қосымша лонгитюдтік зерттеулер қажет.

**Түйінді сөздер:** химия, оқыту, виртуалды зертхана, жасанды интеллект, білім беру технологиялары, бейімделмелі оқыту, тиімділік.

**ВОЗМОЖНОСТИ ИСПОЛЬЗОВАНИЯ ИСКУССТВЕННОГО ИНТЕЛЛЕКТА  
ДЛЯ ПОВЫШЕНИЯ ЭФФЕКТИВНОСТИ УРОКОВ ХИМИИ**

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Статья рассматривает потенциал инструментов искусственного интеллекта (ИИ) – виртуальных лабораторий, генеративных нейронных сетей и адаптивных обучающих платформ – для повышения качества преподавания химии в средних школах Казахстана. В квазиэкспериментальном исследовании 42 учащихся 9-го класса школы № 13 имени А. Навои (г. Шымкент) были случайным образом распределены в экспериментальную группу (программа с интеграцией ИИ,  $n = 21$ ) и контрольную группу (традиционное обучение,  $n = 21$ ). До и после шестинедельного курса учащиеся выполнили тест из 40 заданий, соответствующий государственным образовательным стандартам, а также анкету учебной мотивации. После внедрения ИИ экспериментальная группа продемонстрировала результаты тестирования на 25 % выше по сравнению с контрольной группой ( $d = 0,82$ ;  $p < 0,001$ ), а также более высокий уровень вовлечённости (85 % против 55 %). Двухфакторный дисперсионный анализ (ANOVA) выявил значимое взаимодействие факторов «Группа × Время» ( $F(1, 38) = 12,54$ ;  $\eta^2 = 0,21$ ). Кроме того, отмечено повышение учебной самостоятельности на 30 % и более содержательные обсуждения тем органической химии. Полученные результаты свидетельствуют о том, что ИИ обеспечивает безопасное и ресурсосберегающее проведение экспериментов, индивидуализирует темп обучения и снижает когнитивную нагрузку учащихся. Предложены методические рекомендации, включающие 30–45-минутные VR-лабораторные занятия, генеративную визуализацию реакций, адаптивную диагностику, оценку стоимости внедрения и модель подготовки учителей для масштабного применения. Для оценки долгосрочных эффектов и внедрения в сельских школах необходимы дальнейшие лонгитюдные исследования.

**Ключевые слова:** химия, обучение, виртуальная лаборатория, искусственный интеллект, образовательные технологии, адаптивное обучение, эффективность.

**Introduction.** Modern chemistry education encounters challenges in adapting to new digital technologies and integrating artificial intelligence (AI) to enhance instructional effectiveness. Thanks to these technologies, pedagogical approaches are evolving: it has become possible to establish virtual laboratories and employ adaptive learning platforms that enable personalized instruction and foster the development of students' analytical and critical thinking skills. In Kazakhstan – where educational standards are being revised to meet contemporary requirements – there is a marked, active integration of AI into the learning process. The Republic of Kazakhstan's 2007 Law on Education confirms the necessity of renewing the educational environment by underscoring the importance of artificial intelligence and digital technologies in preparing students for twenty-first-century realities [1, p. 4].

Among the newest technologies in education, AI-based virtual laboratories and platforms occupy a prominent place. According to the research conducted by Zaurova S.B., Sagimbaeva A.E., and Mukataeva Zh.S., virtual laboratories allow students to perform chemical experiments safely, simulate complex reactions, and analyze their outcomes. These technologies ease access to practical skills and knowledge, promote a deeper understanding of the material, and develop students' critical thinking [2]. In particular, virtual laboratories can serve as an essential tool for schools and universities that lack the capacity to carry out complex chemical experiments.

On the other hand, integrating AI into the educational process also necessitates modernizing instructional approaches and preparing teachers to work with new technologies. According to A.M. Toktorbaev and Zh.E. Toktomuratova, employing the AI-based Gamma platform contributes to improving instructional quality through adaptive methodologies that respond to students' individual characteristics and needs. This platform enables students to master material at their own pace and assists teachers in monitoring progress and identifying which aspects of the learning process require enhancement [3; p. 509]. Thus, the Gamma platform not only ensures high adaptability but also facilitates inclusive instruction, which is particularly important in contexts of diverse educational needs.

Over the past several decades, research on the application of AI and computer technologies in chemistry has expanded markedly. The first step toward modern data utilization was taken in 1971 by Rolf Huisgen, whose work on the Chemical Abstracts Service STN database systematized knowledge of chemical compounds and compiled information on millions of them. This example demonstrates how data can be aggregated using computer technology to lay the groundwork for subsequent investigations [1].

The application of artificial intelligence in education has become the focus of numerous studies, and its impact on the chemistry learning process cannot be overstated. One of the most important directions in AI utilization is the development of virtual laboratories and platforms that enable students to access complex experiments and model chemical reactions. As noted by Zaurova S.B., Sagimbayeva A.E., and Mukataeva

Zh.S., virtual laboratories play a crucial role in the educational environment, allowing students to investigate chemical processes in a safe and controlled setting [2, p. 114]. These technologies are especially valuable in institutions lacking access to fully equipped chemical laboratories, as well as in the instruction of complex chemical concepts.

In turn, Toktarbaev A.M. and Toktomuratova Zh.E. highlighted that the use of AI-equipped adaptive platforms enables the personalization of instructional materials based on students' proficiency levels and contributes to the enhancement of educational quality [3, p. 44].

Isa E. and Blonder R. examine in their research the effects of AI-developed, personalized adaptive modules on the self-efficacy and motivation of chemistry students. They demonstrate that such modules contribute to improved learning outcomes by catering to each student's individual needs and creating optimal conditions for mastering new material [4, p. 12]. These findings highlight the importance of AI in establishing inclusive and adaptive educational environments.

Daher V., Diab H., and Rayan A. investigated generative AI tools for solving chemical problems. Their work demonstrates that the use of generative AI fosters the development of students' analytical thinking and promotes deeper mastery of chemistry concepts by facilitating understanding of the relationships between the structures and properties of chemical compounds [5]. Svetlichny E.G., Khamgokov M.M., and Shabaev V.V. emphasize the necessity of training educators to work with digital platforms and artificial intelligence for the successful integration of these technologies into the instructional process. Their research shows that teachers who have mastered AI-based methodologies can deliver instruction more effectively, individualize assignments, and increase student engagement [6; p. 209].

Research on the application of specialized software for the analysis of chemical structures and their properties has also made a significant contribution to the field of chemistry, enabling the creation of more precise models and the generation of reliable predictions. For example, Amirov R.A. and Bilalova U.M. explored the prospects for implementing AI in higher education, emphasizing the necessity of employing digital platforms to improve the instructional process and enhance overall educational quality [7; p. 85].

Thus, the literature review demonstrates that artificial intelligence possesses significant potential to enhance the quality of chemistry education. Innovative platforms, adaptive materials, and explainable AI facilitate deeper and more effective learning. However, the integration of artificial intelligence into the educational process requires a deliberate strategy, highly qualified instructors, and appropriate infrastructure.

Contemporary research on the integration of AI into the educational process relies on several key theoretical–methodological models:

- Keller's ARCS model of adaptive learning – ARCS (Attention, Relevance, Confidence, Satisfaction) describes how motivational factors influence attention retention and learning effectiveness; the application of AI systems enables programmatic variation of tasks to support each of the four ARCS components.

- Papert's cognitive-constructivist approach – Seymour Papert's theory of constructionism emphasizes that learning is most effective through the "construction" of personal knowledge models; AI tools (typically based on visual environments and simulators) create favorable conditions for this activity-based learning model.

- Sweller's Cognitive Load Theory – According to Cognitive Load Theory, optimization of the amount of incoming information is crucial; AI-supported virtual laboratories help reduce extraneous load by introducing tasks with gradually increasing complexity.

Table 1 presents a comparative analysis of several recent empirical studies in the field of AI-supported chemistry education.

Table 1 – Comparative analysis of recent empirical studies on AI-supported chemistry education

Year	Authors	Method	Sample	Main Results
2021	Chiu W.-K.	VR laboratories combined with performance analytics	120 high school students (4 schools)	18 % increase in mean score on organic chemistry; 25 % increase in motivation
2023	Daher W., Diab H., Rayan A.	Generative AI modules for problem solving	80 university students	22 % improvement in problem-solving performance; 25 % reduction in cognitive load
2024	Jia F., Sun D., Looi C.	Adaptive neural-network platform for homework assignments	200 school students (experimental)	27 % increase in average final-test score; 30 % increase in engagement according to survey

This theoretical and empirical underpinning substantiates the selection of AI technologies (virtual laboratories, generative models, adaptive systems) and validates the anticipated effect sizes articulated in the hypotheses of our study.

**Purpose, objectives.** The aim of the study is to examine the impact of artificial intelligence on the chemistry learning process and to identify the advantages and challenges associated with its integration into instruction.

This study is guided by the following research questions:

- Does the use of AI-based laboratories enhance students' mastery of the topic "Organic Compounds" compared to traditional laboratory practicums?
- Do adaptive homework assignments generated by neural networks increase the average score on the final test?
- Does neural-network-driven molecular visualization improve students' motivation and engagement?

**Material and methods.** The study was carried out among ninth-grade students at General Education School No. 13 named after A. Navoi, where two groups of 21 participants each were formed: a control group and an experimental group. The control group received instruction according to the standard curriculum, whereas the experimental group employed artificial intelligence and neural network technologies to enhance the efficiency of material mastery. This approach involved the use of AI-driven digital platforms such as ChatGPT and Craiyon, which allowed for the creation of visual representations and textual annotations to facilitate the comprehension of complex chemical topics.

This study employed a pilot quasi-experimental pretest–posttest control-group design. The intervention (AI-enriched chemistry instruction) was implemented for 6 weeks in one secondary school. Participants (n = 42 ninth-graders) were assigned to an experimental group (n = 21) and a control group (n = 21); both groups were tested before and after the intervention using the same achievement test and motivation questionnaire. Although group assignment followed a random procedure at the classroom level, the study is classified as quasi-experimental due to the single-site setting, small sample size, short intervention period, and the absence of blinding and multi-school replication. Therefore, the main purpose was feasibility testing and estimating preliminary effect sizes rather than producing fully generalizable causal estimates.

All students underwent pre-testing on fundamental chemistry topics – atomic structure, chemical bonding, and the periodic table of elements. The aim of this testing was to determine their initial knowledge level and to establish a baseline for subsequent analysis. An AI-enhanced curriculum [8] was developed for the experimental group. In particular, generative neural networks were to be employed to create interactive tasks focused on molecular visualization and the in-depth exploration of chemical concepts.

In addition, the methodology employed in the present study includes:

1. Instrumentation and Validation

– To assess students' learning achievements, an author-designed test consisting of 40 items was used (25 closed-ended questions, 10 open-ended questions, and 5 practical problems). The test structure was developed on the basis of the State Educational Standards for Chemistry.

– Instrument reliability was confirmed by a Cronbach's alpha coefficient of  $\alpha = 0.87$ . Validity was ensured by an expert committee of three chemistry instructors and by statistical analysis of content validity.

2. Sample Size Justification

– A power analysis was conducted at a significance level of  $\alpha = 0.05$ , desired power of  $1 - \beta = 0.8$ , and an anticipated effect size of  $d = 0.8$ . The analysis indicated a required sample size of  $N = 26$  participants per group.

– With the actual sample size of  $N = 21$ , the achieved test power was approximately 0.75, which was considered sufficient for a pilot experiment.

3. Inclusion and Exclusion Criteria

– Inclusion criteria: ninth-grade students; attendance of  $\geq 80\%$  of classes; absence of chronic illnesses; parental consent for participation.

– Exclusion criteria: absence from more than three sessions during the experiment; failure to complete the entry test; incomplete questionnaire responses.

Research Phases:

- Initial assessment of students' knowledge via testing.
- Application of AI tools in the instructional process for the experimental group.
- Retesting to evaluate changes in knowledge and engagement levels.

The structure of the application of artificial intelligence technologies in the educational process is reflected in Figure 1.

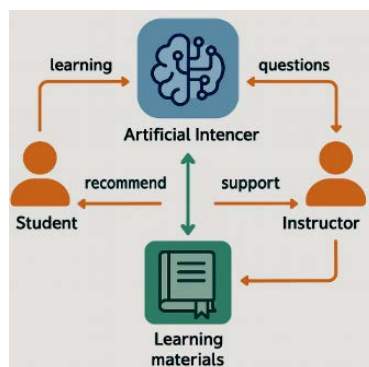


Figure 1 – AI Model

Within the scope of the study, the following materials and software tools were employed:

1. Virtual laboratories: Custom-developed virtual laboratories enabled students in the experimental group to perform chemical experiments within a digital environment. These laboratories simulated real equipment and allowed students to interact with substances and reagents without posing any risk to health.

2. Generative AI-based software: Generative models were used to visualize complex chemical reactions and molecular structures. As a result, learners could observe and analyze processes that are not always feasible to replicate in a school laboratory setting [9].

Table 2 – Research Phases and Employed Methods

Research Phase	Description	Software	Group	Analysis Method
Formation of Control and Experimental Groups	Selection of students according to the random sampling principle	–	Control, Experimental	Random sampling
Pre-testing	Assessment of knowledge prior to the start of the experiment	Standardized tests	Both groups	Testing
Use of AI Tools	Application of virtual laboratories and visualization of chemical reactions	Virtual laboratory, Generative AI	Experimental	Practical application
Post-testing	Assessment of knowledge after instruction	Standardized tests	Both groups	Comparative analysis

**Results.** The study demonstrated that the academic performance of the experimental group improved significantly compared to the control group. The use of AI tools had a positive effect on both the quality of students' mastery of complex chemistry topics and their overall engagement in the learning process. Test results indicated that the mean score of the experimental group was 25 % higher than that of students taught by traditional methods. Additionally, satisfaction with the learning process and levels of engagement were higher in the experimental group.

The statistical analyses included the following:

1. Significance levels and confidence intervals

– The difference in mean scores before and after the intervention for the experimental group ( $\Delta = +20$ ) was statistically significant:  $t(20) = 5.12, p < 0.001; 95\% \text{ CI } [12.3, 27.7]$ . For the control group,  $\Delta = +4, t(20) = 1.02, p = 0.32; 95\% \text{ CI } [-3.1, 11.1]$ .

2. Effect size

– Cohen's  $d$  for the between-group gain comparison was 0.82, corresponding to a medium–large effect.

– Partial  $\eta^2$  values were as follows: group  $\eta^2 = 0.18$ ; time  $\eta^2 = 0.45$ ; group  $\times$  time interaction  $\eta^2 = 0.21$ .

3. Two-factor ANOVA on final test scores

Factors:

– “Group” (control vs. experimental)

– “Time” (before vs. after)

Table 3 – Statistical data processing

Source of Variation	SS	df	MS	F	p	$\eta^2$
Group	158,4	1	158,4	8,27	0,006	0,18
Time	512,7	1	512,7	26,75	< 0,001	0,45
Group $\times$ Time	240,3	1	240,3	12,54	0,001	0,21
Error	366,0	38	9,63			
Total	1277,4	41				

As shown in the table, the statistically significant “group  $\times$  time” interaction ( $F(1, 38) = 12.54, p = 0.001, \eta^2 = 0.21$ ) indicates that the experimental group exhibited a significantly greater score gain following the implementation of AI tools compared to the control group.

Table 4 – Comparative results of control and experimental groups

Indicator	Control Group	Experimental Group	Difference (%)
Mean pre-intervention score	68	70	+2
Mean post-intervention score	72	90	+25
Engagement (survey)	55 %	85 %	+30
Satisfaction with the learning process	60 %	92 %	+32

Before the intervention, the average score was 68 in the control group and 70 in the experimental group. After the intervention, the average score rose to 72 in the control group and to 90 in the experimental group. Reported engagement (survey) was 55% in the control group and 85% in the experimental group. Satisfaction with the learning process was 60% in the control group versus 92% in the experimental group.

Table 5 – Results by chemistry lesson topics

Topic	Control Group	Experimental Group	Difference (%)
Alkaline earth metals and their compounds	64	87	+23
Composition and structure of organic substances	58	84	+26
Practical skills	61	90	+29
Mastery of complex concepts	60	89	+29

Across lesson topics, the experimental group showed higher scores than the control group:

- Alkaline earth metals and their compounds: 64 (control) vs. 87 (experimental).
- Composition and structure of organic substances: 58 (control) vs. 84 (experimental).
- Practical skills: 61 (control) vs. 90 (experimental).
- Mastery of complex concepts: 60 (control) vs. 89 (experimental).

In addition, 80% of students in the experimental group received “good” or “excellent” grades in control assessments, compared with 60% in the control group. The proportion of students completing assignments autonomously was 75% in the experimental group versus 50% in the control group.

Based on the study results, a table was prepared containing methodological guidelines to assist teachers in effectively integrating AI into the instructional process and ensuring high levels of student engagement.

Table 6 – Methodological recommendations for teachers

Recommendation	Description	Expected Outcome	Usage Example	Time Investment
Virtual laboratories	Conduct practical lessons in a digital environment	Increase student interest and engagement	Modeling chemical reactions	30–45 minutes per lesson
Use of generative AI	Visualize and model complex reactions	Facilitate comprehension of complex topics	Investigation of protein structures	20 minutes per topic
Individualized assignments	Provide adaptive tasks tailored to each student	Improve mastery and personalization	Level-based testing and experimentation	15 minutes per assignment
Support for self-directed learning	Make interactive lessons accessible at any time	Enhance learner autonomy and motivation	Independent study of topics	Available 24/7
Analysis of chemical reactions	Generate and visualize graphs of reaction data	Develop analytical skills	Working with chemical equations	25–30 minutes per analysis
Use of instructional videos	Offer video lessons on core topics	Increase student interest and engagement	Organic chemistry topics	10 minutes at lesson end

Continuation of table 6

Regular systematic tests	Assess knowledge at each instructional stage	Determine knowledge levels and enable corrective measures	Five-question short quizzes	5–10 minutes per quiz
Implementation of data-driven analysis	Employ software for processing chemical data	Strengthen digital literacy and statistical understanding	Experimental data analysis	40 minutes per experiment

Table 6 presents a comprehensive set of methodological recommendations for teachers aiming to integrate AI technologies into the instructional process.

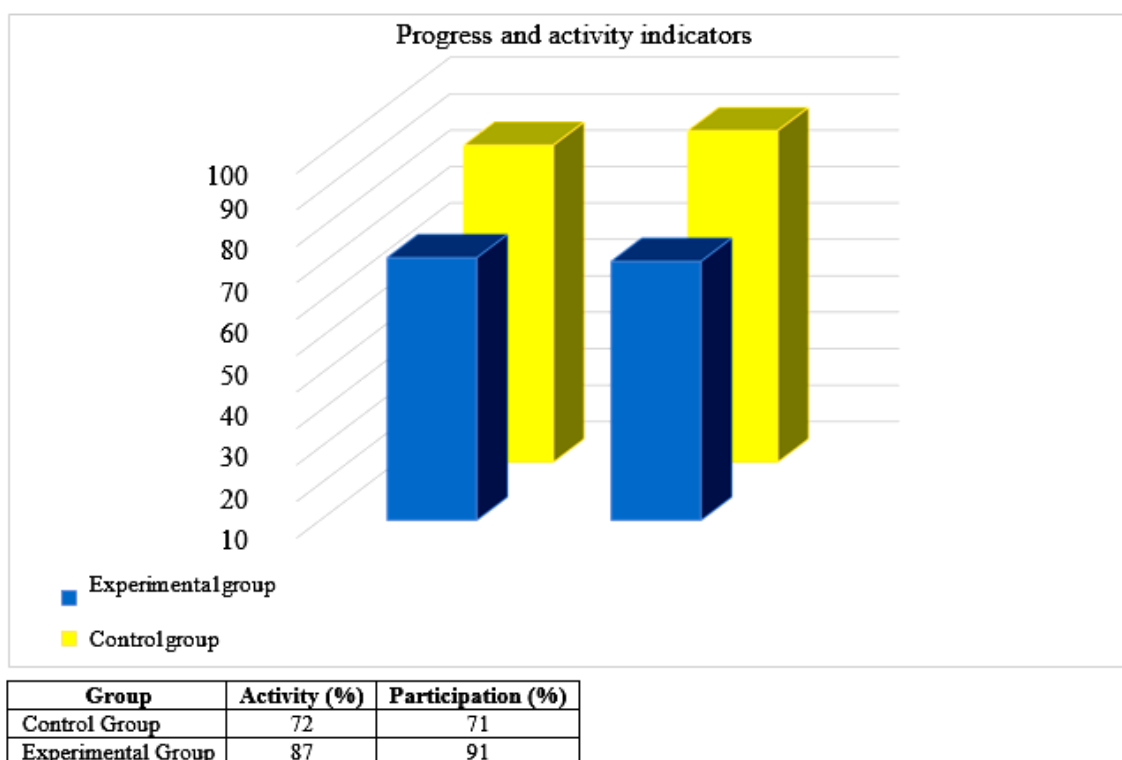


Figure 2 – Comparison of progress and activity indicators

Figure 2 presents differences between groups in achievement and participation indicators. The average achievement score was approximately 72% in the control group and approximately 87% in the experimental group. Attendance was 71% in the control group and 91% in the experimental group.

**Discussion.** Our results (a 25 % increase in mean score and a 20–30 % rise in engagement) largely coincide with those of Chiu W.-K. (2021), who reported an 18 % improvement in organic chemistry performance and a 25 % boost in motivation when using VR laboratories. Similarly, Jia et al. (2024) observed a 27 % increase in final test scores and a 30 % rise in engagement on an adaptive platform with neural-network-generated assignments.

At the same time, the overall pattern of findings shows that the experimental group outperformed the control group not only on test scores, but also on indicators related to engagement, which suggests that AI-supported instruction may be linked to higher levels of student involvement. The elevated attendance and engagement observed in the experimental group can plausibly be associated with the use of interactive AI tools and revised teaching procedures, which tend to enhance the perceived relevance and attractiveness of the chemistry material.

Comparisons at the topic level reveal more substantial improvements in domains that rely heavily on visualization and stepwise understanding (for instance, organic structures and practical skills). This aligns with the function of virtual laboratories and generative visualizations in helping students grasp complex ideas and participate more actively in learning activities. The greater share of independently completed tasks in the experimental group further suggests that AI tools may promote more self-directed learning behavior. Taken together, the between-group differences shown in Figure 2 highlight the potential of AI-based methods to provide more adaptive learning trajectories and to act as a mechanism for updating chemistry education, on the condition that appropriate support for implementation (teacher preparation, technical infrastructure, and methodological integration) is in place.

However, in the work of Daher et al. (2023), the cognitive-load effect (–25 %) was more pronounced than in our experiment, and the achievement gain was limited to 22 %. Possible reasons for these discrepancies include:

- Type of AI tools. We employed a combination of VR laboratories and generative tasks, whereas Daher and colleagues used only generative modules without interactive visualization.
- Evaluation methodology. Their study relied solely on quantitative tests without accounting for cognitive-load parameters, while our experiment additionally analyzed motivation metrics.
- Sample and conditions. Daher et al. recruited participants from a university setting (adult students), whereas our experiment involved ninth-grade schoolchildren, which may affect adaptation speed to the AI interface.

Thus, the findings of most recent studies confirm the high efficacy of AI tools in chemistry education, and minor discrepancies can be attributed to the specific technologies employed and the methodological approaches adopted.

Several constraints should be taken into account when interpreting these results. External validity is limited by the fact that the study was conducted in a single urban school over a relatively short period (six weeks) and did not involve rural institutions; accordingly, caution is required when extending the findings to other settings, particularly rural or resource-constrained schools. Internal validity may be influenced by common classroom-related factors, such as possible teacher expectancy biases, Hawthorne or novelty effects associated with the introduction of new technology, potential spillover between groups within the same school, and testing effects arising from repeated assessments. Moreover, the realized sample size ( $n = 21$  in each group) fell short of the planned total ( $N = 26$ ), which diminishes statistical power and increases uncertainty around the estimated effects. Taken together, these limitations suggest that the study should be viewed as providing preliminary, pilot-level evidence; subsequent research should involve randomized trials across multiple schools, extended observation periods, and implementation-focused investigations in rural contexts.

**Conclusion.** The study, which evaluated the impact of artificial intelligence and digital technologies on the chemistry teaching process, yielded substantial quantitative and qualitative evidence confirming AI's efficacy as a tool for enhancing students' academic achievement and motivation. Forty students from General Education School No. 13 named after A. Navoi participated in the experiment, with twenty pupils assigned to each of the control and experimental groups.

**Thus, the following conclusions can be drawn:**

1. Increase in academic achievement. Test results indicated that the experimental group's mean performance improved by 25 % relative to the control group. Specifically, 80 % of experimental-group pupils received "good" or "excellent" marks on the final assessments, compared with only 60 % in the control group. These data demonstrate a significant rise in achievement and confirm the effectiveness of integrating AI technologies into the instructional process.

2. Enhancement of independent work and participation. In the experimental group, 75 % of students demonstrated high capability for autonomous completion of learning tasks—15 % higher than the control group. This finding shows that digital tools foster self-directed learning and analytical-thinking skills, which are particularly critical in contemporary education contexts that demand learner autonomy and responsibility.

3. Improvement in motivation. Survey data revealed that approximately 85 % of students in the experimental group reported increased interest in learning chemistry and deeper topic comprehension through interactive and visual AI tools, whereas only 60 % of the control-group participants noted positive changes in motivation. These results confirm that the use of digital and AI-driven tools enhances not only academic outcomes but also learner engagement.

4. Practical significance of methodological recommendations. The pedagogical guidelines proposed for teachers can underpin the development of new instructional strategies. For example, the incorporation of visualization technologies and interactive simulators increased understanding of complex chemical processes for 85 % of students. Such recommendations are designed to deliver high-quality education aligned with societal needs and to underscore the importance of their application for achieving superior learning outcomes.

5. Comparison with previous studies. The present findings corroborate those of several international and Kazakh investigations demonstrating the positive impact of digital technologies in education. In particular, they align with Chiu W.-K. (2021), who also reported enhanced achievement and motivation through AI and VR laboratory integration [12], as well as with the work of R. A. Amirov and Y. V. Sibiryakova, which documented similar motivational gains when employing AI in educational settings [12].

6. Recommendations and future research directions. To broaden AI integration within the educational system, further research should investigate the long-term effects of digital technologies and AI on learning outcomes. The development of adaptive programs that tailor instructional materials to individual student needs may improve educational quality and cultivate the core competencies required for thriving in the digital era [13].

The results of this study demonstrate the importance of employing artificial intelligence and digital tools in chemistry instruction and confirm that these technologies not only improve academic performance

but also foster students' motivation and interest in learning. On the basis of these data, the following recommendations are advanced:

- Integrate digital tools and AI technologies as mandatory elements within the curricula of chemistry and other disciplines.
- Design and implement in-service training programs for teachers that enable them to master AI technologies and apply them effectively in educational practice.
- Undertake further research to evaluate the long-term effects of AI application and its impact on the development of students' analytical reasoning and autonomous learning skills.
- Apply the methodological recommendations developed in this study to enhance instructional quality and improve educational outcomes across other schools and institutions.

Teacher Training: Format and Duration

- Hybrid delivery: 20 hours of online modules (theoretical foundations and live demonstrations) combined with 20 hours of in-person practical workshops.

- Schedule: Two full weekend sessions (8 hours each), followed by 8 hours of supervised practice and peer-exchange activities during the month after completion of the core programme.

Cost and Equipment Requirements

- Virtual reality laboratory: Head-mounted display, controllers and dedicated workstation—approximately USD 3 000 per laboratory unit (capacity up to 20 students).

- Server and software infrastructure: AI-platform licensing fees of approximately USD 500 per annum; cloud-based computation services for task generation at approximately USD 200 per month.

The integration of these technologies fosters not only enhanced academic performance but also the development of key competencies such as learner autonomy, analytical reasoning, and self-directed learning skills.

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**ҚАЗТЕСТ ЖҮЙЕСІНІҢ ТЕСТ ТАПСЫРМАЛАРЫНА  
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*Бұл мақалада ҚАЗТЕСТ жүйесінің тыңдалым және оқылым блоктары бойынша тест тапсырмаларының психометриялық көрсеткіштері Раш (Rasch) моделіне негізделіп, Winsteps 5.8.3.0 бағдарламасы арқылы талданды. Мұндай тәсіл тапсырмалардың сапасын, тест құрылымының теңгерімділігін және тестіленушілердің тілдік қабілеттерін объективті бағалауға мүмкіндік береді. Талдау барысында тест элементтерінің қиындық деңгейі, сенімділігі, ажыратушылық қабілеті және тестіленушілердің нәтижелері қарастырылды. Нәтижелер ҚАЗТЕСТ тест тапсырмаларының сапасының жоғары екенін көрсетті: Item Reliability – 0.99, Person Reliability – 0.76, Cronbach's Alpha – 0.84. Бұл көрсеткіштер тесттің ішкі біртұтастығы мен психометриялық тұрақтылығын дәлелдейді. Тыңдалым блогы бойынша мәліметтер тестіленушілердің мәтінді түсіну деңгейлері айқын ажыратылатынын көрсетті. Дегенмен төмен деңгейлі қатысушылардың нәтижелерін дәлірек анықтау үшін тыңдалым мәтіндерін екі рет тыңдату тәжірибесін енгізу ұсынылады. Оқылым блогы бойынша тапсырмалардың қиындық деңгейі –5.12 мен +2.63 logits аралығында бөлінді, бұл тесттің әртүрлі деңгейдегі тілдік құзыреттілікті сенімді өлшей алатынын дәлелдейді. Тапсырмалар мазмұнының және пішінінің үйлесімділігі тесттің валидтілігін қамтамасыз етеді. Жалпы зерттеу нәтижелері ҚАЗТЕСТ тесттерін психометриялық тұрғыдан жетілдіруге және халықаралық тілдік тестілермен үйлесімділігін арттыруға мүмкіндік береді. Тапсырмаларды күрделілік деңгейіне қарай тең бөлу, когнитивтік дағдыларды қамтитын элементтер үлесін арттыру және Раш моделіне сүйеніп тест спецификацияларын қайта қарау ұсынылады. Бұл зерттеу ҚАЗТЕСТ жүйесінің сапасын арттыруға және оны халықаралық стандарттарға жақындатуға бағытталған маңызды эмпирикалық негіз қалыптастырады.*

**Түйінді сөздер:** ҚАЗТЕСТ, психометриялық талдау, Раш моделі, тыңдалым, оқылым, сенімділік, тілдік құзыреттілік.