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Application of artificial intelligence technologies in teaching chemistry

Modern artificial intelligence technologies are being actively introduced into chemistry teaching, expanding the possibilities of learning and experimentation. This article examines the key areas of artificial intelligence application in the educational process, including the use of ChatGPT and VR Chemistry Lab systems. The benefits of AI integration have been analyzed, such as increasing the level of student engagement, improving the assimilation of complex chemical concepts, and optimizing the work of teachers. The purpose of the study is to analyze the use of artificial intelligence in chemical education, its scientific and practical significance in the context of modern educational technologies. The work is aimed at exploring the possibilities of artificial intelligence to create personalized educational trajectories, optimize the learning process and improve the safety of experiments. The research methodology is based on an analysis of existing international research and examples of the use of artificial intelligence in chemistry teaching. As a result, the high potential of artificial intelligence has been identified to improve the quality of education, increase student engagement, and create a safe environment for experimentation. The main findings show that artificial intelligence contributes to an improved understanding of complex chemical processes through visualization, as well as assists in monitoring and analyzing educational activities.

Keywords: Artificial intelligence, chemistry teaching, ChatGPT, VR Chemistry Lab, differentiated tasks, pedagogical technologies, inclusive learning.

Introduction

The near future of humanity is associated with a fundamental change in all spheres of human life under the influence of digital technologies and artificial intelligence [1]. The use of artificial intelligence is becoming an integral part of modern education, opening up new perspectives for students and teachers [2]. In the modern era, a large-scale technological transformation is underway, known as Industry 4.0, characterized by the integration of cognitive and physical systems into production processes and the social space of individuals.

In an implicit or explicit manner, the existence of a significant part of the population is modified under the influence of intelligent computer systems. As an empirical illustration, it can be stated that algorithmic machine learning systems are already integrated into information search engines, educational digital platforms, and electronic communication systems (including the Google and Yandex ecosystems) in order to optimize and amplify user experience.

During the digital evolution of the educational system, the introduction of intelligent technologies into the teaching methodology of chemistry constitutes a progressive didactic approach [3]. Modern molecular science requires students to master the perception of complex atomic interactions, spatial intelligence, and experimental data processing skills. Cognitive systems demonstrate significant potential in optimizing the educational process through individualization of learning, visualization of chemical processes, and automation of pedagogical functions.

The key scientific and practical significance of the research is dictated by the challenges facing the modern system of chemical education: the imbalance between the rapid development of AI technologies and their limited integration into the educational process, the lack of a methodological basis for the implementation of intelligent systems in chemistry teaching, the need to develop adaptive educational platforms.

The modern education system in chemistry education is in critical need of innovative teaching methods based on artificial intelligence technologies that can overcome the limitations of traditional pedagogical approaches by introducing predictive performance analytics and creating personalized educational trajectories.

Methods and materials

‒ The present study analyzes modern literature, including domestic and foreign works devoted to the field of artificial intelligence in chemistry teaching. We have formulated the following research questions:

‒ What are the possibilities and limitations of using artificial intelligence in chemistry teaching?

‒ What is the role of artificial intelligence systems such as ChatGPT and VR Chemistry Lab in optimizing the educational process and the safety of conducting chemistry experiments, as well as creating and analyzing pedagogical components for chemistry teaching?

‒ What are the practical and pedagogical advantages and disadvantages of using artificial intelligence in chemistry teaching?

‒ We have put forward the following hypothesis: The use of artificial intelligence in chemistry teaching, including virtual laboratories and deep learning systems, significantly improves the quality of teaching, contributes to students' enhanced understanding of chemical processes, improves the safety of experiments and increases student engagement.

‒ The stages of the research included:

‒ review of domestic and foreign research: At this stage, an analysis of scientific papers for 2023-2025 was conducted on the use of artificial intelligence in chemistry teaching, as well as the use of specific systems such as ChatGPT and VR Chemistry Lab. This allowed us to identify current trends, problems and opportunities related to the use of artificial intelligence;

‒ comparative analysis: assessment of the effectiveness of some artificial intelligence technologies in the educational process, including their use to create personalized educational trajectories and improve learning outcomes;

‒ developing recommendations: based on the analysis of existing data, recommendations were formulated for more effective implementation of artificial intelligence in chemistry teaching.

‒ Research methods:

‒ a systematic review and analysis of existing research on the use of artificial intelligence in chemistry teaching;

‒ a comparative analysis to evaluate the effectiveness of artificial intelligence-based methods compared to traditional methods of teaching chemistry.

‒ The research used methods of monitoring the educational system, studying the experience of chemistry teachers, modeling, comparison and scientific and methodological analysis.

‒ The primary areas of relevance for such research work are as follows:

‒ The development of useful computer technologies that improve the process of teaching subjects;

‒ The introduction of new generation information and special technologies into the educational process;

‒ The introduction of modern pedagogical, innovative and complex technologies into the educational process, etc. [4].

In the course of pedagogical technologies, the student learns and develops under the guidance of teachers. This means that pedagogical technology is designed to achieve a learner's expected goals. For quality and effective education, teaching methods are especially important. The use of integrated technologies in organizing the educational process in accordance with the requirements of modern requirements is of particular importance. Integrating artificial intelligence into domain-specific learning tasks is important because it reflects how people solve practical problems [5]. Pedagogically integrating technology to develop scientific content in a chemical unit that considers the macroscopic, symbolic, and microscopic levels before explaining chemical phenomena, in order to increase the students' cognitive activity and the effectiveness of the learning process, becomes highly relevant and necessary [6; 5].

One of the major benefits of differentiated use of chemistry assignments is that it provides variety in terms of academic readiness, learning styles, and student interests. By tailoring tasks to meet the specific needs of each student, educators can create a supportive and inclusive learning environment in which all students feel valued and capable of success. This approach also helps prevent students from giving up on tasks that are too easy or too difficult, thereby shaping learning attitudes. To focus the attention of students, the teacher significantly transforms and complicates the work in the learning environment, where the necessary cognitive abilities of students are formed and developed (Fig. 1). Flow occurs when the exercises offered to students match their cognitive abilities. The teacher should try to create conditions for students to have what the famous psychologist Csikszentmihalyi called "an end in itself". For these qualities to be reflected in the

learning process, it is important that the experience of flow occurs frequently and that students and teachers make a conscious effort to develop it. Through the mental stimulation of the teacher, students begin to feel a sense of "order in the mind," resulting in them achieving flow. As individuals seek to master new challenges, they develop greater levels of skill. Once mastered, they must identify progressively more complex challenges to create an ideal match for their skills. Flow thereby invokes a growth principle, in which a more complex set of capacities is sought and developed [7].
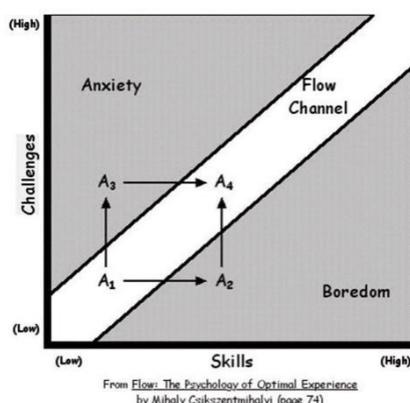

Figure 1. "An End in Self" by Csikszentmihalyi
(https://public-media.interaction-esign.org/images/uploads/3bdf27c0f9980b3227d82bec5f950f20.jpg)

Exercises and tasks tailored to students' abilities in chemistry classes can promote high levels of student engagement and motivation. When students are presented with challenges that match their cognitive abilities, they are more likely to engage in learning and take responsibility for their learning progress. This leads to increased effort, persistencepersistence, and ultimately improved learning outcomes [8]. Differentiated assignments allow students to develop critical thinking and problem-solving skills at an appropriate level.

Differentiated chemistry assignments improve learning outcomes for all students. By meeting a variety of student needs, teachers can effectively support students in mastering basic chemistry concepts. Students demonstrate greater understanding of a subject when they are given tasks that are relevant and interesting to their individual learning needs. In the learning process, learning media play an important role [9]. This approach also helps reduce achievement gaps between students with different levels of prior knowledge and performance. Differentiated tasks play a critical role in effective chemistry teaching and learning.

The study of methods of teaching chemistry has been a topic of interest to many scientists and educators. Several prominent scientists have devoted their research to understanding the most effective ways to teach chemistry in schools. One such scientist, Johnstone, emphasized the importance of using visual representations to learn chemistry concepts [10]. His research focuses on the use of diagrams, graphs, and other visual aids to help students understand complex chemical principles. Johnstone's work had a major influence on the development of chemistry teaching strategies.

Results and discussion

At the present stage, both traditional and highly effective machine learning methods cover a wide range of chemical disciplines: organic chemistry, inorganic chemistry, medicinal chemistry, analytical chemistryanalytical chemistry, and materials science. The number of tasks solved using artificial intelligence has increased significantly and includes, in particular, predicting the thermodynamic and kinetic characteristics of substances, replacing resource-intensive quantum chemical calculations with algorithmic machine learning models, monitoring reaction dynamics and detecting abnormal patterns in mass spectrometry and electron microscopy data. Consequently, artificial intelligence is effectively integrated into most aspects of chemical theory and practice.

Scientists pay special attention to AI's functions, which have the capabilities inherent in humans: thinking, analyzing, solving specific multifunctional, integrated tasks, and self-learning [11].

Machine learning became an integrated component in many fields of chemical science several decades ago. In the field of medicinal chemistry, research has been conducted on correlations between the molecular architecture and the pharmacological activity of organic compounds. In the 80s, statistical methods of linear

regression were used for these purposes, and molecular structures were encoded using matrix representations corresponding to graphs of molecules. In modern conditions, preference is given to deep learning methods — convolutional and recurrent neural networks.

The use of AI in the teaching and learning process is considered in the works of such scientists as Kurbanova Z.S., Ismailova N.P., Filatova O.N., Bulaeva M.N., Gushchin A.V. and Petrov V.V. [12], [13], [14]. According to the authors, artificial intelligence allows changing the approach to learning and increasing student engagementengagement; the introduction of neural networks and the integration of artificial intelligence systems into the educational environment contributes to the openness of learning and its quality improvement [15].

According to the data obtained by Singapore an researchers in 2023, an experiment was conducted on the basis of several schools, which the data describes. Natural science teachers have introduced artificial intelligence into their lessons. In particular, the teachers integrated the structural components of artificial intelligence into the topics "The nature of the particles of matter", "The structure of the atom"atom," and "The cell as the basic unit of life" [16]. The results showed that teachers noted that the use of artificial intelligence in the classroom has made it possible to create models that represent simplified explanations of phenomena and mathematical models, which greatly facilitated the educational process. Models generated by artificial intelligence can be used to predict the structure of a molecule, as well as cell growth at each stage.

Research by the authors Uçar S.Ş. et al. [17] evaluated five major language models (LLM) — ChatGPT, GPT-4, Davinci-003, LlamaLlama, and Galactica — in zero-shot and few-shot learning conditions and showed the diversity of their capabilities in solving various chemistry problems. Competitive results were achieved in two tasks, selective competitiveness was observed in three, and the models showed poor results in the remaining three tasks. GPT-4 stands out in particular, surpassing traditional machine learning algorithms such as random forest and XGBoost in predicting the properties of chemical compounds on multiple datasets.

The EDUCAUSE QuickPoll survey shows that the majority of stakeholders in higher education are confident that artificial intelligence will profoundly change it in the next 3-5 years, and that it has more advantages than disadvantages in higher education [18].

To date, the generative AI chatbot ChatGPT continues to implement and improve its platform. One of the latest studies in this area conducted by the authors Fiorentino M., Gabbard J. L. [19] confirms the effectiveness of its application in the field of organizing educational classes for teachers.

According to a study by the authors Jiménez-Pitre I. et al., ChatGPT can change the way we solve complex global problems and help decision makers develop comprehensive and inclusive strategies [20].

Lee and Zhai (2024) conducted a study in which prospective chemistry teachers were asked to create lesson plans using ChatGPT. 29 future primary school teachers participated in the study, each of them created a lesson plan, assigning specific commands to the chatbot. These lesson plans focused on the objectives of the chemistry curriculum and developing a chosen type of intelligence from multiple intelligence theory. After developing the lesson plan, semi-structured interviews were conducted to capture participants' opinions about their experiences. The results showed dramatically positive results, but it was worth following certain commands when making chatbot requests [21].

− Hunegnaw et al. (2025) conducted a study that compared the impact of virtual and physical laboratory experiments on students' comprehension of chemical kinetics concepts. The results showed that both groups demonstrated significant improvement in their understanding of the material after the experiments. However, qualitative analysis revealed that students using virtual labs were more likely to focus on macroscopic knowledge representation, whereas physical experiments promoted a deeper understanding of submicroscopic and symbolic levels [22].

− Artificial intelligence successfully employs a variety of pedagogical techniques, transforms education into a more dynamic and exciting process, eliminating mechanical memorization of data.

− ChatGPT can provide pedagogical support during classes. The functionality of this technology is remarkable: a language model that generates meaningful answers, creates detailed texts texts, and tasks [23].

− Possible applications of this artificial intelligence system:

− assistance in developing the lesson structure. The system provides a detailed response to a correctly formulated request. Illustration: "Develop a lesson structure about the element oxygen. The lesson duration is 45 minutes. Students are 14-15 years old. The task of the lesson is to master the chemical element".

− control of the development of the material. The AI will help you create a list of questions for the studied section.

— create custom tasks. The system will develop individual home exercises based on the completed material.

— creating a list of auxiliarytasks in the form of reports. The system will help you determine the subject.

— to consolidate and effectively assimilate the material, it is possible to ask questions of the system. The information received can be discussed with the studentsto determine if they share the presented position.

— checking the completion of homework.

For the correct use of artificial intelligence, it is necessary to understand that programs can be used exclusively as an auxiliary tool for improving the effectiveness of teaching [24].

It is of the utmost importance to emphasize that a key characteristic of artificial intelligence is the possibility of personalizing the educational process. Technology is able to create a personalized educational plan for the effective development of knowledge. The algorithm can select appropriate resources, taking into account the students' competencies, or combine students according to similar indicators.

This approach helps to improve academic performance in the discipline while maintaining the same amount of time spent on training. The algorithm is straightforward: the assessment is carried out through test papers that provide accurate information about the level of training. Subsequently, the task of artificial intelligence is to determine the teaching methodology applicable to different groups of students. The artificial intelligence system also demonstrates the ability to identify problem areas, after which it focuses on these aspects (revision of the material, additional exercises).

VR Chemistry Lab is a chemical laboratory, enabling safe manipulation of chemical reagents. In the laboratory, students can design and implement experimental research, formulate theoretical assumptions and verify them empirically, identify and correct errors.

The software package enables analysis of students' manipulative actions and calculate performance indicators for chemical reactions. Consequently, the algorithmic structure does not contain preset reaction schemes such as "component A, when integrated with component B, turns purple", but integrates molar parameters, quantitative ratios, volume characteristics of substances, factors influencing reaction completeness or thermal destruction, sedimentation processes and related phenomena.

Currently, the software platform provides numerous laboratory protocols in the following thematic areas: the study of amphoteric properties, hydration processes of oxide compounds, reducing properties of halogen-containing substances, metal oxide complexes, analytical identification of anionic groups, spectral flame analysis and other research topics.

Nowadays, the use of artificial intelligence in chemical education seems to be an effective tool for stimulating students' cognitive activity in the study of various topics, integrating them into the pedagogical process, and providing autonomy in conducting experiments. It is possible for systematic or methodological errors to occur. Although these errors can be corrected, monitoring of these systems is necessary. The teacher should be able to monitor their students' research activities during experimental classes.

Finally, the most important thing that needs to be emphasized in this context is that experiments involving the use of various chemical reagents, solutions, powders, and others may not be safe, and compliance with safety regulations and experimental conditions is quite strict.

After mastering the theoretical material in chemistry, it will be useful to use a virtual laboratory and conduct an experiment. Thus, an advantage can be identified here from the perspectives of effective training, convenience, and especially economics. A school or university can reduce its equipment costs. It is important to note that the use of a virtual chemical laboratory does not mean that traditional methods should be completely excluded traditional methods of conducting experiments. In particular, students specializing in chemistry-related fields or pursuing narrowly focused professional training still require traditional laboratory experiments .

The introduction of artificial intelligence systems in schools and universities for teaching chemistry is necessary and requires a clear understanding of the directions for their application. First of all, it is worth remembering personalized learning, in which there is a need to adapt educational material to students' individual topics and learning styles, to automatically identify knowledge gaps, and to form a personal educational trajectory and generate individual tasks and exercises in chemistry.

The next thing worth emphasizing is that in a virtual laboratory, as mentioned above, it is possible to simulate various (from simple to complex) chemical reactions and processes, and it is safer to conduct experimental research and to interactively simulate almost all types of chemical processes and visualize them.

Artificial intelligence systems also allow to automatically check assignments completed by students, including test assignments and projects. The system also allows to analyze chemical formulas and reaction

equations, which is the basis of chemistry, and at the same time track the learning process and progress of students and provide feedback instantly.

We have analyzed the advantages and disadvantages of artificial intelligence in chemistry teaching, the advantages include the following:

An absolutely safe environment for conducting the experiment (exclusion of risks and hazardous effects of reactions on the experimenter, safe development of skills and the possibility of conducting dangerous experiments);

− accessibility (the ability to conduct experiments without expensive equipment, round-the-clock access to materials and the possibility of distance learning);

− the effectiveness of learning (increased involvement of students, understanding of complex concepts with visualization, the possibility of repeated practice of the experiment and the development of practical skills);

− Analytical capabilities for the teacher (analysis of academic performance, analysis of errors in completed assignments, prediction of learning difficulties, etc.);

− Pedagogical opportunities for the teacher (creation of assignments, tests, lesson plans, lesson content, etc.).

The disadvantages include the following:

− possible technical limitations (a constant high-quality Internet connection, technical failures, etc.);

− methodological limitations (teachers' lack of experience, limited development of practical skills in working with technology, difficulties in applying or carrying out complex tasks, and the inability to fully replace traditional experiments);

− pedagogical aspects (there are risks of reducing the role of the teacher in the educational process, a possible dependence on technology and the need for regular teacher training);

− psychological aspects (there are risks of reducing social interaction, possible loss of interest in traditional experiments and other pedagogical methods and the formation of an incomplete understanding of chemical processes).

Thus, it is necessary to understand that the successful implementation of artificial intelligence and its systems in chemical education requires a balanced approach, where technology does not replace, but complements the role of the teacher, contributing to a deeper understanding of the subject and the development of theoretical and practical skills of students. At the same time, it is necessary to continuously improve teaching methods, improve the teachers' skills and regularly monitor the effectiveness of the technologies used.

Conclusion

The introduction of artificial intelligence into chemistry teaching demonstrates significant potential for transforming the educational process. VR Chemistry Labs allow for the conduct of secure virtual experiments, automate the processes of knowledge analysis and assessment, including the development of training programs and methodologies, and much more. Studies conducted in various countries confirm the effectiveness of the use of artificial intelligence in chemical education. Based on the literature analysis, we can offer recommendations for the effective implementation of artificial intelligence in chemistry teaching.

It is recommended to apply an integrated approach, starting with the phased introduction of technologies and careful training of teaching staff. It is important to organize regular advanced training courses on working with artificial intelligence and provide teachers with the necessary methodological materials and technical support. Special attention should be paid to the personalization of trainingby using the capabilities of the systems to create individual educational programs and adapt the educational material to the level of each student. At the same time, it is necessary to ensure a high level of security and quality of the educational process, regularly checking the accuracy of the information generated and protecting the personal data of students.

In practical application, it is recommended to combine virtual experiments with real laboratory work, use artificial intelligence for preliminary preparation for practical exercises and develop interactive tasks that contribute to a deeper understanding of chemical processes. Such an integrated approach will make it possible to maximize the potential of artificial intelligence in chemical education, while maintaining a balance between innovative and traditional teaching methods.

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Химия пәнін оқытуда жасанды интеллект технологияларын қолдану

Қазіргі заманғы жасанды интеллект технологиялары химия пәнін оқытуда белсенді түрде енгізілуде, бұл оқыту мен эксперимент жүргізу мүмкіндіктерін кеңейтеді. Мақалада жасанды интеллектің білім беру процесіндегі қолданылу бағыттары, соның ішінде ChatGPT және VR Chemistry Lab жүйелерін пайдалану қарастырылған. Жасанды интеллект интеграциясының оқушылар белсенділігін арттыру, күрделі химия ұғымдарын меңгеруді жақсарту және мұғалімнің жұмысын оңтайландырудағы артықшылықтары талданған. Зерттеудің мақсаты — химиялық білім беруде жасанды интеллект қолданудың ғылыми және практикалық маңыздылығын қазіргі білім беру технологиялары контексінде талдау. Жұмыс жасанды интеллектің жеке білім беру траекторияларын құру, оқу процесін оңтайландыру және эксперименттердің қауіпсіздігін арттыру мүмкіндіктерін зерттеуге бағытталған. Зерттеу әдістемесі халықаралық зерттеулер мен химияны оқытудағы жасанды интеллект қолдану мысалдарын талдауға негізделген. Нәтижесінде білім беру сапасын жақсарту, студенттердің белсенділігін арттыру және эксперименттер үшін қауіпсіз жағдай жасау үшін жасанды интеллектің жоғары әлеуеті анықталды. Негізгі тұжырымдар жасанды интеллект визуализациялау арқылы күрделі химиялық процестерді түсінуді жақсартуға ықпал ететінін және оқу жұмыстарын бақылау мен талдауға көмектесетінін көрсетеді. Жұмыстың құндылығы химиялық білім беруде жасанды интеллекті қолданудың артықшылықтары мен кемшіліктерін негіздеу, оны енгізу және инновациялық технологияларды оқу процесіне сәтті интеграциялау үшін оңтайлы жағдайлар жасау бойынша ұсыныстар беру. Жұмыстың практикалық маңыздылығы оқу орындарында химиялық білім беру сапасын жақсарту үшін ұсынылған ұсыныстарды қолдану.

Кілт сөздер: жасанды интеллект, химияны оқыту, педагог, ChatGPT, VR Chemistry Lab, сараланған тапсырмалар, педагогикалық технологиялар, инклюзивті білім беру, оқу-тәрбие процесі.

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Применение технологий искусственного интеллекта в преподавании химии

Современные технологии искусственного интеллекта активно внедряются в процесс преподавания химии, расширяя возможности обучения и экспериментирования. В данной статье рассмотрены ключевые направления применения искусственного интеллекта в образовательной практике, включая использование систем ChatGPT и VR Chemistry Lab. Проанализированы преимущества интеграции ИИ, такие как повышение уровня вовлеченности учащихся, улучшение усвоения сложных химических концепций и оптимизация работы педагогов. Цель исследования — анализ применения искусственного интеллекта в химическом образовании, его научная и практическая значимость в контексте современных образовательных технологий. Работа направлена на исследование возможностей искусственного интеллекта для создания персонализированных образовательных траекторий, оптимизации учебного процесса и повышения безопасности экспериментов. Методология исследования основана на анализе существующих международных исследований и примерах применения искусственного интеллекта в преподавании химии. В результате был выявлен высокий потенциал искусственного интеллекта для улучшения качества образования, повышения вовлеченности студентов и создания безопасных условий для экспериментов. Основные выводы показывают, что искусственный интеллект способствует улучшению понимания сложных химических процессов через визуализацию, а также помогает в мониторинге и анализе учебных работ. Ценность работы заключается в обосновании преимуществ и недостатков использования ИИ в химическом образовании, рекомендациях по его внедрению и создании оптимальных условий для успешной интеграции инновационных технологий в учебный процесс. Практическое значение работы заключается в применении предложенных рекомендаций для улучшения качества химического образования в учебных заведениях.

Ключевые слова: искусственный интеллект, преподавание химии, педагог, ChatGPT, VR Chemistry Lab, дифференцированные задания, педагогические технологии, инклюзивное обучение, образовательный процесс.

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