# Investigating the Effectiveness of AI-Supported Applications for Chemistry Teachers

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# LIST OF ABBREVIATIONS

**AI** – Artificial Intelligence

**GenAI** – Generative Artificial Intelligence

**STEM** – Science, Technology, Engineering, and Mathematics

**VR** – Virtual Reality

**AR** – Augmented Reality

**ITS** – Intelligent Tutoring Systems

**ML** – Machine Learning

**NLP** – Natural Language Processing

**PD** – Professional Development

**PCK** – Pedagogical Content Knowledge

**CK** – Content Knowledge

**TPACK** – Technological Pedagogical Content Knowledge

**TAM** – Technology Adoption Model

**ADDIE** – Analysis, Design, Development, Implementation, Evaluation

**IoT** – Internet of Things

**CAS** – Chemical Abstracts Service

**PCB** – Physics, Chemistry, Biology

# ABSTRACT

In this study, the impact of AI-assisted applications on teachers' teaching practices, namely the usage of certain AI applications, challenges in using them, and the required professional development needs were investigated. Qualitative content analysis of 30 peer-reviewed scientific papers was complemented by semi-structured interviews of 15 chemistry teachers, thus making it possible to verify theoretical insights in practice. It turned out that using AI technology can significantly help in saving teachers' time while grading, planning lessons, and explaining complex chemistry notions through visualizations. Nevertheless, the significant discrepancy occurred in terms of the tools that teachers utilized. Namely, most of the interviewed teachers used only those technologies that generate text based on the input, such as ChatGPT, neglecting the technologies more relevant for chemistry learning. The reasons behind this include low reliability of AI-based solutions, digital divide, and a lack of specialized professional development programs. Therefore, the results showed that AI is very promising for chemistry teaching. However, its implementation requires three main factors - accessibility, trustworthiness, and integration assistance.

***Keywords:*** *Artificial Intelligence, chemistry teachers, ChatGPT, effectiveness, qualitative design, chemistry education.*

# АҢДАТПА

Бұл зерттеу жасанды интеллектті қолдайтын қосымшалардың мұғалімдерді оқыту практикасына әсерін, атап айтқанда жасанды интеллектті қолдана отырып, белгілі бір қосымшаларды қолдануды, оларды қолданудағы қиындықтарды және кәсіби дамудың қажетті қажеттіліктерін зерттеді. Рецензияланған 30 ғылыми жұмыстың сапалы мазмұнын талдау 15 химия мұғалімдерімен жартылай құрылымдалған сұхбаттармен толықтырылды, бұл теориялық тұжырымдарды іс жүзінде тексеруге мүмкіндік берді. Жасанды интеллект технологиясын қолдану мұғалімдердің уақытын үнемдеуге, сабақ жоспарлауға және визуализация арқылы химияның күрделі ұғымдарын түсіндіруге айтарлықтай көмектесетіні белгілі болды. Дегенмен, мұғалімдер қолданған құралдарға қатысты айтарлықтай алшақтық пайда болды. Атап айтқанда, сауалнамаға қатысқан мұғалімдердің көпшілігі химияны үйренуге қолайлы технологияларды елемей, chatgpt сияқты кірістерге негізделген мәтінді жасайтын технологияларды ғана пайдаланды. Мұның себептері AI негізіндегі шешімдердің сенімділігінің төмендігі, цифрлық алшақтық және арнайы біліктілікті арттыру бағдарламаларының болмауы болып табылады. Осылайша, нәтижелер AI химияны оқыту үшін өте перспективалы екенін көрсетті. Алайда оны жүзеге асыру үшін үш негізгі фактор қажет - қол жетімділік, сенімділік және интеграцияға көмек.

***Кілт сөздер:*** *жасанды интеллект, химия мұғалімдері, ChatGPT, тиімділік, сапалы дизайн, химиялық білім.*

# АННОТАЦИЯ

В этом исследовании было изучено влияние приложений с поддержкой искусственного интеллекта на практику преподавания учителей, а именно использование определенных приложений с использованием искусственного интеллекта, проблемы при их использовании и необходимые потребности в профессиональном развитии. Качественный контент-анализ 30 рецензируемых научных работ был дополнен полуструктурированными интервью с 15 учителями химии, что позволило проверить теоретические выводы на практике. Оказалось, что использование технологии искусственного интеллекта может значительно помочь в экономии времени учителей при выставлении оценок, планировании уроков и объяснении сложных понятий химии с помощью визуализаций. Тем не менее, существенное расхождение возникло в том, что касается инструментов, которые использовали учителя. А именно, большинство опрошенных учителей использовали только те технологии, которые генерируют текст на основе входных данных, такие как ChatGPT, пренебрегая технологиями, более подходящими для изучения химии. Причинами этого являются низкая надежность решений на основе ИИ, цифровой разрыв и отсутствие специализированных программ повышения квалификации. Таким образом, результаты показали, что ИИ очень перспективен для преподавания химии. Однако для его внедрения необходимы три основных фактора - доступность, надежность и помощь в интеграции.

***Ключевые слова:*** *искусственный интеллект, учителя химии, ChatGPT, эффективность, качественное проектирование, химическое образование.*

# INTRODUCTION

## Background of the Study

Technology has revolutionized the dissemination of information in education. Today, students and teachers have technologies at their disposal that they didn't even think about two decades ago. The use of technology makes it possible to improve the learning process by increasing efficiency and individualization, as well as providing many new opportunities for both teachers and students. Modern teachers can make their lessons more interactive and interesting by using technological advances. Advanced technologies allow for more efficient, convenient, and productive knowledge transfer (Raja & Nagasubramani, 2018). One of the latest achievements is the introduction of artificial intelligence in teaching.

Artificial intelligence (AI) is computers capable of performing tasks that humans perform using cognitive functions such as pattern recognition, text generation, and providing feedback. AI systems analyze large amounts of information using a machine learning algorithm (Oxford Languages, n.d.). As stated by Chen (2020), this makes the interaction between supercomputer technology and its user much more efficient. AI is a very complex technology that has been able to influence a number of sectors in recent years, including education. In educational institutions, this implies technologies that can answer questions asked by students and teachers, analyze texts, or adapt lessons depending on student achievements.

In recent years, AI technology has gained much more popularity and has become widely used for various educational purposes. Moreover, it is crucial for improving the educational process and teaching methods. In the field of chemical education, the use of AI in various aspects of the educational process is becoming increasingly common, starting with laboratory experiments, modeling, virtual laboratories, data analysis and assessments. At the same time, there is still a lack of comprehensive reviews of existing applications of AI in chemical education (Iyamuremye et al., 2024).

Teaching chemistry is fraught with various challenges. In chemistry, theory, mathematical calculations and experimental practice go hand in hand. Traditional

teaching methods, based mainly on textbooks and lectures, do not always consider the individual characteristics of students' understanding processes. Teachers constantly face the same challenges: explaining things that cannot be seen at the molecular level, ensuring proper safety in the laboratory, checking whether all students in the classroom understand the material, and developing classroom materials that correspond to different levels of knowledge.

The introduction of AI technologies has been suggested as one of the possible ways to solve some of these problems. The generative model of AI will help teachers make lesson plans or explain concepts from different perspectives. AI tools will reduce the amount of time that teachers spend on routine activities, such as checking papers. According to Mondal et al. (2023), AI-driven tools may prove useful for chemistry teachers when it comes to creating content, providing feedback, or developing customized materials for each student.

## Statement of the Problem

The use of AI tools has become increasingly widespread in various disciplines in schools; nonetheless, there is insufficient research regarding the application of AI technologies in teaching chemistry. More research has been undertaken in AI and language studies and AI in math than in AI and chemistry. Chemistry requires special skills such as the ability to understand theories and apply them in practice and work with substances in a safe manner.

In addition, chemists require skills related to spatial reasoning of molecular models that cannot be seen. The problem is that the use of AI technology by chemistry teachers is still a relatively new thing; as a result, chemistry teachers may not know how to apply AI technology appropriately. There are few opportunities to get formal training in AI for chemistry teachers; as a result, there is much variability. Some teachers use generic tools like ChatGPT. Despite the growing availability of AI-powered educational tools, little is known about their actual effectiveness in supporting chemistry teachers in classroom practice. This underscores the need for research on the effective use of AI in chemistry education.

## Significance of the Study

Research on AI in education tends to focus on general applications or on subjects like mathematics and language learning. Chemistry-specific studies are fewer and less developed. This study addresses that gap by examining AI use through the perspective of chemistry teachers.

The findings are relevant to several groups. Teachers can use the results to make more informed decisions about which tools to try and what to expect from them. Schools and universities can draw on the study when deciding whether and how to introduce AI tools into science curricula. Teacher training programs can use the findings to identify what competencies are missing and what kinds of support are most needed.

Teachers are central to any technology adoption in education. Their decisions about which tools to use, how often, and for what purpose shape student experience more than the technology itself (Yildirim & Akcan, 2024). A study that examines their actual experiences, rather than the theoretical potential of AI, provides more grounded and actionable information.

## Aim of the Study

This study aims to explore the effectiveness of AI-supported applications for chemistry teachers by examining their influence of teaching practices, identifying challenges, and exploring professional development needs.

## Research Objectives

1. To search for existing AI-supported applications for teachers.
2. To evaluate their functions, which may be useful for chemistry teachers.
3. To conduct interviews with chemistry teachers about their experiences with AI.
4. To analyze effectiveness through teachers' perceptions of impact, challenges, and professional development needs.

## Research Questions

1. What AI-assisted applications influence chemistry teachers' teaching practices?

2. What are the challenges and limitations for teachers in applying AI-powered tools to the chemistry class?
3. What professional development needs and strategies support the effective integration of AI in chemistry teaching?

## Research Hypothesis

AI-supported applications can improve the effectiveness of chemistry teaching, but it is influenced by teacher readiness and technological conditions.

## Research Contribution

Studies that have been conducted so far on AI in education cover general topics rather than detailed studies of individual disciplines. In this study, the focus will be on chemistry education, which allows for making the results more applicable to the practice of chemistry teachers and to those who prepare future chemistry teachers.

Methodologically, this study incorporates two sources of information: academic papers and teachers' interviews. By conducting such a study, we will be able to compare what is said about the abilities of AI in literature with the experience shared by teachers in interviews. The difference between the two is important because the distance between theory and practice can always be seen.

Further, this study highlights the training requirements expressed by chemistry teachers, which are beneficial in creating training programs at universities, ministries of education, and professional organizations. The findings contribute to the growing body of research on AI in STEM education and may support the development of more effective teacher preparation and training initiatives.

# LITERATURE REVIEW

## 1.1 Overview of AI in Education

The emergence of AI has revolutionized conventional modes of instruction to produce novel ideas that improve the process of both teaching and learning. AI-based innovations have turned out to be possible sources of innovations in the education field with remarkable impacts. This literature review, which is based on the analysis of theoretical foundations, will summarize the past research findings and give recommendations for further investigation in an attempt to critically examine the existing knowledge about the application of AI in teaching and learning.

As the role of AI in education becomes increasingly evident, there arises a need to analyze this development theoretically. The idea of the constructivist theory of learning, created by Vygotsky (1978) and further developed by Jonassen (1994), stated that knowledge is created through social interaction and the performance of actions, rather than being observed. This means that the described concept is relevant both for student education and for the professional development of teachers, since skills related to the use of AI technologies are acquired by chemistry teachers through collaboration, experimentation, and reflective interaction with colleagues and mentors.

Drawing on constructivism, Davis (1989) developed the Technology Adoption Model (TAM), which considers usefulness and ease of use as two key elements influencing whether people accept new technologies and put them into practice. This model is one of the most frequently used approaches in educational technology research, as it provides a framework on the basis of which it is possible to predict the acceptance or rejection of AI systems by teachers. Chemistry as a field of science is unique due to practical experiments, abstract theories and procedural knowledge that require certain technologies. The same applies to perceived usefulness and ease of use as key factors in the implementation of AI systems.

There has been an increased usage of AI in educational institutions in the past ten years. Harry (2023) highlights four major uses of AI, which include personalized learning, intelligent tutoring, chatbot instruction, and automatic assessment.

Personalized learning allows for the adjustment of materials to individual learners, thus giving them the ability to learn at their own pace. On the other hand, intelligent tutoring helps the instructors evaluate the learners' understanding of concepts and gives them specific advice about issues that they cannot comprehend. The chatbots provide the learners with instructions even outside class time. Additionally, the use of automatic assessment eliminates the tedious process of having to mark papers. According to Harry (2023), AI promotes learner engagement and helps to decrease the teachers' workload through automatic assessment. This is especially useful in chemistry because of its preciseness.

In their study, Zhai et al. (2021) examined 100 papers published during the period from 2010 through 2020 and indexed within the Social Science Citation Index, categorizing applications of AI in education into three levels. The development level consists of applications such as classification, pattern recognition, and matching, determining how AI analyzes and provides information. Adaptive learning and feedback are some examples at the application level, assisting learners in navigating content. Affective computing, gamification, and immersive learning are some examples of more advanced technology used at the integration level in an effort to boost engagement. The researchers point out some research directions, namely IoT, swarm intelligence, deep learning, and neuroscience-related studies among others. However, apart from those exciting research opportunities, some challenges have been identified such as the potential misuse of AI technology, changes in the roles of teachers and learners, as well as data privacy issues.

A systematic review of AI applications in science education was done by Fayzullina et al. (2025), who highlighted that AI can be used for five types of purposes: ITS, adaptive learning systems, virtual labs, automatic assessment systems, and generative AI. The findings indicate that AI contributes positively to learning customization, students’ motivation, and prompt feedback. Most importantly, the researchers point out that effective use of AI requires not only the development of adequate technology, but also teacher preparedness.

In terms of policies, UNESCO (Miao & Holmes, 2023) released its first guidance on the usage of generative AI in education since applications such as ChatGPT became widely used in education settings globally. Eight implementation issues are identified by UNESCO as part of the guidance, including issues like access equity, data security, algorithmic bias, and academic honesty. In addition, seven strategic actions for both governments and organizations are proposed. It is highlighted in the report that less than 10% of all schools and universities worldwide have any official guidelines on AI. The training of teachers is needed, so that technology assists instead of hinders them and their students. This issue relates directly to this study focused on chemistry teachers at the national level.

Woolf (2013) listed personalized tutoring and data feedback as the two potential uses of AI technology in the education sector, stating that adaptive systems could personalize instruction in line with the learner's pace of comprehension. These were observations made well before the emergence of current-generation AI technology.

The use of AI technology in education was evaluated by Tahiru (2021) in a comprehensive literature review of its strengths, weaknesses, and challenges. According to the findings, the effectiveness of education has been enhanced by AI through personalized learning experiences and intelligent tutoring systems. In addition, AI enhances students' critical thinking and digital literacies for the new century. Nevertheless, issues of algorithmic biases, privacy, limited human contact in teaching processes, and high expenses required for implementation continue to emerge. The researcher recommends developing policies, intersectoral dialogue among educators and technologists, and equity concerns in poor nations.

Almasri (2024) provides a summary of the literature in the field of AI in science education that was conducted between 2014 and 2023. The results of such research are contradictory. While students appreciate the personalization of feedback and the freedom offered by AI, there were also concerns voiced regarding less contact with teachers. On the part of educators, there is recognition of AI as potentially helpful in

streamlining the preparation process, but proper training and ethical considerations need to be considered (Almasri, 2024).

Namatherdhala et al. (2022) review the introduction of AI in education along three lines, specifically, the integration in the following spheres of educational practice: administrative management, creation of learning materials, and instruction facilitation. Concerning administration, the Knewton platform performs the function of automatic performance tracking and providing timely feedback. Regarding material creation, virtual and augmented realities are utilized by educators to create learning materials appropriate for different levels and are highly useful for subjects like chemistry where it is hard to demonstrate abstract concepts of molecular structure. When discussing instruction facilitation, AI supports personalized learning and predicts student problems relying on the collected behavioral data. Namatherdhala et al. describe the history of the evolution of AI technology in education, starting from the 1920s and ending with machine learning algorithms, while still stressing the necessity of proper teacher training.

Chemistry educators are presented with new educational technologies designed to improve teaching quality. Technological advancements such as mobile devices, cloud computing, and AI have made learning possible outside the classroom setting. Moreover, new methods, such as three-dimensional printing and virtual and augmented reality, allow new ways to develop visualization skills in chemistry learning (Pence, 2020). One of the most notable innovations in the field of technology is AI. The use of AI in teaching chemistry necessitates a change in conventional practices. As Pence (2020) contends, the curriculum for chemistry must be modified in response to technological advancements. He observes that artificial intelligence in learning helps to create customized learning programs for learners by determining their level of proficiency in a subject. Such an approach enables real-time monitoring of student involvement and modification of content when students display signs of confusion and disinterest. Learning analytics provides learners and educators with immediate data about progress. Another important innovation in education is three-dimensional

printing and AR as visualization tools that solve one of the main problems of chemistry education (Pence, 2020).

Berber et al. (2025) explored the use of AI in chemistry research and its impact on pedagogy. Looking at advancements made between 2022 and 2023, they found that AI was able to process vast amounts of chemical data, discover new materials and simulate reaction processes, thus, making these skills an essential part of chemistry research and something that must be taught in secondary and higher education. As part of their study, Berber et al. (2025) organized a workshop for chemistry teachers in secondary schools, collecting feedback regarding the relevance of various AI competencies and topics that could be incorporated into classroom learning. The teachers showed a high level of interest in incorporating AI technologies in chemistry lessons but had many reservations related to students' dependence on technology, unequal access to technological resources and implementation complexities.

A common pattern emerges from these studies. There are tangible benefits to be gained from using AI technologies in teaching chemistry: customized feedback, visualization of difficult-to-grasp ideas, lower workloads associated with marking, and learning opportunities beyond classroom hours. Yet the same challenges keep recurring in various settings: lack of proper teacher preparation, technological shortcomings, data protection issues, and a threat of students' dependence on AI instead of their own skills of logical reasoning. It appears that the success of AI in teaching chemistry depends more on how it is implemented than what it can offer technologically.

## 1.2 AI-Supported Applications for Chemistry Instruction

The application of AI to the realm of chemistry education has resulted in the creation of numerous AI-driven tools that contribute to the improvement of teaching-learning processes. Considering the rather abstract character of chemistry and the need for combining theoretical knowledge with practical skills, together with the necessity of timely feedback from tutors, the field of chemistry becomes one of those where AI-driven tools may be effectively used in the process of educating students. According to existing literature, AI tools in the context of chemistry education can be classified

into several types of functional groups, including generative AI tools and chatbots, virtual labs and simulation techniques, tutoring systems, and AI-driven assessment systems.

Holistic approach to pedagogy as a means to understand the use of emerging technologies in chemical education has been proposed by Chiu (2024) through conducting a systematic review about digitalization and AI in chemical education. The systematic review includes all current findings on the application of AI-based tools, virtual labs, simulations technology, and data-based learning tools in chemistry education context.

The review done by Chiu (2024) on digitalization and artificial intelligence and their place in chemistry education states that "the adoption of emerging technologies involves both a technological change and a pedagogical one." According to the review, for a successful incorporation of emerging technologies in chemistry teaching, technology should be aligned with pedagogy, specifically the inquiry process, concept development, and higher-order thinking. Even though the incorporation of digital and AI-based technologies offers many possibilities for personalized education and engagement, it is necessary to emphasize the importance of the teacher's role.

However, it highlights certain problems in the shape of ethical considerations, digital divide, and insufficient professional development; nonetheless, it adds credibility to the claim that there is an essential need for the pedagogical preparedness to support the technological advancements. The systematic review offers a solid theoretical framework for the analysis of AI-enabled applications in chemistry education, which corroborates the categorization used in the current study.

### 1.2.1 Generative AI and Chatbots in Chemistry Teaching

There is now significant interest in the use of generative AI (GenAI) technologies and conversational agents in the field of chemistry education owing to the opportunities that they provide for explanatory, inquiry-based, and reflective learning. There is an increasing trend of using chatbots developed through language models, like ChatGPT,

among others, as additional learning tools to facilitate comprehension and discussions of chemical ideas.

Korolev et al. (2024) analyzed the effects of utilizing two neural network models, namely Craiyon and ChatGPT, in education and their influence on the motivation and performance of students.

Traditional instruction of chemistry such as lectures, reading from textbooks, laboratory work, remains relevant, but with the help of AI, as it mentioned before, it is possible to significantly diversify and personalize learning. Intelligent algorithms allow neural network platforms to respond to students' individual needs, provide instant feedback, and help students learn complex information, which leads to increased learning efficiency (Korolev et al., 2024).

As part of the experimental half of the research, the authors conducted a follow-up of 3 months among 60 high school students divided into 3 groups: a control group that studies with the traditional method, an experimental group making use of Craiyon, and a group using ChatGPT. A Craiyon was utilized to illustrate chemical reactions and molecular structures in a real-time mode so that pupils could more easily understand abstract processes. The ChatGPT, in turn, provided real-time answers to questions, initiated a debate, and pushed the boundaries of the subject of research.

The experimental results revealed that the students, who were doing their work using Craiyon, improved their understanding of abstractions by 25%, and the students who used ChatGPT improved their autonomy in learning the subject by 30%. Both experimental groups, according to final estimates, were better than the control group, and the students' engagement reached 70%. Such an indicator testifies to the high effectiveness of using AI to teach chemistry.

In addition, the article contains excellent feedback from students, on the basis of which the use of AI contributed to increased motivation, clearer understanding of complex issues and more interest in the topic. The students appreciated the ease of use and convenience of neural network tools and also declared that they were willing to use them for additional research (Korolev et al., 2024). The authors also consider the

need to adapt AI to pedagogical conditions and develop tools that ensure the introduction of AI as an auxiliary, rather than replacement, element of pedagogical activity.

Taken together, the findings of Korolev et al. (2024) suggest that neural network-based tools can meaningfully shape how students interact with chemistry content - not merely by delivering information more efficiently, but by shifting the conditions under which motivation and comprehension develop. The study's experimental design, while limited in scope, provides early evidence that deliberate instructional framing of AI tools matters as much as the tools themselves.

Similarly, dos Santos (2023) examined the use of ChatGPT, Bing Chat, Bard, and Claude as "tools for thinking" in chemistry education. The study has a constructivist theoretical base on the basis of which successful learning is dependent on active student participation in the construction of their own knowledge. A method of content analysis of conversation between chatbots and emulation of the personality of a student while studying chemistry subjects was utilized for the study. Throughout the experiment, the author discussed how various AI agents contribute towards developing critical thinking, problem-solving, and boosting students' understanding of concepts as well as creativity.

The result of the research was that four of the chatbots, to a greater or lesser extent, can also serve as "agents for reflection" and support interpretation and perception of teaching material. Forming questions asked in the style of the Socratic method was most effective, culminating in self-examination and reflection on the part of the student. ChatGPT did the best in this respect, followed closely by Bing Chat, and it is marginally superior to Bard and Claude when it comes to depth, accuracy, and contextualization of response (dos Santos, 2023).

The study puts emphasis on skills in rapid development, which affect the quality of communication with AI bots. Teachers need the skill to question properly in order to make proper use of AI potential to augment the reflection and independent thinking of students (dos Santos, 2023).

But the author also suggests limitations: AI agents give incorrect or incomplete answers, and therefore critical analysis of received information on the side of the user is required. In this sense, training of teachers as an additional important requirement: teachers must be trained in order to adapt and to enable interaction with AI within education.

The article demonstrates the real ability of AI software to foster critical thinking and deep understanding of the chemical principles and finds essential factors influencing the effectiveness of AI in education, including the level of studies, teachers' will and pupils' ability to perceive the acquired data critically.

More empirical evidence on the integration of generative AI in the teaching and learning of chemistry is given by Jere and Mpeta (2025). The authors sought to determine the effect of AI chatbots on student engagement and conceptual understanding. The study shows the effect of affective variables, such as motivation and student attitude towards technology, on the effectiveness of generative AI in the teaching and learning of chemistry.

The study shows that the integration of AI chatbots in the teaching and learning of chemistry enhances student engagement and conceptual understanding of chemistry concepts. The study also shows that the affective variables play a role in the effectiveness of AI in the teaching and learning of chemistry. This implies that the effectiveness of generative AI in the teaching and learning of chemistry depends not only on the functionality of the AI but also on the affective variables (Jere and Mpeta, 2025).

In their paper Araújo and Saúde (2024) take into account possibilities and limitations of ChatGPT to produce chemistry laboratory reports like the 11th grade course in Portugal. The research is dedicated to the practice of query generation as a form of human-computer interaction, improving the quality of learning content generated.

The examination of five required lab papers showed that ChatGPT can read and copy a specific chemical vocabulary, giving organized tasks for a mass of students as

its user base. Artificial intelligence demonstrates its ability to write laboratory tasks according to set objectives and topics of investigation, using words in the same way as it is used in an ordinary study environment. Nevertheless, the authors emphasize the shortcomings with regard to the scientific precision and pedagogical effectiveness of the designed tasks. Special attention must be given in the area of experiment safety and responsible use of resources, where artificial intelligence is not yet able to provide adequate depth and criticality of research (Araújo & Saúde, 2024).

Therefore, despite the demonstrated potential, ChatGPT should be used in practice intentionally and at the initiative of a professional instructor. The used artificial intelligence tools can effectively assist the educational process, stimulate the formation of new ideas and inspire student interest, but they cannot replace the teacher's expertise. The activity of the teacher should still be aimed at ensuring the scientific validity, safety and methodological convenience of laboratory lessons.

Leite (2024) compared how ChatGPT, Gemini, and Copilot define five core chemistry concepts, using the IUPAC Compendium of Chemical Terminology as a preference point. All three chatbots produced coherent definitions, but Gemini and Copilot gave inaccurate information in some responses. Leite (2024) concludes that these tools can serve as useful didactic resources in chemistry teaching, but teachers need subject-matter knowledge to catch errors that students might otherwise accept uncritically.

This concern is further supported by Clark (2023), who examined the performance of ChatGPT on chemistry exam questions. Regarding the outcome achieved, it was found that, although the model possesses an excellent ability to recognize chemical concepts and indicators in trial problems, its actual efficiency in solving issues makes up only 44%, a far cry from typical students (69%).

The least strong part of artificial intelligence is its use where it must employ special knowledge and skills that are taught mainly in lectures. Although the solutions provided by ChatGPT for the open exercises were correct in grammar and rational, they were flawed and lacking in persuasiveness in terms of logic, which may have

made them acceptable to beginners. This signals a serious problem: AI responses are deceptive through their apparent reasonableness and correctness, while they may actually be incorrect (Clark, 2023).

The author notes that at the current level of development, ChatGPT can by no means be employed as an explanation or response source to questions on the test of chemistry. But they suggest an effective means of introducing artificial intelligence into education - utilizing ChatGPT answers as a source for developing critical thinking skills. For example, students can be required to evaluate, correct, and perfect artificial intelligence answers and thereby develop their own chemistry knowledge.

### 1.2.2 AI-Supported Virtual Laboratories, Simulations, and Visualization Tools in Chemistry Education

When teaching chemistry, educators can use one of the most established and widely researched AI-based apps such as virtual laboratories and simulation-based technologies. Such tools can be used effectively to meet the needs of individual students through customized support and feedback, which helps in building up their comprehension of difficult chemistry concepts and helps in facilitating the work of teachers as well.

Selvam (2024) conducts a review of the literature surrounding the application of artificial intelligence (AI) in teaching natural sciences, especially physics, chemistry and biology (PCB). By means of critical analysis of existing scholarly literature, the author aims at exploring systems powered by AI and utilized to assist student learning and assess their academic progress. Each field of natural science (physics, chemistry, and biology) serves as an independent section of Selvam's study. The main benefits of applying AI in teaching as mentioned by Selvam (2024) include higher motivation among students, improved comprehension of theoretical concepts, better problem solving, and critical thinking skills development. Another advantage of using AI technologies in teaching is reduced mental pressure on learners caused by excessive amount of material.

AI technology has been incorporated into chemistry teaching in such a way that AI technology was applied to make virtual labs and model chemical reactions. In addition, these tools made it easier for learners to interact with information that would have been otherwise difficult for them to grasp (Selvam, 2024). AI technology has also encouraged learning since it has made it easy for students to interact with the content by making complex processes easier. Notably, the research does not evade the problems that may arise during its use.

Despite this, however, Selvam (2024) still maintains his cautious optimism, pointing out that there is some real hope in regard to AI being a tool for changing the ways in which science teaching is carried out and leading to improved learning outcomes for students. Nonetheless, the author emphasizes that further study needs to be conducted to address the challenges related to implementation.

Alli (2025) offers an excellent overview of different applications that allow implementing AI in order to facilitate and improve the learning experience in chemistry classes. It becomes possible due to using intelligent learning systems, virtual laboratories, and adaptive platforms that will help students learn better by reducing complexity of chemical theories and making the educational process more interactive and engaging.

By means of AI, studying complicated chemical disciplines could become more efficient since it will provide users with feedback, personalized approach, and visualization of chemical processes (Alli, 2025). The author highlights the importance of virtual laboratories where dangerous chemical reactions can be tested without the risk of harm and without purchasing expensive laboratory equipment that can be difficult to obtain in certain settings (Alli, 2025).

In addition, the paper explores in-depth the educational benefits of AI, which are manifested in the development of critical thinking, analytical skills, and motivation for further learning. The intelligent systems, for example, Cognii or Labster, are not limited to problem-solving; rather, they stimulate the development of independent

problem-seeking skills, error analysis, and collaboration among students in a coworking environment.

Meanwhile, it cannot be denied that the author has the full right to talk about these existing problems. Among them are an absence of proper infrastructure, excessive dependence on technology, diminishing importance of educators, and ethical problems such as data protection. The main emphasis is made on improving AI proficiency of teachers and their further education. Based on the findings of the report, educator training should include the following six elements: goal setting, curriculum development, ethics, and assessment of learning outcomes.

The uses of AI technology in teaching chemistry described by Alli (2025) span such areas as intelligent tutoring and virtual experiments, and it is stressed that these technologies are not to be regarded primarily as replacements for traditional learning, but rather as an opportunity to extend what is practically possible for a teacher to achieve individually with each student.

In line with this view, Martínez et al. (2025) analyzed contemporary research concerning the application of AI-driven virtual labs in exact sciences learning among secondary-school learners, emphasizing the factors contributing to successful and ethical integration. According to the results of their work, there are some positive aspects such as the ability to simulate reality, get instant feedback, and receive personal assistance. However, in the case of teachers, things become somewhat complicated as they demonstrate a high level of willingness to adopt technologies and average levels of confidence. This proves that mere possession of technology will not work.

According to Ananikov (2024), his article provided a systematic review on the top 20 AI-based technologies that are influencing digital chemistry, which is becoming a trend in chemistry today. This paper outlines the significance of digitalization in research, education, and industries in highlighting key applications of AI including laboratory automation, molecular engineering, and data analysis of chemicals.

The paper outlines 7 major thematic areas of consideration, namely; chemical biology and digital medicine, environmental technology, data analysis, innovations in

laboratory practices, materials science, quality control and modeling. Amongst these instruments considered, more emphasis is placed on learning system, machine learning, digital twins, virtual laboratory and virtual reality technologies, as well as smart spectroscopic data analysis tools and predictive toxicology.

In regard to chemical education, innovations like virtual labs, augmented reality, computer-aided planning of synthesis and NLP play a more significant role in scientific information search and systematization. Such innovations may offer new opportunities for enhancing the accessibility of practical experience, making personalized learning possible and helpful in the case of education of students in chemistry at school or university.

One of the main points made by the author is that the development of AI technologies in the sphere of chemistry should be accompanied not only by progress in technologies, but also by training specialists able to effectively use these technologies with due expertise. Consequently, the paper can be considered relevant to the topic of my dissertation, since it addresses the issue of the effectiveness of AI as an educational technique in chemistry.

In addition, Pence (2020) highlights the role that technologies like virtual reality and augmented reality play in fostering visualization skills in chemists. In other words, the use of such technologies allows chemistry students to learn more about molecular structures and reactions.

There is evidence that the use of virtual laboratories contributes to students' increased involvement, improves safety conditions, and fosters practical skills development among students. However, for virtual laboratories to be used successfully, there needs to be sufficient technological capacity in the school and professional training of teachers.

### 1.2.3 Intelligent Tutoring Systems and Adaptive Learning Platforms

Intelligent tutoring systems (ITS) and adaptive systems are different in their approach compared to other AI applications. They do not provide all learners with the same material but monitor them and tailor the next material according to their

performance. The student who faces difficulties with stoichiometry receives additional tasks for it. A student who moves quickly gets harder problems. The system responds to what each person actually does. (Nawaz, 2024).

Al Braiki et al. (2020) provide some of the most compelling answers to the questions related to the use of AI in education and application for assessment purposes. Based on the results of their literature review, the authors look at the way AI is used in educational processes aimed at improving both the learning process and the way the student knowledge is evaluated. One of the key concepts used throughout the entire paper refers to personalization, which means that AI should be implemented to develop a personalized approach toward education depending on students' background, skills, and level of education.

The most useful application of AI in education is learning personalization. Machine learning applications and artificial intelligence systems are capable of examining student data, both their strengths and weaknesses, in a manner to offer individually customized study materials. One of the best examples of utilizing this application is creating adaptive education websites that change task difficulty in accordance with the manner in which the student copes with the prior tasks. This helps in ensuring that each student receives material at their understanding level and also helps in the correct assimilation of new topics (Al Braiki et. al, 2020).

Zhang & Aslan (2021) provides a summary overview of AI technologies applied in education. The article focuses on chaos, expert systems, intelligent teachers, machine learning, personalized learning environment, and virtual learning environment, with a focus on their potential advantages and disadvantages. Each of the technologies is discussed through specific examples of how they can enhance student engagement, learning, and provision of tailored feedback. The review does call for additional studies to explore such areas as the need to advance particular artificial intelligence deployments and the need for longitudinal studies (Zhang & Aslan, 2021).

AI has the potential to enhance an individualized learning setting, provide individualized feedback, and encourage student engagement. Intelligent teachers and

expert systems, for example, allow for personalized learning on natural topics such as chemistry, adapting to the needs of students and providing instant advice. In addition, the integration of artificial intelligence with visualization and virtual environments has the ability to simplify the understanding of complex chemical principles.

The article by Baum et al. (2021) analyzes trends in AI-related chemistry publications over the past two decades. The authors used collections of CAS materials, which have seen a sharp increase, especially since 2015. The greatest integration of artificial intelligence is observed in analytical chemistry and biochemistry. The study highlights key research areas such as data processing, chemical process modeling, and automated synthesis.

AI is also actively used in the analysis of substances, especially in the life sciences and analytical chemistry (Baum et al., 2021). These developments have an impact on chemical education, which requires updating curricula in order to introduce AI-based technologies. Integrating AI technologies in the learning process allows automated data analysis, the creation of digital educational resources and virtual laboratories. Future chemists should possess not only traditional methods, but also interdisciplinary skills combining chemistry, machine learning and data science. Overall, although this primarily focused on AI in chemical research, it demonstrates the growing integration of data-driven technologies within chemistry. The importance of personalized learning systems in education is highlighted by Tahiru (2021), who states that AI-powered systems can help improve the educational process through customized approaches.

There are real possibilities for using such technologies in chemistry, in particular, because students frequently find themselves struggling with similar issues such as balancing equations, working out molar ratios, and reading reactions. An adaptive system can catch those gaps earlier than a teacher working with thirty students at once. That said, none of this works if the teacher is not involved in deciding how and when the tool is used.

### 1.2.4 AI-Supported Assessment, Feedback, and Instructional Support

Grading takes time. For a chemistry teacher with multiple classes, marking written answers, lab reports, and problem sets can consume hours that could go elsewhere. AI-based assessment tools address this directly: they process large amounts of student work, apply consistent criteria, and return feedback faster that any teacher can alone. For example, algorithms of AI are already implemented at some institutions of learning to assess students' written work, but which, apart from speeding up the assessment process, enables the identification of prospective errors or flaws in argumentation. This approach increases the quality of student feedback as well as allows teachers to focus more on artistic aspects of instruction, such as mentoring and nurturing critical thinking (Al Braiki et al., 2020).

However, besides being able to offer real-time feedback, another benefit of introducing AI into the learning process, according to Al Braiki et al. (2020). Real-time feedback is important for active learning, where the learner has access to information on the error that has occurred and has an opportunity to change the approach in real time. AI-enabled systems are capable of assessing the performance of learners and offering ways to improve it. These systems include examples like learning systems that employ AI to monitor student progress and provide supplementary materials to enhance their knowledge. Thus, the use of AI in the educational field provides significant opportunities for improving the quality of learning and assessment. Using these opportunities in teaching chemistry, it is possible to facilitate the work of teachers.

One important contribution to AI-based feedback and assessment in chemistry education is offered by Eitemüller et al. (2023). In their study on the digitalization of multi-step chemistry exercises using automated formative feedback, the authors examine the potential of digital tools to support students in solving complex chemistry problems in a multi-step process.

The study’s findings show that AI-based formative feedback can positively influence students' problem-solving processes by leading them through the individual

steps of the problem-solving process, not just the final answers. This is particularly important for students' deeper understanding of chemistry concepts and for reducing common mistakes in the procedural understanding of chemistry problems. The study also shows the potential of digital feedback tools for the process of assessing students' performance from a pedagogical point of view.

Whilst not exclusively discussed under the umbrella of artificial intelligence, the inclusion of automated feedback systems can be considered an important aspect of an artificial intelligence-based learning environment. The research demonstrates the potential of digital technologies to support teacher instruction, enabling more individualized and process-oriented learning in chemistry education (Eitemüller et al., 2023).

Application of AI is also of particular interest as far as computer-aided support to students in exam preparation is concerned. The article of Clark (2023) discusses the prospect of using the ChatGPT chatbot to solve exam questions in a closed (multiple-choice) and open format in a general chemistry course. This finding underscores the importance of using AI as a supportive tool rather than as a primary source of assessment.

Alli (2025) further notes that AI-supported feedback systems can assist teachers by tracking student performance over time and suggesting instructional interventions. In addition, elements of AI-supported feedback observed in the study by Korolev et al. (2024) indicate that timely feedback contributes to increased student autonomy and engagement in chemistry learning.

However, some of the weaknesses associated with the use of AI in assessment include accuracy problems, ethical considerations, and the danger of reducing the teachers' role in evaluation. Therefore, the use of AI in assessing students' performance will only be effective if there are proper guidelines and teachers' involvement.

More general information on the application of AI and ML in chemical education may be obtained from a literature review conducted by Iyamuremye et al. (2024) where they analyzed 62 publications ranging from 2018 to 2024. The review reveals

important implementation trends: virtual labs, adaptive learning technologies, intelligent tutoring systems, and AI-based assessment tools. The authors point out that most applications focus on higher educational settings and that teacher preparedness, good quality data, and ethical issues play a critical role. The results indicate that although AI technologies have a high level of promise, it is necessary to consider pedagogical fit and teacher expertise to be successful.

Particularly after 2021, the application of AI in scientific and chemistry education has grown significantly (Erümit & Sarıalioğlu, 2025). The review by Erümit & Sarıalioğlu (2025) compiles research on the application of AI in science and chemistry classrooms from 2014 to 2024. They discovered eighteen studies that demonstrate how rapidly AI-based educational innovations have proliferated during the past five years. The majority of research with secondary pupils, college students, or teachers employed mixed techniques or quasi-experimental designs. ChatGPT, chatbots, virtual labs, simulations, and AI-based evaluation systems were among the methods examined in the study. These resources enable transdisciplinary experiences, facilitate online learning, make learning easier, provide many lab learning options, and promote individualized learning.

According to the review, AI-enhanced environments improve student engagement through personalization and interactive feedback, strengthen content grasp, and encourage independent learning. It also highlights some major problems, such as algorithmic prejudice, ethical dilemmas, pupils' over reliance on automated feedback, and inadequate educational infrastructure. It's intriguing that the authors stress that in order to create both technological and critical literacy, AI must be appropriately integrated through pedagogical coherence with the goals of teaching and educating teachers.

Their suggestions about future research agendas with respect to the applications and particular disciplines of interest, more specifically chemistry, would help explore how the use of AI tools could enhance experimental learning, conceptual modeling, and assessment accuracy. Thus, through the systematic investigation provided in the

paper, we can say that it provides a theoretical approach for understanding the integration of AI in chemistry education. The results of the research conducted by Erümit & Sarıalioğlu (2025) emphasize the importance of attaining an optimal balance where AI serves to complement but not replace human teaching, thus facilitating scientific study via technology and not vice versa.

According to this larger study, Sari (2025) offers a particular synthesis of literature in relation to the empirical research related to the implementation and use of artificial intelligence for teaching and practicing chemistry. On the other hand, Iyamuremye et al. (2024) give a general overview and analysis of this larger study. However, Sari (2025) conducts a micro-level analysis of the application of artificial intelligence and its implications for the development of conceptual knowledge among chemistry students. In essence, the findings from this research reveal that the use of AI technology is effective in chemistry teaching and practice; however, there are still challenges relating to teachers' training and assessment.

In all four categories, the scholarly sources reveal a common trend. AI-driven applications have the potential to facilitate the teaching of complex notions, provide prompt feedback, accommodate individual differences, and alleviate routine activities performed by chemistry teachers. The critical issue here, however, is that neither the availability of such technology nor its inherent features make it effective for education. It is necessary that the instructor is familiar with the application, is confident in using it, and is able to integrate it into the process of delivering the lesson in chemistry.

## 1.3 Teacher Readiness and Professional Development for Effective AI Integration in Chemistry Education

In order for the AI-assisted software application used in chemistry education to be effective, teachers’ preparedness for its use and their professional capabilities become critical. There are three frameworks used to assess teacher preparedness for technology integration.

Mishra & Koehler (2006) created the technological, pedagogical, and content knowledge (TPACK) model, which stipulates that efficient use of any technology in

teaching presupposes a more comprehensive knowledge about the technology as well as about the discipline taught. Hence, when a chemistry teacher uses the AI, he or she integrates his or her knowledge of chemistry, the principles of its learning, and the functioning of the AI. Nowadays, the TPACK framework is a prevailing method to assess teacher preparedness for the AI integration in chemistry teaching.

The notion of Bandura's (1997) 'self-efficacy', which refers to the teacher's conviction regarding their capacity to execute the task effectively, incorporates the motivational component into this model of professional competence. Teachers who have higher self-confidence regarding technology use are inclined to experiment with new technologies, overcome challenges, and analyze their experience. What is especially important about the concept of self-efficacy is that it can be acquired through training and practice, thus making it possible to change teachers' attitudes towards their professional practice.

What can be observed as a common pattern in different empirical studies is that teachers who teach chemistry show interest in AI but are underprepared for applying it. Yildirim and Akcan (2024) collaborated with 17 chemistry teachers to design the framework of professional development and identified that those people have limited knowledge regarding available AI technologies, little experience in designing lessons based on AI, and uncertainty about possible ethical concerns. This does not mean that they did not see any benefits - quite the opposite, they believed that AI has a high potential when applied to visualize chemical concepts and provide personalized feedback.

Similarly, Hammoud (2025) conducted a survey on 285 chemistry teachers in Lebanon and reached a similar conclusion. While only 19% had a high level of awareness regarding the potential usage of AI technology in education, over 75% agreed that AI technology can enhance the quality of teaching. Time efficiency, increased interactivity of lessons, and improved curricular development were listed by chemistry teachers as the key benefits. In his study among chemistry teachers enrolled in professional courses, Kim (2024) achieved similar results.

According to Damola et al. (2025), when a survey was conducted among science teachers at large, 61% reported having an understanding of the application of AI technologies, but poor infrastructure, inadequate training, and issues related to plagiarism and bias emerged as recurring challenges. What is striking about all these investigations is that teacher resistance was not the problem - the teachers actually wanted to use AI - but rather the lack of proper support structure.

The paper by Shi et al. (2024) provides a good illustration of how things actually unfold once teachers embrace the use of artificial intelligence in the classroom. When they tested six teachers who were using the AI-supported inquiry system in their lessons, Shi et al. found out that those teachers engaged in the use of technology in very different ways – while some saw technology as a tool which was freeing them up from the routine to interact more deeply with the students, the others saw it as something slowly encroaching upon their responsibilities. This approach of AI-based co-teaching requires active and continuous decision-making by teachers. And that, of course, is extremely important in a subject like chemistry.

Ratniyom et al. (2025) focused on the utilization of ChatGPT as a formative assessment instrument in teaching stoichiometry to pre-service science teachers. It proved useful in delivering instant feedback to learners, yet this was only effective where teachers ensured the activity was planned out. In cases where there was no structure, the tendency to copy arose. This is a small but important finding: AI can support formative assessment in chemistry, but the teacher's design of the activity is what determines whether students actually learn from it.

The article by Feldman-Maggor and others (2024) outlines the application of GenAI (more precisely, ChatGPT) in chemistry instruction and how traditional pedagogic models such as the TPACK model can be utilized to explain the new pedagogical competencies that arose with the presence of AI.

The correct use of GenAI instruments, as well as technical competence, also relies on advanced subject and pedagogical training (knowledge of content and knowledge of pedagogical content - CK and PCK). By some examples of a dialogue

between ChatGPT and teachers, it is shown that without proper subject preparation and familiarity with typical student misconceptions, the teacher will not be able to set questions correctly (operational engineering) and critically examine the received answers. Such an examination is especially important in chemistry, where accurate accuracy in question setting is of utmost importance (Feldman-Maggor et al., 2024).

The authors make the argument that the original TPACK model is no longer sufficient. In the context of using AI for education, however, new elements such as AI literacy and awareness of ethical considerations need to be incorporated. As the article suggests, "query development" should be understood as a unique pedagogical skill that integrates technology, academic discipline, and critical thinking.

The discussion from an educational perspective also supports this understanding. According to Huwer et al. (2025), three areas can be distinguished within the context of AI usage in chemistry education, which include AI research in the field of chemistry, the application of AI in education, and the development of specialists who will collaborate with AI systems effectively and responsibly. The effectiveness of AI use in chemistry teaching depends on teachers' competencies that involve assessment of the credibility of the provided information, incorporation of AI into teaching material design, and conducting instruction based on research.

In turn, Blonder and Feldman-Maggor (2024) broaden the conversation, concentrating on responsible usage of AI in chemistry education. According to them, being able to utilize a particular tool may seem sufficient for a teacher to perform effectively. Nonetheless, there are some additional skills which cannot be neglected in chemistry instruction since a mistake regarding a chemical reaction may have severe academic and health consequences. Namely, one should know how to tell whether an explanation provided by AI is scientifically incorrect, whether the chosen source can be considered reliable, and how to convey all those insights to their students honestly.

An expanded perspective on AI in teacher preparation can be derived from the study conducted by Verma (2024). The author explores the opportunities and challenges related to the integration of ChatGPT and other generative artificial

intelligence models in science teacher preparation. The study indicates that GenAI models have tremendous opportunities in terms of planning lessons, creating content, and innovating teaching. However, these opportunities can only be realized through critical digital literacy and pedagogical awareness among teachers. For example, ChatGPT could produce structurally organized lesson outlines, but that teacher review was required before any AI-generated material was used with students, as some outputs lacked scientific depth and age-appropriate accuracy (Powell and Courchesne, 2024).

The study conducted by Verma (2024) indicates that if AI is not integrated in a more critical manner, it may result in superficial rather than transformative teaching. This perspective also supports the argument that the effectiveness of AI in chemistry teaching is mediated through teachers' competence.

Estrada et al. (2025) reviewed 38 studies at the intersection of AI, inclusive education, chemistry teaching, and professional development. The most important discovery of these authors is that the literature is scattered - there is an increased focus on the application of AI technology in chemistry education, but only a handful of studies provide models integrating all these aspects: the pedagogy of chemistry, ethics in AI learning, and inclusive practice. The authors suggest four competency domains that should be integrated into a model if it is worth consideration: knowledge in chemistry pedagogy, ethics in AI, inclusive practice, and AI utilization skills.

Berber et al. (2025) organized a workshop for secondary chemistry teachers on the integration of AI technologies into research as well as teaching of chemistry. While teachers had a very positive view regarding AI technologies, especially the possibility of personalized learning and virtual labs, there was a clear understanding of some of the limitations of the use of such tools, such as dependence of students on AI and issues related to access to AI technologies. There is a need for cooperation between chemistry teachers, chemists, and AI developers to develop relevant technology.

International literature makes a vital background for research, while the current research takes place in Kazakhstan, thus having peculiarities of its environment. The digital competence of the Kazakhstani teachers was found to be at the medium level.

According to Amiresheva et al. (2025), the TPACK score among 165 pre-service science teachers of Kazakh National Pedagogical University reached the medium level; moreover, there were no significant differences based on gender and year of study. This means that the differences in the level of the Kazakhstani teachers' digital competence are systemic. Abiltayeva et al. (2025) reported high levels of pedagogical knowledge, whereas the technological knowledge showed high variability, depending upon the university.

Karmanova et al. (2024) examined the use of digital technologies in chemistry teacher preparation at South Kazakhstan University and found measurable gains in professional competence when digital tools were integrated systematically into training. This is relevant because it shows that structured digital preparation is achievable - through the study focused on general digital tools rather than AI specifically, and the gap between digital literacy and AI literacy remains meaningful. Temirkhanova et al. (2024) offer a more directly encouraging example: a PD programme at Astana International School improved teacher's integration of digital tools into subject-specific teaching, with students of those teachers showing measurable gains in practical skills. The implication is that content-embedded, structured training works - something that should inform how AI PD for chemistry teachers in Kazakhstan is designed.

The only study to date examining AI use in chemistry education from a Kazakhstani institutional perspective focuses on students rather than teachers. Bauyrzhan and Zhylysbayeva (2025) surveyed university students and found that most were already using tools like ChatGPT and virtual laboratories to work through chemical concepts and solve problems. Students found them useful but raised concerns about factual accuracy, over-reliance, and ethical issues - and specifically noted that they needed more guidance from teachers on how to use AI critically. That this study focuses on students rather than teachers reveals an important point; there is no empirical evidence to date on how chemistry teachers in Kazakhstan understand and apply AI technology. This is where the current research fills the existing gap.

On the governmental level, Kazakhstan has been rather fast in implementing new changes. In September 2025, the Ministries of Education and Digital Development have adopted the Conceptual Foundations of Implementing Artificial Intelligence in Education for 2025-2029, which outlines the criteria for ethically using AI technologies, protecting personal data, and integrating AI into educational curricula. As of the 2025-2026 academic year, AI-related content became a part of the curricula of different disciplines, and three-level PD programs for teachers were launched (Ministry of Education of Kazakhstan, 2025).

Probably one of the key developments for chemistry teachers will be the publication of an officially approved methodology manual developed by the National Academy of Education and named after I. Altynsarin in 2025. This manual will deal exclusively with artificial intelligence in chemistry education, including students from grades 7 to 11. Approved in December 2025, the document provides chemists with practical recommendations on how to apply artificial intelligence at different stages of the educational process. Such tools as PhET simulations, MolView, virtual laboratories in ChemCollective, and language models such as ChatGPT were referred to in this regard. At the same time, the main advantages of the application of artificial intelligence in this sphere can be seen: individualized approach to teaching, simulation of potentially dangerous experiments that could not be carried out in the laboratory in school, work with research projects of students, etc.On the other hand, they do not shy away from identifying the possible dangers - factual inaccuracies in AI output, plagiarism among students, excessive dependency on technology, and threats to privacy. They highlight that rather than relinquishing all control to AI, a chemistry teacher should supervise its application carefully. It is telling that there exist guidelines for AI implementation specifically in chemistry in Kazakhstan now. What does this mean? In the past, chemistry teachers were advised to discover ways of using AI; now, they are expected to integrate the technology into the curriculum. Whether teachers are prepared for this expectation is what the current research aims to find out. From various studies conducted in many countries, it is apparent that while chemistry teachers are

generally receptive towards AI, they lack the adequate preparation required for effective implementation. The gaps that exist are not motivational since chemistry teachers realize the benefits that can be derived from using AI. The gaps include being technologically aware of AI software, using AI for pedagogically relevant purposes, and addressing issues of integrity and accuracy related to AI in a scientific field. TPACK, self-efficacy theory, and TAM help account for these gaps.

This problem becomes even more complicated in Kazakhstan because the development of policy on the use of AI in the educational process happened faster than the readiness of teachers for such changes at the level of individual classes. The development of the AI guidelines specific to the field of chemistry (National Academy of Education, 2025) and the national PD framework (Ministry of Education of Kazakhstan, 2025) indicates a certain responsibility on the part of institutions; however, considering the data on the digital competence of Kazakhstani science teachers, this responsibility remains unfulfilled.

# METHODOLOGY

This chapter describes the general methodology applied within the research, explaining the structure of the research process, data collection techniques, the subjects of participation in the research, and the approaches used in analyzing data in relation to measuring the effectiveness of the application of AI-supported technologies for teaching chemistry.

## 2.1 Research Design

The research employs the qualitative method, based on two separate stages of investigation, including both literature analysis and semi-structured interviews.

The first stage will include a qualitative content analysis of literature on using AI in chemical education. At this stage, an attempt will be made to identify the main types of AI-supported applications in chemistry education, the areas in which AI has been applied in the field, the pedagogical influence of AI and the challenges facing AI application in the field, and the strategies developed to ensure chemistry teachers are equipped to effectively integrate AI in teacher professional development.

The second stage involves semi-structured interviews with chemistry teachers to identify the experiences, perceptions, and needs of teachers in the field regarding the application of AI. This phase allows the research to compare the theoretical conclusions drawn in stage 1 with the practical conclusions drawn by teachers in the field and to understand how AI applications function in the field. The combination of both phases will enable the researcher to achieve methodological triangulation and enhance the validity of the study.

## 2.2 Data Collection

### 2.2.1 Literature Corpus

The content analysis focused on peer-reviewed publications addressing AI-supported applications in chemistry education and chemistry teacher practice were identified through database searches. Searches were performed using Google Scholar and further academic databases (for instance, Scopus/Web of Science/ERIC if available). The time frame for the articles is between [2013] and [2025], which

corresponds to the fast advancement of AI applications in educational settings and its development.

Searched keywords or combinations thereof: (“artificial intelligence” OR “generative AI” OR “AI-supported tools” OR “chatbot” OR “virtual laboratory”) AND (“chemistry education” OR “chemistry teaching” OR “chemistry teachers”).

Criteria for inclusion:

- Scholarly journal articles that have undergone peer evaluation, as well as systematic reviews;
- Related to the AI usage in chemistry education or in science education;
- Discussion of pedagogical impact, problems, or teacher training/teacher professional development;
- Availability of full text in English.

Studies were excluded if: (a) they focused only on the development of AI itself; (b) papers unrelated to chemistry education; and (c) non-academic sources.

After screening titles, abstracts, and full texts, a final corpus of 30 studies was selected for qualitative content analysis. The units of analysis were peer-reviewed research publications and consisted of meaningful text segments such as sentences or paragraphs. The final corpus consisted of 30 studies published between 2013 and 2025. These included the types of AI software and applications, its usage in education, benefits, shortcomings, and some recommendations regarding professional development programs for teachers. Each section pertaining to the research topic was then coded according to themes.

### 2.2.2 Semi-Structured Interviews

The semi-structured interviews involved chemistry teachers. The interview guide was developed before conducting the interviews, asking 9 open-ended questions which are included in Appendix 1 (p. 66). The questions were about teachers’ knowledge of applications supported by AI technology, experience in using AI technologies, influences of teaching methods, obstacles encountered, difficulties, and professional development requirements.

The interview protocol was based on open-ended questions that were related to the research questions. The participants were encouraged to give their responses at length and with examples from their practical experience. In order to achieve content validity of the semi-structured interview, the tool was evaluated by 4 experts. Each expert was required to rate all 9 interview questions with the help of a four-point Likert-scale in terms of 6 different validity criteria - Clarity, Relevance, Content Coverage, Comprehensibility, Ethics, and Usefulness. Possible ratings ranged from 1 point (Not relevant) to 4 points (Fully relevant). To test for experts' consensus about the tool's content validity, Kendall's Coefficient of Concordance (W) was used. Since Kendall's W is non-parametric, rankings rather than numerical ratings were computed automatically by SPSS. Mean ranks of 9 questions are presented in Table 2.1.

*Table 2.1 Kendall's W-Test Mean Ranks*

| Group Questions | Mean Rank |
|---|---|
| 1 | 6.63 |
| 2 | 5.88 |
| 3 | 1.5 |
| 4 | 6.63 |
| 5 | 6.63 |
| 6 | 2.25 |
| 7 | 2.25 |
| 8 | 6.63 |
| 9 | 6.63 |

From Table 2.2, it is clear from Kendall's W test that there is a statistically significant and extremely high degree of consistency within the ranks of the 4 experts concerning the nine categories of questions ($W = 0.942$, $X2(8) = 30.154$, $p < 0.05$). The value of this test statistic shows the existence of perfect harmony among the ranks assigned by the experts. From the mean rank scores, the top-ranking category with an equal score of 6.63 was found to be group 1, 4, 5, 8, and 9, while the bottom-ranking category was group 3 with a mean rank score of 1.50.

*Table 2.2 Kendall's W-Test Statistics*

| | |
|---|---|
| N | 4 |
| Kendall's W[a] | 0.942 |
| Chi-Square | 30.154 |
| df | 8 |
| Asymp. Sig. | 0.00 |

*Note: a - Kendall's Coefficient of Concordance*

Given the practical limitations of conducting interviews in person, the research adopted an online written approach to interviewing. The interviewees would receive questions through electronic means, and written answers would be submitted back to the researcher. Enough time was provided for the teachers to give well-thought-out responses. Where responses required further elucidation, more contact would be made to seek clarification.

## 2.3 Participants

In total, 15 chemistry teachers were involved in the study, which is ideal for qualitative research designed to reach in-depth insights. The participants were selected using purposive sampling, focusing on teachers who use AI applications in their practice. This was logical, as the nature of the study required teachers with experience of using AI applications; otherwise, they could not give any valuable comments regarding the impact of AI tools, problems connected with their application, and necessary training.

The recruitment process was done using social media platforms, mainly Instagram, which is filled with groups of Kazakhstani professionals such as teachers. The use of social media platforms enabled me to get access to teachers of chemistry in various regions of the country rather than relying on a specific school or region. Teachers of chemistry who have experience in teaching in secondary and other high institutions of learning were interviewed. Participants in the research are identified by their codes (T1-T15).

## 2.4 Data Analysis

### 2.4.1 Qualitative Content Analysis (Literature)

The literature corpus was analyzed using qualitative content analysis. Each article was carefully read and coded according to a structured coding framework developed from research questions.

The coding process involved using predetermined categories and themes that emerged during the analysis. Some of the predetermined categories were based on research questions developed for the study. These included:

- Types of AI-supported applications
- Influence on teaching practices
- Challenges and limitations
- Professional development needs

The codes were subsequently grouped into broader thematic categories to identify dominant patterns and trends across the literature.

### 2.4.2 Thematic Analysis (Interview Data)

Interview responses were analyzed using thematic analysis following the framework proposed by Braun and Clarke (2006). It is widely used in qualitative research, including education, to identify and interpret themes within data. The following steps were involved in thematic analysis:

- Reading all written responses to obtain an overall idea;
- Identifying important segments in the written responses;
- Coding important ideas;
- Grouping similar codes into broad categories;
- Comparing the results obtained from the interviews with those obtained from content analysis.

The emerging themes that came out of interviews were matched with the findings obtained from the literature review for any similarities and differences. This strategy enhanced the quality of analysis done in the research through triangulation.

The second consideration for the interpretation of findings was the number of times themes appeared.

## 2.5 Ethical Considerations

Ethical considerations were taken into account at each stage of the research process. Research was carried out in accordance with the general principles of academic integrity and rights of the research subjects. The review of the existing literature was based on freely available scientific articles. In order to prevent any cases of plagiarism, all resources utilized in the course of this study were properly cited following academic requirements. Only reputable academic resources were used in the research.

The ethical principles were well considered during the survey stage of the research. The respondents were given the freedom to participate in the surveys voluntarily, and they were made aware of the purpose of the research before they contributed their information to the research. The confidentiality of the research respondents was ensured during the analysis and reporting stage of the research, whereby the research did not collect any information that could identify the respondents. The information collected was used for scientific purposes only.

# RESULTS

The results of the qualitative content analysis of 30 peer-reviewed articles and thematic analysis of interviews with 15 chemistry teachers are presented in this chapter. The results are organized based on the research questions.

Each study included in the study for the qualitative content analysis was categorized based on various elements, such as the type of AI application, the level of education, the benefits of AI in teaching and learning, the challenges, and references to teacher training. A coding table for the research is included in Appendix 2 (pp. 67-70).

The interview analysis revealed several recurring themes related to the specific application names and their purpose of use, its impact on teaching and student learning, challenges, perceived effectiveness and needs for professional development. The full table of analysis shown in Appendix 3 (pp. 71-74).

## 3.1 Types of AI-Supported Applications in Chemistry Education

This section aims to answer to the first research question (RQ 1).

### 3.1.1 Findings from Content Analysis

The identification of the main categories of artificial intelligence application used in chemistry education was the aim of the first research question. Several categories of AI-enabled products that are often discussed in the literature have been identified. These categories include chatbots/AI tools, virtual labs/simulation technologies, intelligent learning systems/adaptable learning platforms, and AI-enabled evaluation/feedback systems. There has also been some study on the general application of AI in data analysis and chemical research, which may impact teaching practices.

The main categories of AI-enabled applications identified in the reviewed literature are presented in Table 3.1. According to this table, generative AI tools represent the most frequently discussed category (33.33%), followed by virtual laboratories and simulations (30%) and AI-supported assessment systems (23.33%).

These findings show a tendency for the use of AI to help improve the effectiveness of the learning process by improving conceptual explanations, visualization, lesson planning, and feedback automation.

*Table 3.1 Types of AI-Supported Applications*

| **AI Application Category** | **n (%)** |
|---|---|
| Generative AI tools and chatbots | 10 (33.33%) |
| Virtual laboratories, AI simulations and VR/AR | 9 (30%) |
| AI-supported assessment and feedback systems | 7 (23.33%) |
| Intelligent tutoring systems and adaptive learning platforms | 6 (20%) |
| AI applications in chemistry research and data analysis | 4 (13.33%) |

### 3.1.2 Results from Teacher Interviews (Thematic Analysis)

As a result of the thematic analysis, several themes related to the role of AI in influencing teaching were identified.

According to Table 3.2, the first dominant theme was AI as a source of assistance in reducing the workload of teachers. It has been reported that using AI helps teachers save time and reduce their efforts. For example, AI was used by teachers to “create tasks for students” and “generate presentations and visual materials” (T5).

Another important theme was AI, which helps simplify the explanation of complex topics. The use of AI tools allowed the teacher to simplify the explanation of the complex chemistry concepts and make it more understandable. They used AI to “study lesson materials” and solve problems (T4, T5).

Moreover, the theme of AI as a means of facilitating interaction and active learning was found. This was reflected in the fact that teachers noted greater student engagement and a higher level of participation in classes. “Increased classroom activity” and “increased student engagement” (T1, T13) were mentioned.

*Table 3.2 Impact of AI Use on Teaching Practices*

| **Impact Type** | **Description** | **n (%)** |
|---|---|---|
| Time-saving and instructional efficiency | Timesaving, reduced preparation time, easier lesson planning, improved efficiency, faster content preparation, time management | 9 (60%) |
| Improved teaching quality and explanation | Better teaching quality, clearer explanation, support for problem-solving, simplification of complex concepts | 7 (46.67%) |
| Interactive and student-centered teaching | More interactive lessons, greater use of visual materials, student-centered instruction, gamification | 5 (33.33%) |
| Creativity and innovation in teaching | Increased creativity and motivation, method integration, innovation support | 5 (33.33%) |
| Differentiation | Differentiated instruction, adaptation to student level | 1 (6.67%) |
| No | No major change in teaching approach | 1 (6.67%) |

AI-supported applications were also noted as a source of creativity and innovation. This theme included such activities of teachers as the creation of "new ideas" and "content enrichment" (T10, T15).

Furthermore, the exact names of the AI applications that teachers use in their actual practice were also revealed. According to Table 3.3, ChatGPT is the most widely used AI among participants (100%). Other commonly used ones are Gemini and Kahoot (40% each), it shows that teachers combine generative AI tools with interactive learning platforms that support AI.

Canva (27%), Gamma and Copilot (20% each) are used less frequently, while other AI-based applications are used by only one participant each (7%), suggesting limited use.

*Table 3.3 AI Tools Used by Participants*

| **Frequency** | **Tool Names** | **n (%)** |
|---|---|---|
| Most frequently used | ChatGPT | 15 (100%) |
| Commonly used | Gemini, Kahoot | 6 (40% each) |
| Moderately used | Canva | 4 (27%) |
| Occasionally used | Gamma, Copilot | 3 (20% each) |
| Less frequently used | Khanmigo | 2 (13%) |
| Rarely used | Grammarly, Bing Chat, Claude, Character AI, DeepSeek, Higgsfield, SlidesAI, Magic School, Nearpod, NotebookLM | 1 (7% each) |

## 3.2 Challenges and Limitations of AI Use for Chemistry Teachers

The second research question (RQ 2) for research considers difficulties associated with the implementation of AI in teaching chemistry.

### 3.2.1 Results from Literature Analysis

The literature presents a number of difficulties that might hinder the implementation of AI technologies in educational institutions despite the fact that a number of studies emphasize the potential benefits of AI technologies. The main difficulties identified in the content analysis are presented in Table 3.4.

According to Table 3.4, ethical concerns were mentioned in a great number of studies (n=9). By following it, teacher low AI literacy and infrastructure limitations are also one the main problems. Reliability and accuracy issues (n=5) have limits on effective implementation of AI in chemistry teaching. Overreliance is also one of the challenges in this field, but it is mentioned less than others in literature (n=2). In addition, many of these challenges tend to reinforce one another - limited infrastructure often compounds access and resource constraints, while language barriers further reduce the reliability of AI-generated content for Kazakh-speaking teachers.

*Table 3.4 Challenges of AI Implementation in Chemistry Education*

| **Reported Challenges** | **n (%)** |
|---|---|
| Ethical concerns and data privacy issues | 9 (30%) |
| Teacher low AI literacy | 8 (26.67%) |
| Technological infrastructure limitations | 8 (26.67%) |
| Reliability and accuracy of AI-generated content | 5 (16.67%) |
| Risk of student overreliance on AI tools | 2 (6.67%) |

### 3.2.2 Results from Teacher Interviews (Thematic Analysis)

There were identified several key challenges for teachers in using AI tools according to thematic analysis.

*Table 3.5 Challenges in Using AI Tools*

| **Challenges/Limitations** | **Description** | **n (%)** |
|---|---|---|
| Information Quality & Reliability Issues | Reliability of information, limited accuracy, inaccurate/excessive information, need for verification | 7 (46.67%) |
| Access & Resource Constraints | Cost and access limitations, institutional restrictions, lack of institutional support | 6 (40%) |
| Technical & Infrastructure Limitations | Lack of infrastructure, limited internet access, lack of devices, technical issues | 6 (40%) |
| Ethical & Safety Concerns | Data privacy, need for moderation | 2 (13.33%) |
| User & Context Limitations | Some language barrier, limited Kazakh support | 2 (13.33%) |
| None | No significant challenges | 2 (13.33%) |
| Time constraints | Don’t have enough time to learn AI | 1 (6.67%) |

The most common theme was concerns about reliability and accuracy (See Table 3.5). Teachers reported the need to verify information obtained using AI technology. For example, “information reliability” and “verification required” (T3, T8).

Another common theme was access and resource restrictions (n=6). The study involved teachers who faced problems with “cost and access limitations” or “need for paid subscription” and “lack of devices” (T6, T7 and etc.).

Table 3.5 shows that technical and infrastructural constraints were also another common topic (n=6). Among them were “technical problem” and “poor Internet connection” (T11).

Other less common problems included ethical considerations (n=2), such as “data privacy” (T14), and user restrictions (n=2), such as “language problem” (T13). There were also participants who did not encounter any noticeable difficulties or limitations (n=2).

Overall, the results indicate that the successful implementation of AI in chemistry education depends not only on the availability of AI tools but also on adequate infrastructure, institutional support, and teachers’ ability to critically evaluate AI-generated content. Therefore, addressing these challenges is essential for promoting the effective and responsible use of AI in educational settings.

## 3.3 Professional Development Needs

To answer the third research question findings from both the qualitative content analysis of peer-reviewed literature and the thematic analysis of teacher interviews were examined and compared.

### 3.3.1 Results from Literature Analysis

The analysis by Table 3.6 showed that the most frequently mentioned types of professional development are practical training and pedagogical integration. The necessity of the practical implementation of AI tools and tips about ways of implementation into pedagogical practices were mentioned in many studies. Also, there were quite a few papers focused on literacy in AI and literacy in subjects (e.g., chemistry), but there was a shortage of information concerning the ethical issues of AI

usage. In addition, some of the literature did not mention the topic of teachers' professional development but rather discussed technical or pedagogical issues related to using AI. Thus, only N=20 studies shown in Table 3.6.

*Table 3.6 Categories of Professional Development in Literature (N=20)*

| **PD Category** | **n (%)** |
|---|---|
| Practical training | 8 (40%) |
| Pedagogical integration | 6 (30%) |
| Chemistry-specific training | 5 (25%) |
| AI literacy | 3 (15%) |
| Ethical/critical AI use | 2 (10%) |

In addition to the 30 peer-reviewed studies included in the content analysis, one national policy document is worth noting separately. The methodological guidelines published by the National Academy of Education named after I. Altynsarin (2025) are dedicated specifically to AI use in chemistry teaching for grades 7-11 - making them, to the researcher's knowledge, the first subject-specific AI guidance document for chemistry teachers in Kazakhstan. This is important for the current research study, which indicates that there was already an expectation set forth from the institution that would require chemistry teachers to adopt AI technology into their teaching, supported by tangible tools and techniques. Whether teachers were aware of this document, and whether it had reached classroom level, was not a focus of this study - but its existence raises a direct question about the gap between policy and practice that the interview findings begin to answer.

### 3.3.2 Results from Teacher Interviews (Thematic Analysis)

According to the thematic analysis various professional development needs were identified. As shown in Table 3.7, the need for practical training in AI application is the most important (n=7), especially the participants who mentioned the use of AI tools

in classroom practice. For example, teachers talked about “practical training” and “content generation workshops” (T13).

*Table 3.7 PD Needs for AI integration*

| **Type of Training** | **Description** | **n (%)** |
|---|---|---|
| Practical AI training | Hands-on training on how to use AI tools in real classroom practice;<br>Content generation workshops | 7 (46.67%) |
| Formal / continuous professional development | PD courses; continuous PD; “Orleu” programs; Online training courses; Self-directed learning; AI ethics training | 6 (40%) |
| Chemistry-specific training | Courses focused on applying AI in chemistry teaching (tasks, formulas, experiments) | 4 (26.67%) |
| Digital pedagogy & integration | Understanding how to integrate AI into teaching methods and curriculum; Guidance on selecting effective AI tools | 4 (26.67%) |
| School-based & collaborative learning | In-school seminars; School-based training; Peer collaboration | 4 (26.67%) |
| Prompt engineering skills | How to write effective prompts to get best results | 2 (13.33%) |
| Accessibility of training | Free training and courses | 1 (6.67%) |
| Minimal training required | No need for extensive training | 1 (6.67%) |

Chemistry teachers also emphasized the significance of formal and continual PD (n=6). These include “AI training courses”, “and “self-directed learning” and online learning” (T5, T8). Several teachers referred to ‘Orleu’, the national professional centre - a few had already completed courses there, while others were simply aware it existed.

Furthermore, another critical need highlighted in the interview is associated with the necessity of having comprehensive training in chemistry (n=4), such as “AI applications for chemistry” (T6), and digital pedagogy with integration and school-based training with peer collaboration (e.g. “mutual cooperation” (T7)). Three participants mentioned that Nazarbayev Intellectual Schools (NIS) had held internal events related to AI, though they did not go into detail about the format or content.

Some other requirements mentioned include rapid engineering skills (n=2) to write prompts effectively. Very few teachers expressed their views on affordable (free) education (n=1) and one participant thinks that there is no need for extensive training.

What stood out was that no participant mentioned the methodological guidelines published by the National Academy of Education named after I. Altynsarin (2025), which are specifically designed for chemistry teachers working with Artificial Intelligence in grades 7-11.

These findings highlight conditions that may influence the effective integration of AI in teaching practice.

To sum up, the results of the study indicate the positive influence of AI tools on teaching practice; nonetheless, there are also a number of problems that should be noted. The results also highlight the obvious need for professional development, especially in practical AI training.

# DISCUSSION

Objectives of this research include studying the impact of applications based on AI in chemistry studies. For that reason, the data obtained during the process of literature review and semi-structured interviews are to be combined to interpret the obtained results in the light of the research problems.

## 4.1 AI-Assisted Applications and their Influence on Teaching Practices

This research found that there is a link and also some differences between the findings of the literature review and those from the interviews about what AI-enabled applications influence on teaching practices of chemists. This section addresses the first research question (RQ 1) about what AI-supported applications influence chemistry instructors' teaching practices.

From an examination of existing literature, there were found to be many main classifications of AI technology that could be utilized in chemistry education. Such classifications include generative AI tools, developing virtual laboratories and simulators, developing intelligent learning systems, and developing AI based assessment tools. Many researchers report that these technologies can assist teachers in the explanation of complicated subjects, simplifying the visual representation of difficult-to-visualize subject matter, also helps with lesson planning and provide automated feedback. As examples, AI tools like ChatGPT have assisted in providing explanations of chemical concepts, generated laboratory activities for students, and enhanced students' critical thinking abilities (Araújo & Saúde, 2024; Korolev et al., 2024). Virtual laboratories and simulators such as Labster and AI-powered virtual worlds allow teachers to easily explain chemical concepts such as molecular structures and perform experiments in a safe environment. These technologies help foster better understanding and participation (Alli, 2025; Selvam, 2024). In addition, intelligent tutoring systems like Knewton help personalize the teaching experience by automatically adjusting the difficulty levels of assignments and giving timely feedback based on learner progress (Al Braiki et al., 2020; Namatherdhala et al., 2022).

Moreover, according to Al Braiki et al. (2020), the assessment technology aided by AI allows automation of the evaluation and continuous tracking of students.

On the one hand, the data from the interviews confirmed the previous studies. The main themes identified in the thematic analysis are AI as a tool for reducing teachers' workload, AI as a support for explaining complex concepts, and AI as a facilitator of student engagement - indicating that AI contributes to improved teaching practices. Moreover, the most significant confirmation was related to the frequency at which educators utilize AI tools and how they affect educators' practices. The interviewed teachers claimed to be using ChatGPT extensively, along with other supportive tools like Canva and Kahoot, mostly in creating lessons and learning material, and conducting assessments. Similar to the literature review, the teachers have stated that the use of AI tools enables them to make complicated chemical terms easier for understanding, clarify explanations, and visualize the information via presentations and interactive material. Additionally, several teachers mentioned time-saving advantages, such as saving time while preparing for classes.

On the other hand, one of the main differences between what has been found in literature and interviews is the depth and type of AI. As mentioned earlier, the literature describes a wide range of AI applications, ranging from intelligent learning systems, adaptive learning technologies, and even laboratory simulations of AI. More advanced systems, such as adaptive learning systems or AI-based tutoring systems, virtual laboratories and simulations were not mentioned by participants. They prefer to use readily available and easy-to-use AI technology, particularly generative AI. Thus, in practice, AI integration for chemistry teachers is influenced more by accessibility and ease of use than by the full range of available technologies. It conforms to the principles of the TAM model, where teachers use the technology if they find it to be useful and user-friendly. ChatGPT fits both criteria - it is free, requires no setup, and produces immediate results - while more specialised platforms do not, regardless of their pedagogical value.

Generally, from the findings, it can be stated that AI-enhanced applications have been having an effect on the process of teaching chemistry through increased efficiency, explanation of complex topics, and development of learning material. Despite this, the application of AI has not reached a very sophisticated stage since the majority of the teachers utilize general AI applications rather than more sophisticated and subject-related AI programs. It is clear that despite the wide coverage of AI in teaching chemistry being discussed in literature, AI application in this field has not yet reached maturity.

## 4.2 Challenges and Limitations for Teachers in Applying AI-Powered Tools to the Chemistry Class

The findings from both the literature analysis and interview data of this study determined several key challenges and limitations to applying AI tools to chemical education according to the second research question (RQ 2). These challenges include reliability and accuracy of AI-generated content; access and infrastructure restrictions; teacher competence issues; ethical considerations and other aspects.

One of the most important obstacles can be the lack of reliability of information and the low level of accuracy of information obtained through AI. According to the literature review, ChatGPT and other similar technologies may provide false information in complicated scientific fields, such as chemistry (Korolev et al., 2024; Araújo & Saúde, 2024; Clark, 2023). The validity of this claim was supported by interview data, where several respondents claimed that it was important to validate the answers provided by AI. Thus, the impact of AI on teaching is limited by the need for critical review and supervision by the teacher. This indicates that concerns about reliability directly limit the effectiveness of AI-supported tools in teaching.

Second, access and infrastructure limitations were identified in both literature and interview data. Some studies have emphasized that effective AI integration requires stable Internet access, appropriate devices, and institutional support (Alli, 2025; Selvam, 2024). Teachers who participated in the interview also reported issues such as limited Internet connectivity, a shortage of devices, and institutional

restrictions, including a ban on the use of mobile phones in schools. At the same time, most of these teachers identified the paid version of AI applications as a common problem, which is not always available to everyone. These results indicate that even with the availability of AI-supported tools, they are limited to paid access and their implementation largely depends on the technological environment. This result can be also supported by Adejo (2025), who indicated that the primary challenges include poor Internet connectivity, limited computer access, lack of technical assistance, inadequate teacher preparation, and constraints within the curriculum. In addition, slightly outside the range of international literature, there is the official restriction regarding the use of mobile devices in Kazakhstani schools, highlighted by some of the interviewees. This issue is not just about the lack of infrastructure; rather, it is an actual clash of two simultaneous goals on a national scale, namely limiting the use of students' devices and increasing the role of AI in education. A teacher who wishes to provide interaction with AI applications in a class of chemistry students cannot use personal devices because they are still the only accessible option in most schools.

Thirdly, another major constraint is the unpreparedness and inadequate professional development of teachers. According to the literature review, for the success of AI implementation, there needs to be AI literacy on the side of teachers, pedagogical knowledge, and capability to critically assess AI outputs (Sari, 2025; Yildirim & Akcan, 2024; Feldman-Maggor et al., 2024). Nonetheless, this problem does not feature frequently within the interviews. Teachers have expressed that even highly motivated instructors might struggle with integrating AI into the classroom process owing to a lack of time to learn how to utilize AI. This means that the effectiveness of AI in chemistry education is dependent on teachers' competencies.

Fourth, but not as frequent, came ethical and contextual challenges. From reading, risks related to privacy, dependence on artificial intelligence (AI), and a possible loss of critical thinking ability were raised. Nevertheless, these risks were mentioned relatively fewer times during interviews, mostly concerning privacy and the extent of control over the use of AI by learners. This indicates that the current teaching

generation is more worried about practical matters rather than potential ethical concerns.

The main difficulties with using AI technology in chemical education have been identified by both scientific literature and interviews equally well. On the other hand, when interviewing teachers, the actual problems turned out to be much more significant than theoretical concerns considered by scientists.

This means that the presence of appropriate technology alone is not sufficient for effective AI usage in chemistry teaching. It is necessary to develop specific methods of training for teachers. AI is likely to be used only in basic forms, without revealing its full pedagogical potential. Therefore, these challenges and limitations may reduce the overall effectiveness of AI integration in chemistry.

## 4.3 Professional Development Needs for Effective Integration of AI in Chemistry Teaching

The results of the literature analysis and interview data revealed several key professional development needs and strategies that contribute to the effective integration of AI into chemistry education. This suggests that PD is a key condition influencing the effectiveness of AI integration in chemistry teaching based on the third research question (RQ 3).

First, practical training has become the most important need. The literature emphasizes that teachers are required not only to have a theoretical understanding of AI, but also to be able to apply AI tools in real-world learning environments. According to Iyamuremye et al. and other studies, effective use depends on teachers' ability to design tasks and evaluate AI outputs. This is strongly supported by the results of interviews in which participants reported that they use AI tools mainly for lesson planning, content generation, assessment design, and classroom interaction, however, they lack practice-based training. It is evident that professional development should focus on practical application in life situations.

Second, the research results emphasize the necessity for pedagogical integration of AI technologies. According to literature, AI may play a crucial role in implementing

inquiry-based learning, understanding theoretical concepts, and motivating students during chemistry lessons (Fayzullina et al., 2025; Chiu, 2024). On the other hand, the interview results revealed that teachers tended to use AI primarily for the purpose of improving efficiency instead of changing the approaches used. In other words, there is a need for PD programs aimed at helping teachers incorporate AI in lesson planning, specifically in explaining abstract chemical concepts and promoting active learning.

Thirdly, chemistry education has been identified as an important component of teacher training. The literature shows that AI applications can support visualization of chemical processes, virtual laboratory modeling, and problem-solving activities (Berber et al., 2025; Selvam et al., 2024; Alli, 2025). The interview participants mostly use general AI tools and for example no one highlighted virtual laboratories with AI support and emphasized the need for subject applications. The complete absence of virtual laboratories in teachers' responses is worth pausing on. These tools appear consistently in the chemistry education literature as among the most pedagogically valuable AI applications for the subject - precisely because chemistry involves experiments that are dangerous, expensive, or impossible to run in a standard school setting. However, none of them referred to their use. This is no trivial matter, since it indicates the possibility of using AI within chemistry - the specific potential that can help solve the problems associated with teaching chemistry - has yet to be exploited. Simply increasing teachers' general knowledge about AI cannot bridge this gap. The use of chemistry-specific software by teachers needs to be encouraged.

Fourth, the development of AI literacy and critical evaluation skills is necessary for effective and responsible use of AI. The results from the second research question showed that questions about reliability and accuracy of the content generated by AI tools were important. These conclusions are confirmed by the fact that the use of AI tools can result in producing scientifically inaccurate or misleading information especially in relation to chemistry (Yildirim & Akcan, 2024; Huwer et al., 2025). Thus, teachers should be able to assess outputs produced by AI, develop prompts and guide their students properly when working with AI tools.

These results align with other existing literature. Kaana et al. (2026) stress the importance of teachers' readiness to incorporate AI into chemistry classes successfully, and the authors point out that one of the main challenges facing this task is the absence of sufficient training programs for educators who work within chemistry and AI education. This supports the present study's findings about the importance of PD that is more complex than simple digital literacy.

One teacher stood out by stating that formal professional development - courses, seminars, workshops - was simply unnecessary, arguing that AI tools can be picked up through independent exploration. And it is an issue worth addressing rather than ignoring. Indeed, if anything, it seems to support the claims made by the study: the confidence probably stems from the knowledge that the use of ChatGPT to generate the content is easy, and, in that capacity, it is indeed not hard. What is hard, though, and what needs to be taught, is the ability to analyze AI-generated content, create tasks more complex than efficient, and educate the students on proper content usage.

Guidelines on Methodology offered by the National Academy of Education named after I. Altynsarin (2025) could be considered appropriate in this case since the presence of such an educational document already signifies a formal framework being in place. Nevertheless, the interview data indicates that such a framework has yet to be translated into practice. The participants made no mention of this document and did not describe any activities they performed within the framework of the requirements specified in this document for the use of specialized chemistry equipment.

In summary, the findings indicate that AI is becoming an increasingly valuable tool in chemistry education, supporting both teaching and learning processes. However, the benefits of AI can only be fully realized when challenges related to infrastructure, reliability, and teacher competence are addressed through appropriate support and professional development. Therefore, the successful integration of AI in chemistry teaching requires a balanced approach that combines technological innovation with pedagogical readiness and institutional support.

# CONCLUSION

The aim of this research is to determine the effectiveness of AI-supported technologies in the chemistry teachers' activities based on the qualitative literature review and experimental data acquired during semi-structured interviews. There are strong indications that AI technology has a great potential in improving the practice of chemistry teaching, but there are a variety of factors influencing this impact.

Firstly, this research proved that a great number of AI-enabled applications can be used in the process of chemistry teaching, which includes AI creation applications, virtual laboratories, intelligent tutoring systems, and assessment tools powered by AI technology. AI applications have a positive impact on the improvement of teaching techniques through helping explain complex concepts, visualize abstract processes, provide differentiated learning and feedback. These innovations have a direct connection to improved efficiency of the teaching process in relation to instructional clarity, efficacy, and student engagement.

Moreover, secondly, it was revealed that there is a large gap between what can be theoretically achieved using innovative technologies and classroom reality. While the review indicates that the primary emphasis is on the use of advanced AI, like adaptive learning technology and virtual simulation software, in fact, teachers opt for the implementation of the AI which is available for them, such as ChatGPT. Thus, it follows that the use of AI in the field of chemistry education is highly practical.

Some problems and weaknesses were identified during research. First and foremost, there is the problem associated with the reliability and validity of data produced using AI tools, the absence of technical facilities, and insufficient training of teachers. According to the teachers, data provided through AI should always be checked for validity, since AI merely serves as a supplementary tool. Moreover, practical obstacles such as limited access to the Internet, unavailability of devices and subscriptions, etc., have a profound impact on the effectiveness of utilizing AI tools in the field of education.

Another significant finding from this study is the fact that the success of AI use in the education of chemistry does not depend on the tool but on teacher readiness and competence. From the results achieved through this research, it becomes evident that teachers use AI as a tool to make their work easier and not to change the way they teach.

On top of that, it has been found out that there are certain PD needs that must be fulfilled to enable an effective AI integration process. This includes training on AI use, developing ways to integrate AI in teaching, training of AI specifically in chemistry, and developing AI literacy and skills of critical assessment of AI use. Also, it has been found out that PD must be consistent and collaborative in nature.

In summary, the contribution of this research paper is highly important because it is dedicated to one sphere of activity and emphasizes the use of AI for enhancing chemistry education by incorporating the theoretical and practical aspects of education. Indeed, while the possibilities of artificial intelligence in chemistry education are vast, it is essential that the proper use of such technology should be carried out in a systematic way.

## Implications

The conclusions drawn from this study indicate that there is a lot that AI has to offer when it comes to chemistry education, although its successful application would need adequate teacher training and incorporation. There is a need for AI training and courses to be incorporated into teacher training programs. Besides, the provision of increased technological availability and creation of AI tools dedicated to chemistry would make the process easier. Chemistry teachers also need pedagogical strategies with technical knowledge to effectively use AI tools into their practice.

Based on these findings, a proposed Online Professional Development Course for Chemistry Teachers on the Integration of AI Tools was developed as a practical outcome of this study. The course was designed to address the professional development needs identified through both the literature review and teacher interviews. It includes modules on AI literacy, chemistry-specific AI applications, prompt

engineering, AI-supported lesson planning and assessment, as well as ethical and responsible use of AI in education. Although the course has not yet been implemented, it is proposed as a framework for future teacher training initiatives aimed at supporting more effective AI integration in chemistry education. The full course syllabus is provided in Appendix 4 (pp. 75-78).

Universities and educational institutions should include AI literacy, operational design, and critical evaluation of AI-generated content in their curricula to train future teachers.

# LIMITATIONS

There were certain limitations that appeared during the investigation. First, the sample used in the study is quite small, since only 15 chemistry teachers were interviewed. Though such several participants is sufficient for qualitative studies, it makes it impossible to generalize the findings obtained within the framework of the study to other teachers.

Second, the research was conducted based on the data gathered in written interviews. Such a methodology can lead to subjectivity, since the participants might provide socially desirable responses. But there was a problem that many teachers could not devote time to a full-fledged interview, and some did not use AI applications at all, so it was decided to use a written format.

Third, the study focused mainly on qualitative methods and did not include a quantitative assessment of learning outcomes. Thus, although the study reveals the supposed effectiveness of AI-supported tools, it does not provide statistical data on their impact.

Finally, another limitation was about using general AI tools like ChatGPT by chemists. There were fewer mentions of more advanced tools such as virtual laboratories or intelligent learning systems. Thus, it can reduce the comprehensiveness of knowledge obtained about various kinds of AI-supported tools.

# REFERENCES


*Abiltayeva, A., Zhumagulova, K., Satayev, M., Yechshzhanov, T., Maimatayeva, A., & Balta, N. (2025). Teacher competencies and digital integration into teaching practices: Perceptions from pre-service biology teachers in Kazakhstan. Frontiers in Education, 10, 1628034. https://doi.org/10.3389/feduc.2025.1628034*

*Adejo, O. L. (2025). Evaluating the effectiveness and challenges of artificial intelligence tools in chemistry instruction at the Federal University of Education, Zaria. FNAS Journal of Mathematics and Science Education, 6(4), 16–25. https://doi.org/10.63561/fnas-jmse.v6i4.907*

*Al Braiki, B., Harous, S., Zaki, N., & Alnajjar, F. (2020). Artificial intelligence in education and assessment methods. Bulletin of Electrical Engineering and Informatics, 9(5), 1998–2007. https://doi.org/10.11591/eei.v9i5.1984*

*Alli, A. O. A. (2025). Review of the potential of artificial intelligence (AI) in enhancing chemistry education. https://doi.org/10.5281/zenodo.15202897*

*Almasri, F. (2024). Exploring the impact of artificial intelligence in teaching and learning of science: A systematic review of empirical research. Research in Science Education, 54(5), 977–997. https://doi.org/10.1007/s11165-024-10176-3*

*Amiresheva, B. E., Butabayeva, L. A., Ibatova, G. B., Ismagulova, S. K., & Nogaibayeva, G. A. (2025). Are they prepared for the use of digital technology? The competencies of prospective teachers in terms of technological pedagogical content knowledge. Eurasia Journal of Mathematics, Science and Technology Education, 21(11), em2727. https://doi.org/10.29333/ejmste/17340*

*Ananikov, V. P. (2024). Top 20 influential AI-based technologies in chemistry. Artificial Intelligence Chemistry, Article 100075. https://doi.org/10.1016/j.aichem.2024.100075*

*Araújo, J. L., & Saúde, I. (2024). Can ChatGPT enhance chemistry laboratory teaching? Using prompt engineering to enable AI in generating laboratory activities. Journal of Chemical Education, 101(5), 1858–1864. https://doi.org/10.1021/acs.jchemed.3c00745*

*Baum, Z. J., Yu, X., Ayala, P. Y., Zhao, Y., Watkins, S. P., & Zhou, Q. (2021). Artificial intelligence in chemistry: Current trends and future directions. Journal of Chemical Information and Modeling, 61(7), 3197–3212. https://doi.org/10.1021/acs.jcim.1c00619*

*Bauyrzhan, L., & Zhylysbayeva, A. (2025). Exploring the use of artificial intelligence in teaching chemistry at higher education institutions. Journal of Educational Sciences, 83(2). https://doi.org/10.26577/JES20258324*

*Berber, S., Brückner, M., Maurer, N., & Huwer, J. (2025). Artificial intelligence in chemistry research: Implications for teaching and learning. Journal of Chemical Education. https://doi.org/10.1021/acs.jchemed.4c01033*

*Blonder, R., & Feldman-Maggor, Y. (2024). AI for chemistry teaching: Responsible AI and ethical considerations. Chemistry Teacher International, 6(4), 385-395. https://doi.org/10.1515/cti-2024-0014*

*Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. Qualitative research in psychology, 3(2), 77-101. https://doi.org/10.1191/1478088706qp063oa*

*Chen, L., Chen, P., & Lin, Z. (2020). Artificial intelligence in education: A review. IEEE Access, 8, 75264–75278. https://doi.org/10.1109/ACCESS.2020.2988510*

*Chiu, W. K. (2021). Pedagogy of emerging technologies in chemical education during the era of digitalization and artificial intelligence: A systematic review. Education sciences, 11(11), 709. https://doi.org/10.3390/educsci11110709*

*Clark, T. M. (2023). Investigating the use of an artificial intelligence chatbot with general chemistry exam questions. Journal of Chemical Education, 100(5), 1905–1916.* https://doi.org/10.1021/acs.jchemed.3c00027

*Damola, F. M., Dayo, U. O., Sheriff, A., Edem, M. E., Daniel, C. N., Ebite, C., & Paul, M. E. (2025). Science educators' perspective on the use of generative artificial intelligence (AI) in the teaching of chemistry in Lagos State, Nigeria. Global Journal of Educational Research, 24(2), 169–185.* https://doi.org/10.4314/gjedr.v24i2.6

*Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. MIS quarterly, 13(3), 319-340.* https://doi.org/10.2307/249008

*dos Santos, R. P. (2023). Enhancing chemistry learning with ChatGPT, Bing Chat, Bard, and Claude as agents-to-think-with: A comparative case study. arXiv.* https://doi.org/10.48550/arXiv.2311.00709

*Eitemüller, C., Trauten, F., Striewe, M., & Walpuski, M. (2023). Digitalization of multistep chemistry exercises with automated formative feedback. Journal of Science Education and Technology, 32(3), 453-467.* https://doi.org/10.1007/s10956-023-10043-2

*Erümit, A. K., & Sarıalioğlu, R. Ö. (2025). Artificial intelligence in science and chemistry education: A systematic review. Discover Education, 4(1), 178.* https://doi.org/10.1007/s44217-025-00622-3

*Estrada, P. A., Agudelo, K. P., & Flórez, E. P. (2025). Artificial intelligence and inclusive education: A professional development model for chemistry teachers in secondary education. Educational Process: International Journal, 17, e2025380.* https://doi.org/10.22521/edupij.2025.17.380

*Fayzullina, A. R., Filippova, A. A., Garnova, N. Y., Astakhov, D. V., Kalmazova, N., & Zaripova, Z. F. (2025). Artificial intelligence in science education: A systematic*

*review of applications, impacts, and challenges. Contemporary Educational Technology, 17(4), ep613. https://doi.org/10.30935/cedtech/17519*

*Feldman-Maggor, Y., Blonder, R., & Alexandron, G. (2025). Perspectives of generative AI in chemistry education within the TPACK framework. Journal of Science Education and Technology, 34(1), 1–12. https://doi.org/10.1007/s10956-024-10147-3*

*Hammoud, R. (2025). Exploring chemistry teachers' knowledge and perceptions of AI: Opportunities and challenges. International Journal of Research in Education and Science, 11(1), 49–60. https://doi.org/10.46328/ijres.3584*

*Harry, A. (2023). Role of AI in education. Interdisciplinary Journal & Humanity (INJURITY), 2(3). https://doi.org/10.58631/injurity.v2i3.52*

*Holmes, W., & Miao, F. (2023). Guidance for generative AI in education and research. Unesco Publishing. https://doi.org/10.54675/PCSP7350*

*Huwer, J., Maurer, N., Mundt, P., & Belova, N. (2025). AI in chemistry and chemical education: AI in chemistry. International Journal of Physics and Chemistry Education, 17(1), 1–4. https://doi.org/10.51724/ijpce.v17i1.403*

*Iyamuremye, A., Niyonzima, F. N., Mukiza, J., Twagilimana, I., Nyirahabimana, P., Nsengimana, T., & Nsabayezu, E. (2024). Utilization of artificial intelligence and machine learning in chemistry education: A critical review. Discover Education, 3(1), Article 95. https://doi.org/10.1007/s44217-024-00197-5*

*Jere, S., & Mpeta, M. (2025). Integrating generative artificial intelligence chatbots into chemistry teaching: Impact of affective factors on engagement and conceptual understanding. Eurasia Journal of Mathematics, Science and Technology Education, 21(10), em2713. https://doi.org/10.29333/ejmste/17077*

*Jonassen, D. H. (1994). Thinking technology: Toward a constructivist design model. Educational technology, 34(4), 34-37. https://eric.ed.gov/?id=EJ481852*

*Kaana, A., Ugosor, T. P., & Ukpoko, W. U. (2026). Chemistry Education and Artificial Intelligence (AI) In the 21st Century Nigeria: Prospects, Challenges, and the Way Forward. A Review Article. International Journal of Research and Innovation in Social Science (IJRISS), 9(12).* https://doi.org/10.47772/IJRISS.2025.91200097

*Karmanova, A., Madybekova, G., Kavak, N., Ualikhanova, B., Zharylkassyn, A., & Umarova, Z. (2024). Developing the professional competence of future chemistry teachers through digital technologies: A case study of Kazakhstan. International Journal of Information and Education Technology, 14(8), 1119–1126.* https://doi.org/10.18178/ijiet.2024.14.8.2140

*Kim, S. (2024). Analysis of Chemistry Teachers' Perceptions of AI Utilization in Education: Focusing on Participants in First-Grade Teacher Qualification Level Training. Journal of the Korean Association for Science Education, 44(5), 511-518.* https://doi.org/10.14697/jkase.2024.44.5.511

*Korolev, V. D., Ponamarenko, O. V., & Khamitova, A. S. (2025). The use of artificial intelligence in chemistry lessons. Endless Light in Science, 7–11.*

*Leite, B. S. (2024). Generative artificial intelligence in chemistry teaching: ChatGPT, Gemini, and Copilot's content responses. Journal of Applied Learning and Teaching, 7(2).* https://doi.org/10.37074/jalt.2024.7.2.13

*Martínez, L., Matilde, O., Varas, F., Carestia, N., & Zalazar, S. (2025, October). Virtual Laboratories with AI in Exact Sciences Education. In 2025 South American Conference On Visible Light Communications (SACVLC) (pp. 1-6). IEEE.*

*Ministry of Education of the Republic of Kazakhstan & Ministry of Digital Development, Innovations and Aerospace Industry of the Republic of Kazakhstan. (2025). Conceptual foundations for the implementation of artificial*

*intelligence in secondary, technical, vocational, and post-secondary education for 2025–2029.* https://uba.edu.kz/storage/app/media/projects/ru_concep.pdf

*Mondal, H., Marndi, G., Behera, J. K., & Mondal, S. (2023). ChatGPT for teachers: Practical examples for utilizing artificial intelligence for educational purposes. Indian Journal of Vascular and Endovascular Surgery.* https://doi.org/10.4103/ijves.ijves_37_23

*Namatherdhala, B., Mazher, N., & Sriram, G. K. (2022). A comprehensive overview of artificial intelligence trends in education. International Research Journal of Modernization in Engineering Technology and Science, 4(7), 61–67.* https://www.irjmets.com/uploadedfiles/paper/issue_7_july_2022/27772/final/fin_irjmets1658508846.pdf

*National Academy of Education named after I. Altynsarin. (2025). Methodological recommendations for the application of artificial intelligence in teaching and learning of chemistry in grades 7–11. NAO named after I. Altynsarin.* https://uba.edu.kz/storage/app/media/555%20YY%20RS%20RS.pdf

*Nawaz, M. (2024). AI in STEM Education: Enhancing Problem-Solving and Critical Thinking Skills. AI EDIFY Journal, 1(4), 38-48.* https://researchcorridor.org/index.php/aiej/article/view/252

*Oxford English Dictionary. (n.d.). Artificial intelligence. In OED Online. Retrieved April 15, 2025, from* https://www.oed.com

*Pence, H. E. (2020). How should chemistry educators respond to the next generation of technology change? Education Sciences, 10(2), Article 34.* https://doi.org/10.3390/educsci10020034

*Powell, W., & Courchesne, S. (2024). Opportunities and risks involved in using ChatGPT to create first grade science lesson plans. PloS one, 19(6), e0305337.* https://doi.org/10.1371/journal.pone.0305337

*Raja, R., & Nagasubramani, P. C. (2018). Impact of modern technology in education. Journal of Applied and Advanced Research, 3(1), 33–35. https://doi.org/10.21839/jaar.2018.v3iS1.165*

*Ratniyom, J., Boonphadung, S., Intaraprasit, M., & Chumkaeo, P. (2025). ChatGPT as a direct formative assessment tool in stoichiometry: Correlation with achievement and insights into pre-service science teachers' perceptions. Chemistry Teacher International. https://doi.org/10.1515/cti-2025-0048*

*Sari, N. I., & Ahmad, F. (2025). Exploring the impact of artificial intelligence in chemistry teaching: A systematic review of empirical research. Arfak Chem: Chemistry Education Journal, 8(2), 759-771. https://doi.org/10.30862/accej.v8i2.1083*

*Selvam, A. A. A. (2024). Exploring the impact of artificial intelligence on transforming physics, chemistry, and biology education. Journal of Broader Impacts in STEM. https://doi.org/10.21428/a70c814c.747297aa*

*Shi, L., Ding, A.-C. E., & Choi, I. (2024). Investigating teachers' use of an AI-enabled system and their perceptions of AI integration in science classrooms: A case study. Education Sciences, 14(11), 1187. https://doi.org/10.3390/educsci14111187*

*Tahiru, F. (2021). AI in education: A systematic literature review. Journal of Cases on Information Technology, 23(1), 1–20. https://doi.org/10.4018/JCIT.2021010101*

*Temirkhanova, M., Abildinova, G., & Karaca, C. (2024). Enhancing digital literacy skills among teachers for effective integration of computer science and design education: A case study at Astana International School, Kazakhstan. Frontiers in Education, 9, 1408512. https://doi.org/10.3389/feduc.2024.1408512*

*Verma, G., Campbell, T., Melville, W., & Park, B. Y. (2023). Navigating opportunities and challenges of artificial intelligence: ChatGPT and generative models in*

*science teacher education. Journal of Science Teacher Education, 34(8), 793-798. https://doi.org/10.1080/1046560X.2023.2263251*

*Vygotsky, L. S., & Cole, M. (1978). Mind in society: Development of higher psychological processes. Harvard university press.*

*Woolf, B. P., Lane, H. C., Chaudhri, V. K., & Kolodner, J. L. (2013). AI grand challenges for education. AI Magazine, 34(4), 66–84. https://doi.org/10.1609/aimag.v34i4.2490*

*Yildirim, B., & Akcan, A. T. (2024). AI-professional development model for chemistry teacher: Artificial intelligence in chemistry education. Journal of Education in Science, Environment and Health, 10(4), 161–182. https://doi.org/10.55549/jeseh.741*

*Zhai, X., Chu, X., Chai, C. S., Jong, M. S. Y., Istenic, A., Spector, M., & Li, Y. (2021). A review of artificial intelligence (AI) in education from 2010 to 2020. Complexity, 2021, Article 8812542. https://doi.org/10.1155/2021/8812542*

*Zhang, K., & Aslan, A. B. (2021). AI technologies for education: Recent research and future directions. Computers and Education: Artificial Intelligence, 2, Article 100025. https://doi.org/10.1016/j.caeai.2021.100025*

# APPENDICES

***Appendix 1***

**Interview Questions**

1. What artificial intelligence-based applications do you use in your learning?
2. For what purpose do you use them (for example, to create a lesson plan, assessment, development of educational materials, modeling, providing students with feedback, studying lesson material/gaining knowledge/content knowledge, preparing exam questions, getting new ideas)?
3. How have these applications affected your learning methods or approaches?
4. Have you noticed changes in student interests or learning outcomes after using AI tools?
5. What difficulties have you encountered when using AI tools? Are there technical or resource constraints (such as internet access, lack of devices, etc.)?
6. Do you think you need enough training and skills to use AI tools effectively? Why?
7. What kind of professional development or training courses do you think are necessary for the effective use of AI in chemistry teaching?
8. What role do you think AI should play in chemistry teacher training in the future?
9. Do you think AI can make chemistry teaching and learning more effective? Why?

***Appendix 2***

*Table 1. Coding Table for Literature Content Analysis (N=30)*

| **Author** | **Year** | **AI Types** | **Reported Benefit** | **Challenges** | **PD Mentioned** |
|---|---|---|---|---|---|
| Harry | 2023 | AI tutoring systems, adaptive learning | Supports differentiated instruction, reduces teacher workload in assessment | Ethical issues | Yes Pedagogical integration |
| Zhai et al. | 2021 | Various AI technologies (systematic review) | Adaptive learning, improves classroom engagement | Ethical concerns | No |
| Fayzullina et al. | 2025 | AI tools in science education | Supports explanation of complex concepts, supports differentiated instruction | Implementation issues | Yes Pedagogical integration |
| Woolf | 2013 | Intelligent tutoring systems | Supports differentiated instruction | Technology integration | No |
| Pence | 2020 | VR/AR visualization technologies | Visualization of chemical concepts | Technological adoption | Yes Chemistry-specific training |
| Tahiru | 2021 | AI systems in education | Adaptive learning | Ethical concerns | No |
| Almasri | 2024 | AI tools in science education (systematic review) | Instant feedback, automated grading, helps teachers create tests | Data privacy | Yes Practical training |
| Namatherdhala et al. | 2022 | AI learning platforms (Knewton), VR/AR technologies (Jasper and Grammarly) | Administrative work, creating curricula, developing learning material, automation of reviewing assignments, monitoring student performance | Technological barriers | Yes Practical training, Pedagogical integration |
| Berber et | 2025 | VR and AI | Real-world chemistry | Financial problems, | Yes |

| | | | | | |
|---|---|---|---|---|---|
| al. | | simulations, AI in chemistry research and teaching | understanding, speed up research, productive teaching, automatic grading and monitoring, safe labs | overreliance, teacher preparedness | Practical training, Chemistry-specific training |
| Chiu | 2024 | Digital technologies, virtual labs, AI simulation technology | Inquiry learning, improves classroom engagement and supports differentiated instruction | Ethical issues, digital inequality | Yes Pedagogical integration |
| Korolev et al. | 2024 | ChatGPT, Crayon (GenAI) | Supports explanation of complex concepts, reduces teacher workload in assessment (instant feedback) | Reliability of AI | No |
| dos Santos | 2023 | ChatGPT, Bing Chat, Bard, Claude | Critical thinking, creating new ideas and answering to questions | Inaccurate responses | Yes Ethical/critical AI use |
| Jere & Mpeta | 2025 | AI chatbots | Supports explanation of complex concepts, classroom engagement | Overreliance on AI | No |
| Araujo & Saude | 2024 | ChatGPT for lab reports | Writing support | Scientific accuracy | No |
| Clark | 2023 | ChatGPT exam questions | Learning reflection | Incorrect answers | No |
| Selvam | 2024 | Virtual labs, AI simulations | Helps teachers visualize abstract chemistry processes and easily explain to students, more interesting learning | Technological access, ethical considerations | Yes Chemistry-specific training |
| Alli | 2025 | Virtual labs, intelligent systems (Cognii/Labster), adaptive learning platforms | Supports explanation of complex concepts, instant feedback | Infrastructure limitations | Yes Chemistry-specific training, Practical training |
| Ananikov | 2024 | Digital chemistry AI-based | Research-based learning, visualization | Technological integration | Yes Chemistry- |

| | | | | | |
|---|---|---|---|---|---|
| | | technologies, VR, AR, NLP | | | specific training |
| Al Braiki et al. | 2020 | Intelligent tutoring systems, AI-supported assessment | Adaptive learning, supports differentiated instruction, immediate feedback | Data management | No |
| Zhang & Aslan | 2021 | AI learning systems | Supports differentiated instruction | Research limitations | No |
| Baum et al. | 2021 | AI in chemistry research | Scientific data analysis | Curriculum adaptation | No |
| Erümit & Sarıalioğlu | 2025 | AI tools in science classrooms | Improves classroom engagement, interactive feedback | Infrastructure issues | Yes Pedagogical integration |
| Iyamuremye et al. | 2024 | Virtual labs, adaptive learning technologies, ITS, AI-based assessment tools and ML tools | Supports differentiated instruction, reduces teacher workload in assessment | Dataset limitations | Yes Practical training |
| Sari | 2025 | AI applications in chemistry teaching | Supports explanation of complex concepts, classroom engagement | Teacher readiness | Yes AI literacy |
| Yildirim & Akcan | 2024 | AI in teacher education, Gemini, ChatGPT | Professional competence | Low AI literacy | Yes AI literacy |
| Feldman-Maggor et al. | 2024 | Generative AI (ChatGPT) | Pedagogical support | Prompt design challenges | Yes Practical training (prompt skills) |
| Huwer et al. | 2025 | AI in chemistry research and education | Optimizing learning processes | Ethical issues | Yes Ethical/critical AI use |
| Verma | 2024 | Generative AI, | Lesson planning | Critical AI literacy | Yes |

| | | | | | |
|---|---|---|---|---|---|
| | | ChatGPT | support, creating content, innovating teaching | | Practical training, Pedagogical integration |
| Hammoud | 2025 | AI in chemistry teaching | Teaching efficiency | Lack of training | Yes Practical training |
| Kim | 2024 | AI awareness among teachers | Instructional support (lesson planning, assisting with assessments) | Preparedness gaps | Yes AI literacy |

***Appendix 3***

*Table 2. Full Coding Table of Interview Responses (N=15)*

| **Participant** | **AI Tools Used** | **Purpose** | **Teaching impact** | **Student Impact** | **Challenges** | **Effectiveness** | **PD Need** |
|---|---|---|---|---|---|---|---|
| T1 | ChatGPT Grammarly SlidesAI Quizizz | Feedback, learning lesson materials, new ideas | Improved teaching practices | Increased engagement | None | Yes, personalized learning, differentiated instruction, assessment with feedback | Yes In-school seminars |
| T2 | ChatGPT | Assessment design, Reviewing recent research | Enhanced teaching quality | No change | Time constraints (don't have enough time to learn AI) | Yes, differentiation | Yes Training in the use of AI tools |
| T3 | ChatGPT | Assessment design | Improve efficiency | No change | Reliability of information | Potentially | Yes Practical training |
| T4 | ChatGPT Gemini | Learning lesson materials, new ideas, knowledge acquisition, problem solving, assessment design | No major change | No change (doesn't use during lessons) | Cost and access limitations<br><br>Reliability | Yes, time saving, improved teaching quality, enhanced student understanding | Yes Training in the use of AI tools Guidance on selecting effective AI tools |
| T5 | Canva ChatGPT Gemini Magic School Gamma | Creating tasks for students, generating presentations and visual | Faster content introduction, problem-solving support, simplification of | Increased student engagement, increased classroom participation | Limited internet access, Lack of devices Institutional restrictions (e.g., phone | Yes, AI as a supportive teaching tool, connection to real- | Yes Participation in AI-related professional development (Orleu) |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | materials, learning lesson materials | complex concepts | | bans) | life contexts | programs Online training courses on AI tools |
| T6 | ChatGPT Nearpod Kahoot | Lesson planning, new ideas | Differentiation of instruction | Increased student interest | Cost and access limitations | Yes, improves understanding of difficult topics | Yes Chemistry-specific AI applications |
| T7 | ChatGPT Gemini Kahoot Gamma | For interactive lessons, new ideas, generating presentations and visual materials, Assessment design | Reduced preparation time, Easier lesson planning | Increased student interest slightly | Cost and access limitations<br><br>Reliability | Yes, improves understanding of difficult topics, supports teacher work | Yes School-based training Peer collaboration Professional development courses |
| T8 | ChatGPT Gemini Higgsfield | Translation, video/content creation, new ideas, lesson material preparation | Time saving, Improved explanation and teaching quality | Improved understanding, increased interest | Reliabillity Need for verification Limited accuracy Cost and access limitations | Yes, increased teaching efficiency, simplifies learning | Self-directed learning AI training courses Continuous professional development |
| T9 | ChatGPT Gemini Notebook LM | Assessment design (exam/quiz questions), task creation, learning support (notetaking) | Time saving | No change (doesn't use during lessons) | None | Uncertainty about effectiveness, as AI has limited functionality for chemistry | Yes AI training courses Prompt engineering skills |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| T10 | Canva<br>Gemini<br>ChatGPT | New ideas and insights, Creating presentations and video, Content enrichment | Improved teaching quality and explanation, Increased use of visual materials | Improved understanding by visual information, Increased functional literacy | Cost and access limitations | Conditional effectiveness (depends on use) | Integration into curriculum (teacher education), short seminars No need for extensive training |
| T11 | ChatGPT<br>Khanmigo<br>Copilot | Modeling, New ideas, Feedback support | Gamification, simplifying complex terminology | Slight positive impact | Technical issues<br><br>Poor Internet access | Conditional effectiveness | Yes<br>Free training and courses |
| T12 | Kahoot<br>Quizizz<br>ChatGPT<br>Khanmigo | Lesson material preparation, Assessment design | Method integration, Innovation support | Increased interest | Cost and access limitations, Lack of institutional support | Time saving Efficiency improvement | Prompt engineering training |
| T13 | ChatGPT<br>Quizizz<br>Kahoot<br>Canva<br>Copilot<br>DeepSeek | Creating presentations and visual materials, Lesson planning, Assessment design, Translation | Shift to student-centered learning, Increased interactivity and creativity, Reduced preparation time | Increased participation, Improved understanding, Faster comprehension | Some language barrier, Need for verification, Lack of devices | Yes, time saving, personalization and visualization | Practical AI training Chemistry-specific training Digital pedagogy |
| T14 | ChatGPT<br>Kahoot<br>Gamma<br>Claude<br>Character AI<br>Bing Chat | Lesson planning, Lesson material preparation, Visual materials, Criteria development for assessment, | Time management, Increased motivation | Increased participation, Improved conceptual understanding, self-directed learning | Data privacy<br><br>Need for moderation<br><br>Inaccurate or excessive information | Conditional effectiveness<br><br>Proper integration | AI ethics training Chemistry-focused AI use, Content generation workshops |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | Feedback | | | | | |
| T15 | Copilot<br>ChatGPT<br>Canva<br>Kahoot | New ideas, Practical examples, Creating presentations, Assessment design | Interactive teaching, Time saving, Increased creativity | Increased interest | Language barrier<br><br>Lack of infrastructure | Yes, simplifying complex processes through visualization, personalization | Practical AI training<br>Chemistry-specific training platforms<br>Digital pedagogy |

*Appendix 4*

**Proposed Online Professional Development Course**

**For Chemistry Teachers on the Integration of AI Tools**

## 1. Course Information

**Target Audience:** Secondary School Chemistry Teachers

**Delivery Mode:** Online

**Duration:** 40 Academic Hours

**Course Purpose:**

The course is designed to enhance chemistry teachers' AI literacy and support the effective integration of AI-supported applications into chemistry teaching. The course was developed based on the findings of the master's thesis and addresses identified professional development needs including AI literacy, chemistry-specific AI tools, prompt engineering, ethical AI use, and classroom implementation.

## 2. Learning Outcomes

Upon successful completion of the course, participants will be able to:

- Explain the role of artificial intelligence in chemistry education.
- Evaluate the educational potential of AI-supported applications.
- Use chemistry-specific AI tools such as virtual laboratories and intelligent tutoring systems.
- Apply prompt engineering techniques for lesson planning and assessment.
- Design AI-supported chemistry lessons and laboratory activities.
- Critically evaluate AI-generated content.
- Integrate AI responsibly and ethically into classroom practice.

## 3. Course Structure and Educational-Thematic Plan

| Module | Topic | Theory | Practice | Total |
|---|---|---|---|---|
| 1 | Introduction to AI in Chemistry Education | 3 | 3 | 6 |
| 2 | Chemistry-Specific AI Tools and Applications | 2 | 6 | 8 |

| | | | | |
|---|---|---|---|---|
| 3 | Prompt Engineering for Chemistry Teachers | 2 | 6 | 8 |
| 4 | AI-Supported Lesson Planning and Assessment | 2 | 6 | 8 |
| 5 | Ethical and Responsible Use of AI | 2 | 4 | 6 |
| | Final Project | 0 | 4 | 4 |

**4. Module Descriptions**

**Module 1. Introduction to AI in Chemistry Education (6 Hours)**

Topics:

- Fundamentals of AI;
- AI in Education;
- Opportunities and Challenges of AI in Chemistry Teaching;
- Teacher Readiness and AI Literacy.

Assessment: Online Quiz.

**Module 2. Chemistry-Specific AI Tools and Applications (8 Hours)**

Topics:

- ChatGPT, Gemini, Copilot;
- Labster, PraxiLabs, ChemCollective;
- Cognii;
- Kahoot AI, Quizizz AI, Khanmigo.

Assessment: Practical Assignment - design a chemistry activity using one AI application.

**Module 3. Prompt Engineering for Chemistry Teachers (8 Hours)**

Topics:

- Prompt Design;
- Laboratory Tasks;
- Assessment Creation;

- Improving Accuracy.

Assessment: Prompt Engineering Portfolio (10 educational prompts with reflection).

**Module 4. AI-Supported Lesson Planning and Assessment (8 Hours)**

Topics:

- Lesson Planning;
- Differentiated Instruction;
- Personalized Learning;
- AI-Supported Assessment.

Assessment: Micro-Teaching Presentation.

**Module 5. Ethical and Responsible Use of AI (6 Hours)**

Topics:

- Reliability,
- Hallucinations,
- Academic Integrity,
- Data Privacy,
- Scientific Accuracy.

Assessment: Case Analysis Report.

**5. Final Assessment - Project**

Participants develop an AI-Supported Chemistry Lesson Package including:

- Complete lesson plan;
- AI-supported laboratory activity;
- Assessment instrument;
- Collection of prompts used;
- Reflection on ethical AI integration.
- Participants present and justify their instructional design decisions.

**6. Assessment Breakdown**

| Assessment Type | Weight |
|---|---|
| Module Quizzes | 10% |
| Practical Assignments | 20% |
| Prompt Portfolio | 20% |
| Micro-Teaching Presentation | 20% |
| Case Analysis Report | 10% |
| Final Project | 20% |

## 7. Expected Impact and Practical Significance

The proposed course is expected to improve AI literacy, increase teacher readiness, promote effective use of chemistry-specific AI applications, and support ethical AI integration.

The course directly addresses the gap identified in the study between AI applications recommended in the literature and those actually used by chemistry teachers. Although the course has not yet been implemented, it is proposed as a practical outcome and future recommendation arising from the findings of the research.