ISSN: 1991-3494 (Print)
ISSN: 2518-1467 (Online)

SCIENTIFIC JOURNAL OF PEDAGOGY AND ECONOMICS

№6
2025

ISSN 2518-1467 (Online),
ISSN 1991-3494 (Print)

CENTRAL ASIAN ACADEMIC
RESEARCH CENTER

SCIENTIFIC JOURNAL OF PEDAGOGY AND ECONOMICS

PUBLISHED SINCE 1944

6 (418)

November – December 2025

ALMATY, 2025

Scientific Journal of Pedagogy and Economics
ISSN 2518-1467 (Online),
ISSN 1991-3494 (Print).
Owner: «Central Asian Academic Research Center» LLP (Almaty).
The certificate of registration of a periodical printed publication in the Committee of information of the Ministry of Information and Communications of the Republic of Kazakhstan
№ KZ50VPY00121155, issued on 05.06.2025
Thematic focus: *«publication of the results of new achievements inthe field of fundamental sciences»*
Periodicity: 6 times a year.
http://www.bulletin-science.kz/index.php/en/

Scientific Journal of Pedagogy and Economics
ISSN 2518-1467 (Online),
ISSN 1991-3494 (Print).
Меншіктенуші: «Орталық Азия академиялық ғылыми орталығы» ЖШС (Алматы қ.).
Қазақстан Республикасының Ақпарат және коммуникациялар министрлігінің Ақпарат комитетінде 05.06.2025 ж. берілген **№ KZ50VPY00121155** мерзімдік басылым тіркеуіне қойылу туралы куәлік. Тақырыптық бағыты: *«іргелі ғылым салалары бойынша жаңа жетістіктердің нәтижелерін жариялау»*
Мерзімділігі: жылына 6 рет.
http://www.bulletin-science.kz/index.php/en/

Scientific Journal of Pedagogy and Economics
ISSN 2518-1467 (Online),
ISSN 1991-3494 (Print).
Собственник: ТОО «Центрально-азиатский академический научный центр» (г. Алматы).
Свидетельство о постановке на учет периодического печатного издания в Комитете информации Министерства информации и коммуникаций и Республики Казахстан
№ KZ50VPY00121155 выданное 05.06.2025 г.
Тематическая направленность: *«публикация результатов новых достижений вобласти фундаментальных наук».*
Периодичность: 6 раз в год.
http://www.bulletin-science.kz/index.php/en/

CONTENTS

PEDAGOGY

ECONOMICS

МАЗМҰНЫ

ПЕДАГОГИКА

ЭКОНОМИКА

СОДЕРЖАНИЕ

ПЕДАГОГИКА

ЭКОНОМИКА

ПЕДАГОГИКА – ПЕДАГОГИКА – PEDAGOGY

SCIENTIFIC JOURNAL OF PEDAGOGY AND ECONOMICS
ISSN 1991-3494
Volume 6.
Number 418 (2025), 17–29

https://doi.org/10.32014/2025.2518-1467.1055

IRSTI 28.23.15
UDC 378.147.311.21

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AI-SUPPORTED LEARNING IN SECONDARY CHEMISTRY EDUCATION

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Abstract. The relevance of this study lies in the growing demand for developing students' functional literacy as a key educational outcome in secondary chemistry education. Functional literacy is understood as students' ability to apply chemical knowledge to real-life contexts, while artificial intelligence and digital tools are considered supportive instructional means rather than independent educational goals. The purpose of this research is to investigate the effectiveness of artificial intelligence–based digital tools in supporting the development of functional literacy during the study of electrolytic dissociation in secondary school chemistry. The study employed a quasi-experimental design and was conducted in a comprehensive secondary school. Two groups participated: an experimental group taught using artificial intelligence–supported digital tools and a control group instructed through traditional teaching methods. Student learning outcomes were assessed over a three-month period using diagnostic and formative assessment tools. The results demonstrate that the experimental group showed a greater improvement in performance, increasing from

16.5 to 22.4 points, compared to the control group, which improved from 14.2 to 17.8 points. The findings indicate that adaptive feedback, visual representations, and individualized learning pathways facilitated deeper conceptual understanding and more meaningful learning experiences. Despite the limited duration and sample size, which classify the study as a pilot investigation, the results highlight the potential of artificial intelligence and digital tools to support functional literacy development in chemistry education. The practical significance of the study lies in its implications for instructional design, curriculum planning, and future large-scale research on the integration of artificial intelligence in school science education.

Keywords: Artificial Intelligence, chemistry education, functional literacy, digital learning, secondary education

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ОРТА МЕКТЕПТЕ ХИМИЯНЫ ЖАСАНДЫ ИНТЕЛЛЕКТ ҚОЛДАУЫМЕН ОҚЫТУ

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Аннотация. Бұл зерттеудің өзектілігі жалпы орта білім беретін мектептерде химияны оқыту барысында оқушылардың функционалдық сауаттылығын негізгі білім беру нәтижесі ретінде қалыптастыру қажеттілігімен айқындалады. Функционалдық сауаттылық оқушылардың химиялық білімді өмірлік жағдаяттарда қолдана алу қабілетін білдіреді, ал жасанды интеллект пен цифрлық құралдар осы нәтижеге қол жеткізуді қамтамасыз ететін көмекші педагогикалық құралдар ретінде қарастырылады. Зерттеудің мақсаты – орта мектепте «Электролиттік диссоциация» тақырыбын оқыту кезінде жасанды интеллектке негізделген цифрлық құралдардың функционалдық сауаттылықты дамытудағы тиімділігін анықтау. Зерттеу квази-эксперименттік дизайн негізінде жүргізілді және жалпы білім беретін мектеп жағдайында жүзеге асырылды. Зерттеуге екі топ қатысты: жасанды интеллектке негізделген цифрлық құралдар қолданылған эксперименттік топ және дәстүрлі оқыту әдістерімен білім алған бақылау тобы. Оқушылардың оқу жетістіктері үш

ай бойы диагностикалық және қалыптастырушы бағалау құралдары арқылы бағаланды. Зерттеу нәтижелері эксперименттік топтың көрсеткіштері 16,5-тен 22,4 баллға дейін артқанын, ал бақылау тобының нәтижелері 14,2-ден 17,8 баллға дейін ғана өскенін көрсетті. Алынған деректер бейімделген кері байланыс, көрнекі ақпарат және жекелендірілген оқыту траекториялары оқушылардың ұғымдық түсінуін тереңдетіп, мағыналы білім қалыптастыруға ықпал ететінін дәлелдейді. Зерттеудің мерзімі мен іріктемесінің шектеулі болуына байланысты ол пилоттық зерттеу ретінде қарастырылады. Дегенмен алынған нәтижелер химияны оқытуда функционалдық сауаттылықты дамыту үшін жасанды интеллект пен цифрлық құралдарды қолданудың әлеуетін көрсетеді. Зерттеудің практикалық маңызы оқыту үдерісін жобалау, оқу бағдарламаларын жетілдіру және болашақта кең ауқымды зерттеулер жүргізу мүмкіндіктерімен байланысты.

Түйін сөздер: жасанды интеллект, химияны оқыту, функционалдық сауаттылық, цифрлық оқыту, орта білім

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ОБУЧЕНИЕ ХИМИИ В СРЕДНЕЙ ШКОЛЕ С ПОДДЕРЖКОЙ ИСКУССТВЕННОГО ИНТЕЛЛЕКТА

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Аннотация. Актуальность данного исследования обусловлена необходимостью формирования функциональной грамотности учащихся как ключевого образовательного результата при обучении химии в средней школе. Функциональная грамотность рассматривается как способность обучающихся применять химические знания в реальных жизненных ситуациях, тогда как искусственный интеллект и цифровые инструменты выступают в роли вспомогательных педагогических средств, способствующих достижению данного результата. Цель исследования заключается в изучении эффективности цифровых инструментов, основанных на искусственном интеллекте, в развитии функциональной грамотности при изучении темы «Электролитическая диссоциация» в школьном курсе химии. Исследование проводилось на основе

квази-экспериментального дизайна в условиях общеобразовательной школы. В нем приняли участие две группы обучающихся: экспериментальная группа, в которой применялись цифровые инструменты с элементами искусственного интеллекта, и контрольная группа, обучавшаяся с использованием традиционных педагогических методов. Оценка учебных достижений проводилась в течение трех месяцев с применением диагностических и формирующих оценочных инструментов. Результаты исследования показали, что в экспериментальной группе средний показатель успеваемости увеличился с 16,5 до 22,4 балла, тогда как в контрольной группе рост составил лишь от 14,2 до 17,8 балла. Полученные данные свидетельствуют о том, что адаптивная обратная связь, визуализация учебного материала и индивидуализированные образовательные траектории способствуют более глубокому пониманию химических понятий и формированию осмысленных знаний. Несмотря на ограниченную продолжительность и выборку исследования, что позволяет отнести его к пилотным, результаты подтверждают потенциал использования искусственного интеллекта и цифровых инструментов для развития функциональной грамотности в химическом образовании. Практическая значимость исследования заключается в возможностях его применения при проектировании учебного процесса, разработке образовательных программ и планировании дальнейших масштабных исследований в области внедрения искусственного интеллекта в школьное обучение.

Ключевые слова: искусственный интеллект, обучение химии, функциональная грамотность, цифровое обучение, среднее образование

Introduction. Obtaining scientific knowledge, learning to think like a scientist and knowing more about physical reality depend on chemistry education. Secondary students can benefit from chemical teaching as a key subject that provides them with principal scientific knowledge important for future technology. Educational programs in chemistry teach students useful concepts while enabling them to use their obtained knowledge to address actual problems by creating functional literacy capabilities (Popenici & Kerr, 2017). The functional application of chemical knowledge extends past rote memorization because it focuses on using chemical information to address real-life situations that include environmental awareness and technological advancements, and health-related concerns (Makinde & Oyeniyi, 2024). Artificial intelligence (AI) and digital technologies combined with education now transform STEM teaching along with classroom learning techniques throughout the modern educational period. Artificial intelligence development provides exceptional possibilities to improve educational processes while creating responsive teaching methods and individualized instruction, and resourceful educational systems. Virtual laboratories, along with chatbots and platform generators developed by AI, have shown themselves capable of changing how students learn chemistry. Students can perform experiments through virtual laboratories, which create simulated controlled conditions to let them gain practical exposure without dealing with the limitations of

physical laboratories. The combination of chatbots with modeling platforms brings real-time problem-solving and target concept explanation during student interaction (Chiu, 2021; Ali, Talib & Jamal, 2023).

Recent growing interest in artificial intelligence applications for education has revealed an experimental deficit concerning its impact on chemistry learning at the secondary school level. An academic deficiency exists regarding AI-based tools' support for chemistry functional literacy; therefore, more research must investigate their benefits towards improved student knowledge acquisition and concept implementation. The inclusion of AI technology in chemistry education serves two vital functional purposes: it provides students with captivating education experiences and develops their proficiency for the digital future in which AI will dominate (Chassignol et al., 2018). This research holds importance because it investigates how AI and digital technologies can boost secondary school chemistry education for students. The study investigates AI-powered educational platforms to generate findings that expand the current scholarly knowledge about AI implementations in STEM education. Using AI tools within chemistry teaching produces numerous positive effects that result in customized education and elevated student involvement, and enhanced results in exams. The study maintains high relevance for Kazakhstan's educational system because it aligns with the growing national initiative to integrate digital technologies into classrooms for modern teaching practices and student readiness in an evolving world (Senbekov et al., 2020; Floreano et al., 2008; Kornyo, 2021). The research results from this study present potential global significance for educational systems that are starting to implement AI in their classrooms.

Multiple research studies during recent years have investigated how AI technology supports educational development, specifically for STEM subjects. AI-based technological tools enhance student educational success rates while promoting active involvement and delivering feedback, which helps students maintain their academic position according to Park et al. (2023) and Garcia Ramos et al. (2024), and Wahjusaputri et al. (2024). Students benefit from AI-powered virtual laboratories, which eliminate physical equipment boundaries to provide secure laboratories that anybody can access to conduct chemical experiments. The delivery of on-demand tutoring through chatbots enables students to ask questions with real-time responses, which boosts their capability to learn by themselves and fortifies main concepts (Clark, 2023; Bahroun et al., 2023). AI-driven modeling software gives students the power to model chemical reactions as well as simulate chemical processes, which enhances abstract concept comprehension and develops problem-solving abilities (Chiu, 2021; Fakhar et al., 2024).

Although the educational benefits of artificial intelligence are well documented, existing research has predominantly focused on higher education and technology-oriented disciplines, leaving secondary school chemistry education relatively underexplored. In particular, there is a lack of empirical studies examining how AI-supported instructional tools influence students' understanding of abstract chemical concepts at the secondary level. This gap is especially significant in topics such as

electrolytic dissociation, where students often experience conceptual difficulties due to the microscopic and theoretical nature of the content.

Addressing this gap, the present study investigates the use of AI-supported learning tools in secondary school chemistry to better understand how such technologies can support students' conceptual learning and contribute to the development of functional literacy. By focusing on a school-based instructional context, the study provides empirical evidence that extends current discussions on AI integration beyond higher education and offers insights relevant to curriculum design and classroom practice in secondary chemistry education.

Research Objectives. The primary objective of this study is to examine the effectiveness of AI-supported learning in secondary chemistry education, with particular attention to the development of students' functional literacy as an educational outcome.

Specifically, the study aims to:

Investigate the extent to which AI-supported instructional approaches contribute to the development of functional literacy among ninth-grade chemistry students.

Assess students' retention of knowledge and academic performance in the topic of electrolytic dissociation when AI-supported learning environments are used.

Compare learning outcomes between students taught using AI-supported approaches and those receiving traditional teacher-centered instruction.

Examine students' ability to read, interpret, and apply scientific information in chemistry as an indicator of functional literacy development.

Evaluate the feasibility of integrating AI-supported instructional tools into secondary chemistry classrooms while maintaining the central pedagogical role of the teacher.

Materials and methods.

1. Research Design

The study team used a comparative design to investigate how AI and digital technology affected the education of chemistry and 9th-grade students' functional literacy. The research included two distinct groups: students who used AI tools and students who received instruction from their instructors. The research design enabled direct outcome assessment, which measured AI effects on chemical education results between test groups. A pretest assessment was used to evaluate the effects of the intervention because both experimental and control groups received the same assessment before starting their programs. The design investigated whether AI platforms proved superior to traditional educational methods in creating immersive learning spaces.

2. Participants

The research included 42 9th-grade students from a secondary school in Kazakhstan who were divided into two groups of 21 students each. The researchers selected participants randomly from one academic year to guarantee equivalent groups. Students in the experimental group learned with AI-assisted platforms, while the control group received instruction from their teachers. The study measured both

groups through pretests and interim assessments, and posttests that took place at the end of the 3rd quarter. The research included 42 students to create equal groups, which allowed for statistical analysis that could be applied to comparable educational environments.

3. Intervention

Experimental Group: The experimental group learned electrical dissociation through AI-driven platforms that integrated into their educational process. The experimental group utilized these particular AI tools:

Virtual Laboratories: Through the virtual platforms, students performed real-world experimental activities in a digital simulation system. Students gained access to virtual labs that let them study dangerous or difficult chemical interactions, which are unsafe to carry out traditionally.

Chatbots: AI-powered chatbots operated as real-time agents for personal assistance to students at their disposal. The designed chatbots provided students with question answering capabilities and doubt clarification, and progress feedback to support self-directed learning.

Platform Generators for Modeling: Through modeling platforms, students gained visual representations of chemical processes as well as reactions through simulated environments. Students used the modeling platforms to manipulate variables while observing their effects and developed a better comprehension of the studied concepts.

Control Group: The control group underwent standard instructor-led chemistry classes about electrical dissociation without implementing AI technology. Traditional tools, including lectures together with textbooks and physical laboratory experiments, were used as teaching methods to deliver the curriculum. The experimental group followed the identical curriculum as the control group, yet lacked the digital enhancements that AI-driven platforms would have offered. Figure 1 demonstrates the AI tools adopted by the experimental group, opposite to the traditional teaching approaches followed by the control group.

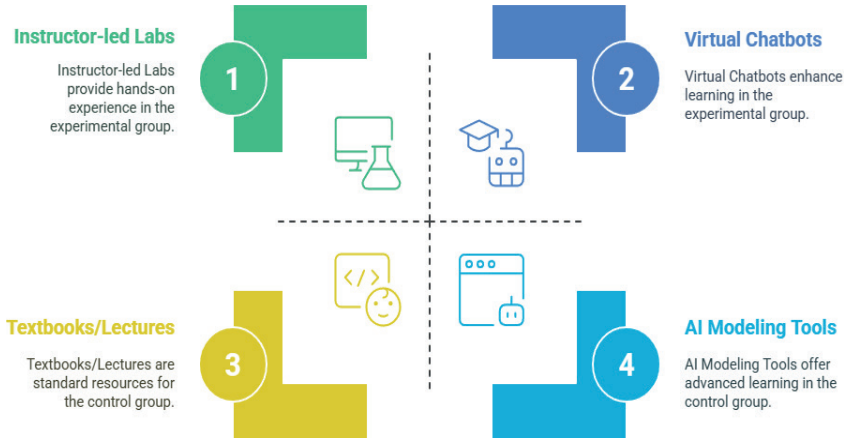

Figure 1- Comparison of AI Tools and Traditional Teaching Methods in the Experimental and Control Groups.

4. Pretest and Posttest

The experimental and control groups completed baseline assessment tests about electrical dissociation through multiple-choice and short-answer questions to ensure equal starting points. The testing procedure at the beginning and end of the study allowed researchers to identify changes that resulted from instructional approaches. The same structure and content-based posttest followed the intervention period to measure knowledge persistence, along with conceptual understanding and application among students. Students had to handle real-world problems alongside conceptual explanations in the posttest, which allowed for both functional ability and academic achievement assessment. This investigative plan allowed researchers to track AI learning outcomes by comparing them against conventional education techniques in a valid manner.

5. Assessment and Data Collection

The experimental and control groups received assessment sessions during the 4-month study duration to evaluate improvements while detecting absent concepts. The evaluations consisted of quizzes and short-answer questions, and practical assessments to check students' understanding of the taught material (Table 1). These tests occurred at scheduled intervals. The research data collection relied on pretest and posttest scores and interim assessment outcomes. Students received scores between 1 and 30 points, and students who scored 19 points or higher achieved the desired learning outcome. The assessment data was structured into groups and assessment times to enable thorough analysis of experimental group and control group progress.

Table 1. Schedule and Structure of Chemistry Assessments Conducted During the Study

Assessment Type	Date of Assessment	Topics Covered	Duration
Pretest	Start of study	Electrical dissociation	1 hour
Interim Assessment 1	Month 1	Electrical dissociation	30 minutes
Interim Assessment 2	Month 2	Electrical dissociation	30 minutes
Interim Assessment 3	Month 3	Electrical dissociation	30 minutes
Posttest	End of 3rd Quarter	Electrical dissociation	1 hour

6. Statistical Analysis

The researchers conducted t-tests for independent samples to analyze pretest and posttest scores between experimental and control group mean scores. A statistical test known as ANOVA demonstrated any variations that occurred in learning results throughout different periods. The research used a $p < 0.05$ significance level to establish statistical significance, which meant any score differences with p-values under 0.05 were considered significant. The evaluation determined if AI technology within the experimental section increased learning performance to a measurable extent than the conventional instructional method in the control division.

Results.

Pretest and Posttest Scores Comparison

The research compares test results from the experimental group, which used AI tools, against the results from the control group, which used traditional teaching

methods. The research evaluates how AI tools affect student comprehension of chemistry concepts, with a focus on electrical dissociation through Table 2.

Table 2. Pretest and Posttest Scores Comparison

Group	Pretest Mean Score (out of 30)	Posttest Mean Score (out of 30)	Improvement (Points)	Improvement (%)
Experimental	14.2	24.1	+9.9	69.6%
Control	14.4	18.3	+3.9	27.08%

Table 2 displays the mean score data from pretests and posttests for both experimental and control groups. The experimental participants who used AI-learning tools achieved a substantial score elevation of 9.9 points (69.6%) in their posttest results after starting at 14.2 pretest points and reaching 24.1 points. The control group students who received traditional instruction methods showed less substantial improvement in their scores from 14.4 to 18.3 points (27.08%) compared to the experimental group. The substantial difference in learning success indicates that AI tools bring positive transformations to student academic achievement.

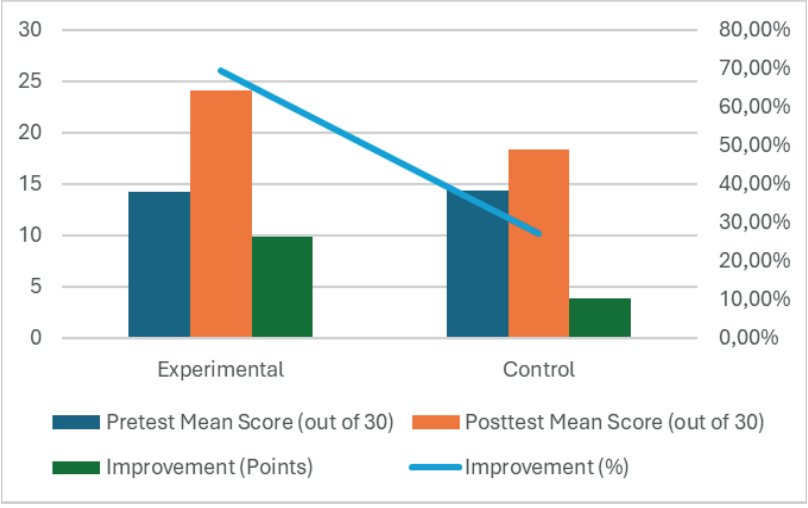

Figure 2- Bar Chart of Pretest and Posttest Scores Comparison

The experimental and control group posttest score differences appear in Figure 2. The experimental group achieved a substantial boost in posttest scores thus strengthening the evidence of AI tools' positive influence on educational results.

Analysis of Statistical Significance and Effect Size

A statistical evaluation determined whether the experimental and control group posttest score differences reached a significant level. The observed differences received statistical validation through independent samples t-tests.

Table 3. Statistical Analysis of Pretest and Posttest Scores

Group Comparison	t-value	p-value	Effect Size (Cohen's d)	Significance
Experimental vs. Control	3.92	0.001	1.15	Significant

Table 3 shows the statistical results that compare the experimental group and control group scores from pretest to posttest. The experimental results show statistical significance because the t-value reaches 3.92 and the p-value stands at 0.001. The experimental group experienced a substantial impact on student learning outcomes based on the large effect size of 1.15. The statistical results validate the effectiveness of AI-driven intervention, as it improved student performance.

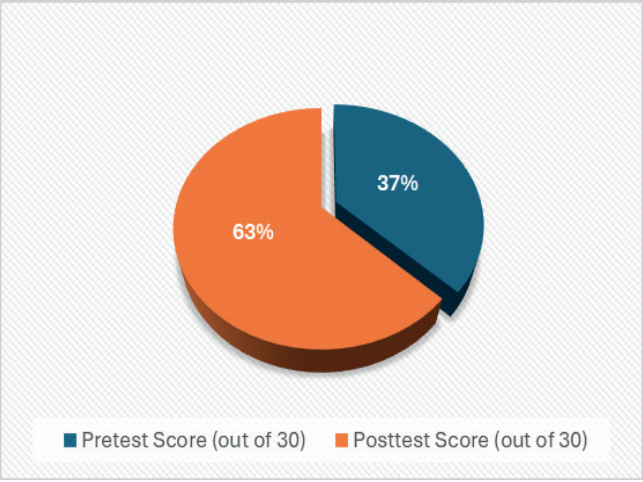

Figure 3- Statistical Significance of Pretest and Posttest Scores

Figure 3 visually represents the statistical analysis of the pretest and posttest scores, showing the significant difference between the experimental and control groups. This figure highlights the large effect of AI tools on improving student learning outcomes.

Interim Assessments and Continuous Progress

The assessments throughout the 4-month study served to track student progress continuously. The assessments revealed important information about students' electrical dissociation understanding development throughout the study period thus enabling continuous learning assessment.

Table 4. Interim Assessments and Performance Trends

Assessment Type	Date of Assessment	Topics Covered	Experimental Group Mean	Control Group Mean
Interim Assessment 1	Month 1	Electrical dissociation	16.5	14.2
Interim Assessment 2	Month 2	Electrical dissociation	19.3	16.1
Interim Assessment 3	Month 3	Electrical dissociation	22.4	17.8

The data in Table 4 shows the results of three-monthly interim assessments, which focused on electrical dissociation topics. Both groups maintained a regular pattern of improved results during the assessment period. The mean scores of students under AI-supported instruction rose consistently from 16.5 at Month 1 to 22.4 by Month 3. The control group, which received traditional teaching methods, demonstrated lower improvement rates from 14.2 to 17.8, while the experimental group showed better results. The research data indicates that artificial intelligence crossover with digital technologies enhanced student achievements within the experimental student cohort across periods.

Discussion. The findings of this quasi-experimental study indicate that the integration of artificial intelligence–based digital tools into secondary chemistry education can positively influence both academic achievement and the development of functional literacy. Over the three-month intervention period, students in the experimental group demonstrated a more pronounced improvement in learning outcomes compared to those receiving traditional instruction. The observed increase in mean scores from 16.5 to 22.4 suggests that AI-supported learning environments may enhance students' understanding of abstract chemical concepts.

The topic of electrolytic dissociation, which is traditionally challenging due to its abstract nature, became more accessible through the use of visual representations, adaptive feedback, and individualized learning pathways. These features supported students' conceptual comprehension and encouraged active engagement with the learning material. In contrast, the control group showed more gradual progress, indicating that conventional teaching methods may offer fewer opportunities for personalized learning and immediate feedback.

The results further highlight the importance of instructional flexibility in classrooms characterized by diverse learning needs and prior knowledge levels. Artificial intelligence–supported tools allowed for differentiated instruction without altering curricular objectives, thereby supporting students at varying levels of preparedness. However, it is important to emphasize that artificial intelligence functioned as a supportive instructional tool rather than a substitute for the teacher, whose role remained central in guiding learning and interpreting instructional outcomes.

Despite the positive findings, this study has several limitations. The research was conducted in a single secondary school in Kazakhstan with two ninth-grade classes over a relatively short period. Consequently, the results should be interpreted with caution and cannot be generalized without further investigation. Additional factors, including students' digital competencies, teachers' experience with AI-based tools, and institutional technological readiness, may have influenced the outcomes.

Conclusion. This study provides empirical evidence that the use of artificial intelligence–based digital tools in secondary chemistry education can positively influence both students' academic achievement and the development of functional literacy. Students exposed to AI-supported instruction demonstrated higher learning gains in the study of electrolytic dissociation compared to those taught using

traditional instructional methods. The findings suggest that adaptive feedback, visual representations, and individualized learning trajectories supported by AI contribute to deeper conceptual understanding, meaningful learning, and increased student motivation.

Importantly, the results confirm that artificial intelligence should be regarded as a pedagogical support mechanism rather than an independent instructional solution. The effectiveness of AI-enhanced learning environments depends on their thoughtful integration into classroom practice and on the active, guiding role of the teacher in instructional planning and implementation.

Given the pilot nature of the study, the findings should be interpreted with caution. Future research should involve longer intervention periods, larger and more diverse student samples, and applications across different chemistry topics and subject areas. Further investigations may also focus on teachers' pedagogical strategies in AI-supported classrooms, students' metacognitive development, and the institutional feasibility of scaling AI-based technologies in school education. Overall, this study establishes a cautious yet promising foundation for the informed and pedagogically grounded use of artificial intelligence in secondary chemistry education.

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www: nauka-nanrk.kz
ISSN 2518–1467 (Online),
ISSN 1991–3494 (Print)
http://www.bulletin–science.kz/index.php/en

Ответственный редактор **А. Ботанқызы**
Редакторы: **Д.С. Аленов, Т. Апендиев**
Верстка на компьютере: **Г.Д. Жадырановой**

Подписано в печать 31.12.2025.
46,0 п.л. Заказ 6.

«Central Asian Academic Research Center» LLP
Алматы, Қонаев к-сі, 142