Торайғыров университетінің
ҒЫЛЫМИ ЖУРНАЛЫ

НАУЧНЫЙ ЖУРНАЛ
Торайгыров университа

Торайғыров университетінің ХАБАРШЫСЫ

Педагогикалық сериясы
1997 жылдан бастап шығады

ВЕСТНИК ТОРАЙГЫРОВ УНИВЕРСИТЕТА

Педагогическая серия
Издается с 1997 года

ISSN 2710-2661

№ 3 (2026)
Павлодар

НАУЧНЫЙ ЖУРНАЛ
Торайгыров университета

Педагогическая серия
выходит 4 раза в год

СВИДЕТЕЛЬСТВО
о постановке на переучет периодического печатного издания,
информационного агентства и сетевого издания
№ KZ03VPY00029269
выдано
Министерством информации и коммуникаций
Республики Казахстан

Тематическая направленность
публикация материалов в области педагогики,
психологии и методики преподавания

Подписной индекс – 76137

https://doi.org/10.48081/BTOUP3.2026/ISSN2710-2661

SRSTI 14.25.09

https://doi.org/10.48081/BTOUP3.2026/309-325

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DESIGN METHOD IN SCHOOL CHEMISTRY: EFFECTIVENESS AND IMPACT ON ACADEMIC PERFORMANCE

The article examines the impact of implementing experimental design methods in middle school chemistry lessons to enhance student engagement and academic outcomes. The main goal was to develop essential skills such as critical thinking and independence by transitioning from traditional teaching to the design of experimental tasks. Employing a quasi-experimental design, the study involved conducting pre-tests and post-tests to assess the educational benefits of this teaching strategy. Quantitative data were analyzed using SPSS version 29.0.2.0, which revealed significant academic improvements among the participants. A paired samples t-test showed a notable increase in students' test results ($t = -6.947$, $df = 23$, $p < 0.001$), confirming the effectiveness of integrating experimental design into the curriculum. This approach not only enhanced students' interest in chemistry but also improved their practical application of scientific concepts. The results advocate for the integration of experimental design tasks into chemistry education, emphasizing their role in making the subject more engaging and practically relevant. Although limited by the sample size and duration of the study, the positive outcomes suggest potential for

broader application. Future research should explore the long-term effects and scalability of this method across various educational settings.

Keywords: Chemistry education, experimental design, school education, academic achievement, teaching methodology.

Introduction

Chemistry, as a school subject, evokes pupils' complex and contradictory emotions. On the one hand, it is a fascinating science that reveals the fundamental laws of the nature, from the structure of substances to global ecological processes. On the other hand, the complexity of chemical concepts and their abstract nature make schoolchildren's comprehension difficult. Schoolchildren do not often understand the connection between the theoretical knowledge and its practical significance, which leads to an interest decrease and motivation for learning [1, P. 1–10]. According to the research of the International Educational Association for the Achievement Evaluation (IEA), only 35 % of schoolchildren have a sustained interest in natural sciences, including Chemistry. The remaining schoolchildren face difficulties in perceiving the material, which reduces significantly their involvement in the educational process [2, P. 77–87]. These problems are not only typical of Kazakhstan, but other countries with different levels of the economy and education have the same issues too.

Current research is focused on the importance of integrating the scientific content with the practice to solve this problem. Innovative approaches are recommended, including teaching based on the planning of laboratory experiments [3, P. 1054–1073]. In accordance with the international experience, integrating a design - based approach into laboratory classes can increase significantly schoolchildren's involvement. For instance, elements of self-dependent experimentation is used actively in the school curriculum on Chemistry in Finland. As a result, it was noted that 78 % of schoolchildren's interest in the subject had increased [4, P. 32–59]. However, such methods have not been studied sufficiently yet and they are rarely used in Kazakhstan. So, it requires to find effective methods for their implementation.

School laboratories on Chemistry play a decisive role in acquiring methodological knowledge and skills [5, P. 1098–1113]. Unfortunatly, lessons are often limited by the teacher's demonstrating an experiment or following step-by-step instructions. Furthermore, pupils' opportunity to understand the logic of experiments is deprived, so perception development is inhibited. Their intellectual activities are suppressed by such "prescription" laboratory work and they are not allowed to develop their critical thinking skills through self-dependent planning experiments [6, P. 1-8]. Indeed, such laboratory exercises are not aimed

at developing pupils' skills that can be useful in real life situations and they are not related to a real-life context. Schoolchildren's active participation in planning the work is involved by approaches to planning experiments because it promotes their development of analytical skills, independence, causal thinking, and the formation of hypotheses and research questions [7, P. 387–396].

Thus, such opportunities can be provided by doing practical tasks. Students are asked to design an experiment based on the provided information and the criteria for a qualititive experimental design. Owing to the use of this approach in studying Chemistry at the secondary school, research results have been proved that it stimulates the critical thinking development [8, P. 1173–1182]. The main indicators of critical thinking are: the education quality improvement and schoolchildren's academic performance. The most important problems of the educational system are considered to be pupils' academic performance and teaching efficiency, and they represent the realization of the educational goal [9, P. 176].

This is a short-term research project aimed at transforming traditional step-by-step instructions into practical tasks for pupils' individual design stages of laboratory work. It was a simple process that didn't require much time or effort. Pupils of the 7th grade of the secondary school were involved in the research. It is very important to use innovative approaches to teach Chemistry during the first academic period, namely in the 7th grade, since this period plays a decisive role in the formation of pupils' interest in science and basic learnng skills [10, P. 599–623]. However, how pupils acquire experimental design skills under time constraints, how this affects their involvement in learning and academic performance have not been studied enough yet.

In view of this, the proposed approach differs from traditional methods of teaching Chemistry because it is oriented on developing self-dependent experimental planning skills than compared with forcing pupils to follow predetermined instructions. Pupils are involved actively in formulating hypotheses, planning experimental activities and interpreting the results unlike "prescription" laboratory work. Elements related to real-life problems, such as environmental issues or daily chemical processes are included in the assignments. These issues make learning Chemistry more practical and meaningful. Unlike time-consuming, complex projects, the proposed tasks are designed to be completed within one lesson. Such methods are seldom used in general school practice, especially at the initial stages of teaching Chemistry. Therefore, this project is especially important for scientific researches.

This research is the first stage of a long-term program to study methods for teaching experimental design in the Chemistry classroom. Practical tasks to be

completed within one lesson were developed and their impact on pupils' academic performances were analyzed.

The aim of the research is to investigate the impact of teaching methods, which is based on the experimental design, pupils' involvement of the 7th grade in the learning process and their academic performance improvement of studying Chemistry at the initial stage. The following tasks were formulated to achieve the stated goals: to develop experimental tasks that can be completed within one school lesson; to conduct an experimental implementation of the developed tasks in the educational process of the 7th grade; to evaluate the impact of completing practical tasks on the pupils' involvement level during the educational process; to study the impact of teaching experimental design method on pupils' academic performance. The object of the research is the educational process on the subject 'Chemistry' for the 7th grade pupils at the secondary school, and the subject of the research is the influence of the teaching experimental design method on pupils' involvement in the educational process and their academic performance on the subject 'Chemistry' at the initial stage.

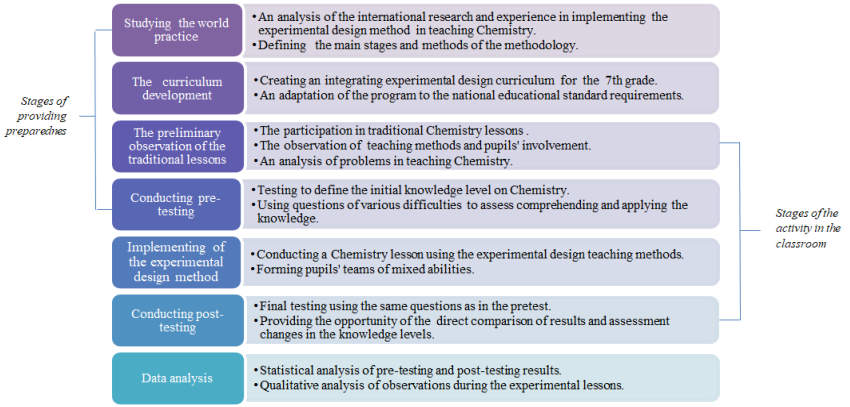
Materials and methods

During the observation it was noticed that Chemistry lessons were conducted in the traditional format before the research. Explanations of theoretical materials and completion of individual assignments were mainly done at the lessons. However, it was noted that pupils had some difficulties in understanding complex concepts, less activeness in the learning process and a lack of motivation in using knowledge self-dependently. Correspondingly, the necessity of improving teaching methods to increase pupils' interest in the subject and teaching effectiveness were reflected by these issues.

It was decided to carry out a research on Chemistry at the secondary school during the first academic quarter, which lasted for four weeks, based on these observations. Each Chemistry lesson lasted for 45 minutes and it was held twice a week. During the research, traditional classes were monitored and 'a trail' lesson was organized. During the trail lesson pupils were given assignments that required self-dependent experimental planning instead of the traditional laboratory work. This method is aimed at pupils' active participation at the lessons, working with real problems, as well as increasing their interests and motivation. All the materials needed for lessons, including task guides and additional resources were prepared by the researcher. At the beginning of the lesson the pupils were presented an introductory presentation to explain the topic and goals. The lessons were conducted according to the standard structure: self-dependent studying the material, discussion in the class, group assignments, presentation results. Current

and important issues were included in the tasks for all groups and an application of the theoretical knowledge in practice was demanded from pupils.

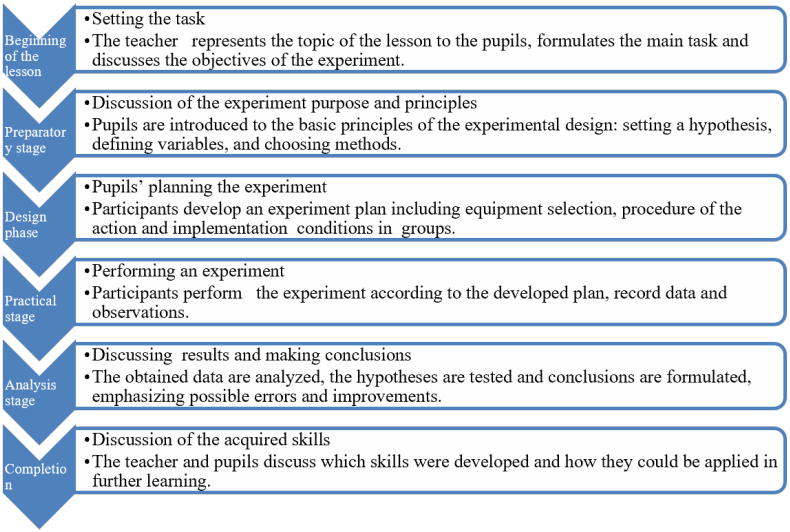
The research was conducted using a mixed-method approach, combining quantitative and qualitative methods. Assessing changes in pupils' academic performance using pre- and post-tests and analyzing the obtained statistic data were included in the quantitative approach. The observation of conducting design Chemistry lessons in the 7th grade at the secondary school, an analysis of the pupils' interaction dynamics, their involvement, as well as arising difficulties and ways to overcome them were included in the qualitative approach. This approach allows us not only to measure changes quantitatively in pupils' academic performance, but it also promotes to gain a deeper comprehending, how experimental learning impacts on pupils and which aspects of the learning processes are particularly effective. The choice of this methodology is justified by recommendations from the world literature, where mixed methods are considered to be more effective for the comprehensive study of educational processes [11, P. 581-610]. Various stages of the research were carried out in accordance with a specially developed plan (Scheme 1).



Scheme 1 – The sequence of research stages

Experimental work in Kyzylorda city. It was conducted with the 7th grade pupils of the Secondary School No. 198 named after Zh. Nurmanov. In total 30 pupils participated in the research. 27 of them took part in the pretest and the same number of pupils participated in the posttest. However, three of them did not participate in the preliminary test. Data of 24 students, who participated in the pre-test and post-test, were used for statistical analysis.

The design method assignments were specifically developed to meet the learning objectives and pupils' basic knowledge level. The following stages such as : a problem statement, a hypothesis formation, an experiment planning, its implementation, presentation of results and their discussion were included in these tasks. The tasks were aimed at solving specific problems related to Chemistry, such as the water purification and separation of impurities. The tasks were composed taking into account pupils' age characteristics, the basic education level and the teaching objectives. The process of completing each task is structured in steps (Scheme 2). The theoretical knowledge and its practical application made the lesson more effective and they were balanced by this algorithm.



Scheme 2 – Stages of organizing and conducting an educational experiment

The quantitative analysis of the pretest and posttest results was carried out using SPSS software (version 29.0.2.0). The normality distribution was tested using the Shapiro–Wilk test, and changes in the academic performance were analyzed using the t-test for dependent samples. The implementation observation of the design tasks, pupils' involvement assessment, participants' interaction in groups, as well as analysis of emerging difficulties and ways to overcome them were included in the qualitative analysis.

All the ethical standards were kept during the research. Conducting the experimental research was allowed by the school administration. Pupils and

their parents got some information about the goals and methods of teaching. The participation was voluntary, the principles of confidentiality and anonymity were kept. All the information was processed and presented only in a generalized form.

Results and Discussion

During the research, a Chemistry textbook for the 7th grade was analyzed (Ospanova M.K., 2018) and four topics were selected for lesson plans and various experiments: "Pure substances and mixtures", "Changes in the state of substances", "Chemical reactions", "Chemical elements and compounds in the human body" [12, p. 136]. However, Topics: "The Air. "The Combustion reaction" were removed for safety reasons, since it had been considered to be dangerous for pupils to conduct such an experiment on their own.

Thus, the structure of experimental lessons for the 7th grade was developed and the basic principles were shown. The teaching materials for classes have been created on the basis of the identified problems and principles of the experimental design teaching. They were prepared in accordance with the curriculum, pupils' age characteristics and their education level.

A special feature of this material is that the tasks are not presented as standard laboratory work, but it has been done in the format of design tasks, including a related story based on life situations and the surrounding world. A situation or problem that might be familiar to pupils from daily life was described in each task, such as filtering the water on a hike, separating metal waste, or cleaning the salt from the sand. This approach assists pupils to understand the practical significance of the chemical knowledge and they can see the connection between the topics they have studied and a real life. Schoolchildren are introduced to methods for solving the given problem, represented in the accessible form after the material is presented. The tasks are developed in such a way that pupils can repeat practically the actions described in the story and make conclusions self-dependently, which makes the completion of the design visual and comprehenable.

This format of work promotes a deeper comprehension of the task essence and increases pupils' motivation to study Chemistry through perception of its applied significance. The topic "Pure substances and mixtures" had been completed during the study period, by the time the experimental lesson was conducted in the 7th grade. Thus, this made it possible to choose the topic for the design, since pupils have already been familiar with the basic concepts and they could apply their knowledge in practice. The experimental lesson was based on the design approach. At the beginning of the lession, the researcher, who also acted as a teacher, made a presentation explaining the structure and purpose of the design. Participants remembered basic concepts such as "pure substance" and "mixture" then they discussed their differences.

The pupils planned the experiment themselves, explained how exactly the tasks would be completed, and what steps needed to be taken to achieve the result. The teacher coordinated the children's work, helped them when it was necessary. Pupils' enthusiasm and great interest were generated by the lesson format, which included practical assignments. They read short and clear stories carefully, which permitted them to move quickly to complete the task. As the practical part of the task was not so difficult, so pupils coped with it on their own in most cases. During the completion of assignments, certain difficulties arose related to the use of laboratory glassware, for example, when installing a separatory funnel on the stand or using clamps for chemical glassware. These difficulties were expected, since pupils had not have much experince in working with chemical equipment, it was their first experience. Over time, they adapted quickly and demonstrated the ability that could complete the task self - dependently. After having completed the practical tasks, the pupils discussed the results of their work and represented their designs (Fig. 1). Each group proved or disproved their hypotheses, analyzed the results and drew conclusions. This work allowed pupils to demonstrate their knowledge gained during the research. Pupils were able to understand the possibilities of applying their research and appreciated the role of Chemistry in the life during the lesson. The use of the research helped pupils deepen their knowledge and proved the importance of using experiments to solve real-world problems.

Figure 1 – Students are in the process of designing, implementing and representing their work

Observing pupils' involvement and activity was consisted of the qualitative analysis of the reseach. It was noticed that most of the pupils were very interested in completing the task during the experimental lesson. They participated actively in the discussion process, read the design work cases carefully , analyzed the instructions and began to complete practical tasks. Pupils' motivation and their active participation throughout the lesson were encouraged by the interesting lesson format, including practical exercises. During the assessment of group work, pupils are divided into groups to complete design assignments. Pupils demonstrated their abilities that they could apply theoretical knowledge in practice while completing practical assignments. For instance, when creating a water purification filter, they analyzed the role and properties of each layer when planning the experiment and defined their importance in the filtration process. Pupils of the group, who performed an experiment on separating mixtures using a magnet, did not only understand why metal objects are attracted to magnets, but they also explained this phenomenon using interdisciplinary knowledge gained from the subject 'Physics'. These examples proved that pupils did not only follow instructions, but they also understood the connection between their actions and previously learned theoretical concepts.

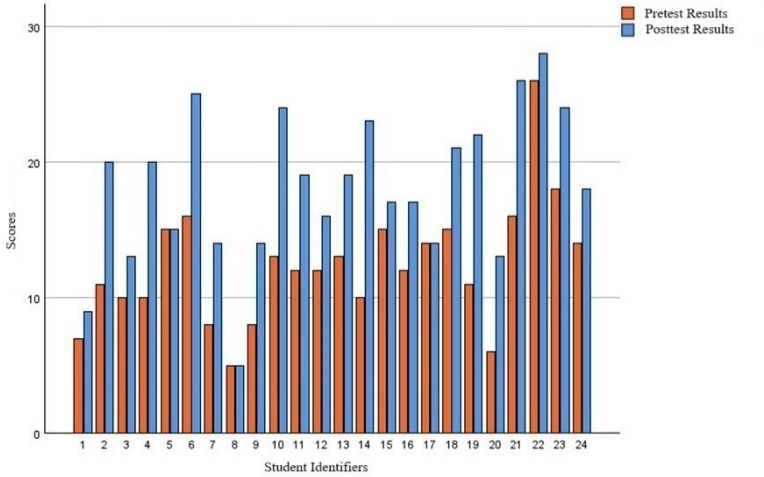
The data obtained during the research were analyzed using SPSS version 29.0.2.0. A paired samples t-test was conducted to compare the results before and after intervention (Table 1). The difference in test results was statistically significant ($t = -6.947$, $df = 23$, $p < 0.001$). The significance level ($p < 0.001$) confirms that the changes in pupils' academic performance after participating in the educational project are statistically significant. This data demonstrate the effectiveness of the educational project, as the observed in pupils' educational perfomance cannot be attributed by random factors. Thus, the results of the research confirm that the educational project has a positive impact on pupils' learning outcomes.

Table 1 – Paired Samples t-Test Results

Pair	**t**	**Degrees of freedom (df)**	**Significance**	
			One – sided	**Two-sided**
Pretest – Posttest	-6.947	23	<.001	<.001

A comparison of pretest and posttest results of 24 pupils is shown on Diagram 1. The data for plotting the graph was obtained during the research, aimed at assessing the impact of the educational project on the pupils' knowledge level. Pupils' IDs are displayed by the abscissa axis and their scores are displayed by the ordinate axis. The pretest results are shown in orange bars and they reflect

the pupils' initial knowledge level. The post-test results are shown by the blue bars which demonstrate the knowledge level after the project. The increase is reflected almost in all participants' scores, which justifies a positive impact of the training project. The gap between pretest and posttest scores vary, indicating differences in the pupils' degree progress. The general trend of a significant increase in the knowledge level is clearly demonstrated by the graph which is consistent with the conclusions of the statistical analysis.



Graph 1 – Comparison of the pretest and posttest results

Descriptive statistics were calculated to summarize the main characteristics of the sample to analyze the results of the pretest and posttest, as well as pupils' progress expressed in percentages. (Table 2).

Table 2 – Descriptive Statistics

Variable	N	Mini-mum	Maxi-mum	Mean	Standard deviation
Pretest results	24	5	26	12.38	4.441
Posttest results	24	5	28	18.17	5.546
Progress (%)	24	0	130	51.78	37.408
N valid (listwise)	24				

24 pupils were involved in the research. Pretest scores ranged from 5 to 26, with an average significance of 12.38. The spread of results among participants is

shown by the standard deviation (4.441), which indicates different levels of the initial knowledge. The minimum posttest score remained unchanged (5), but the maximum score increased to 28, indicating significant improvement in the knowledge among individual pupils. The average score was 18.17, demonstrating a positive learning effect. The standard deviation increased to 5.546, which may reflect individual differences in learning. Pupils' progress ranged from 0 to 130 %, with an average significance of 51.78 %. The high standard deviation (37.408) indicates a large variation in scores, indicating individual differences in performance improvement. Despite this, most students showed a significant progress after participating in the project, although the extent of this progress was uneven. Data of the descriptive statistics confirm that the pupils' average knowledge level increased significantly after the training, but the variation in results requires further study of the factors influencing on the assimilation of the material.

Cronbach's Alpha was used to assess the reliability of the data, yielding a value of 0.838 with two items (pretest and posttest). Cronbach's Alpha value greater than 0.8, indicates high reliability of the obtained data and confirms their internal consistency (Table 3).

Table 3 – Reliability Statistics

Cronbach's Alpha	**N elements**
0.838	2

Thus, the obtained results of the descriptive statistics and t-test confirm the effectiveness of the conducted training program. A significant increase in the average pos-ttest score relative to the pre-test indicates a positive impact on the pupils' educational activities. The reliability of the obtained data is also confirmed by the high Cronbach Alpha's value. In accordance with the results of the research, it is demonstrated that the proposed teaching method improves pupils' academic performance and enables them to better learning the material.

Conclusions

The results of this research indicate that the design lesson through the developed plans of different types of experiments is an effective approach to teach Chemistry in the 7th grade of the secondary school. The design method promotes to achieve educational goals, increases pupils' interest in the subject, develop their practical and cognitive skills. Data analysis conducted using the SPSS program showed a significant increase in the pupils' knowledge level after participating in design based activities, which is confirmed by the results of the t-test ($p < 0.001$). It indicates a statistically significant increase in the pupils' academic performance.

Pupils' high degree involvement in completing practical experiments is revealed by the qualitative analysis. The pupils worked actively in groups, demonstrated their critical thinking skills and self-dependence, which contributed to a better assimilation of the theoretical knowledge and its successful application in practice. Planning the lesson using design experimental plans is not only effective in improving pupils' knowledge level, but it also promotes to develop their key competencies.

The internal consistency and accuracy of the obtained results were confirmed by the high reliability coefficient of the data (Cronbach's alpha 0.838). In addition, differences in pupils' academic performances highlighted the need for further studying factors which influence in mastering learning materials, such as: a motivation for learning and individual cognitive peculiarities. The research also had some limitations, in particular, a small sample size (limited one class) and a short duration of the research (one semester), that reduces the opportunity to generalize findings to a wider audience.

Thus, by developing various experimental plans, it was proved that the design method lesson is not only an effective one to improve the education quality, but it also promotes to modernize the school education system in Kazakhstan. Structuring the learning process, ensuring pupils' active participation and mastering the material is promoted by this method. In conclusion, the research with a larger sample size and long-term follow-up are recommended to further improving of the method and clarifying its versatility and long-term effects.

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Received 03.02.25.
Received in revised form 17.12.25.
Accepted for publication 03.08.26.

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03.02.25 ж. баспаға түсті.
17.12.25 ж. түзетулерімен түсті.
03.08.26 ж. басып шығаруға қабылданды.

МЕКТЕПТЕГІ ХИМИЯ САБАҒЫНДА ЖОБАЛАУ ӘДІСІ: ТИІМДІЛІГІ ЖӘНЕ АКАДЕМИЯЛЫҚ ҮЛГЕРІМГЕ ӘСЕРІ

Мақалада орта мектеп химия сабағында эксперименталдық жобалау әдістерін енгізудің оқушылардың белсенділігін және академиялық нәтижелерін арттыруға әсері қарастырылған. Негізгі мақсат дәстүрлі оқытудан эксперименталдық жұмыстарды жобалауға өту арқылы сын тұрғысынан ойлау және тәуелсіздік сияқты маңызды дағдыларды дамыту болды. Зерттеу квазиэксперименталдық дизайнды қолдана отырып, оқыту стратегиясының білім беру артықшылықтарын бағалау үшін алдын-ала және соңғы тесттерді өткізуді қамтыды. Сандық деректер SPSS бағдарламасының 29.0.2.0 нұсқасымен талданып, қатысушылар арасында айтарлықтай академиялық жетілдірулер анықталды. Жұп үлгідегі t-сынағы оқушылардың тест нәтижелерінің белгілі бір дәрежеде артқанын көрсетті ($t = -6.947$, $df = 23$, $p < 0.001$), оқу бағдарламасына эксперименталдық жобалауды енгізудің тиімділігін растады. Бұл әдіс тек оқушылардың химияға деген қызығушылығын арттырмай, сонымен қатар ғылыми ұғымдарды тәжірибеде қолдануды жақсартты. Нәтижелер химия біліміне эксперименталдық жобалау тапсырмаларын енгізуді қолдайды, олардың пәнді тартымды және тәжірибелік маңызды етуге әсерін атап өтеді. Зерттеу көлемі мен ұзақтығының шектеулілігіне қарамастан, оң нәтижелер кеңінен қолданудың әлеуетін көрсетеді. Болашақта осы әдістің ұзақ мерзімді әсерін және әртүрлі білім беру орталарындағы масштабтау мүмкіндігін зерттеу қажет.

Кілтті сөздер: химиялық оқыту, эксперименттік жобалау, орта мектеп білім беру, академиялық үлгерім, оқыту әдісі.

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Поступило в редакцию 03.02.25.
Поступило с исправлениями 17.12.25.
Принято в печать 03.08.26.

МЕТОД ПРОЕКТИРОВАНИЯ НА УРОКАХ ХИМИИ В ШКОЛЕ: ЭФФЕКТИВНОСТЬ И ВЛИЯНИЕ НА УСПЕВАЕМОСТЬ

В статье рассматривается влияние внедрения экспериментальных методов проектирования на уроках химии в средней школе для повышения вовлеченности учащихся и академических результатов. Основная цель состояла в том, чтобы развивать такие важные навыки, как критическое мышление и самостоятельность, путем перехода от традиционного обучения к проектированию экспериментальных работ. Используя квазиэкспериментальный дизайн, исследование включало проведение предварительных и итоговых тестов для оценки образовательных преимуществ стратегии обучения. Количественные данные были проанализированы с помощью SPSS версии 29.0.2.0, которая выявила значительные академические улучшения среди участников. Парный выборочный t-тест показал заметное увеличение результатов тестов студентов ($t = -6,947$, $df = 23$, $p < 0,001$), что подтверждает эффективность интеграции экспериментального проектирования в учебную программу. Такой подход не только усилил интерес учащихся к химии, но и улучшил их практическое применение научных концепций. Результаты выступают за интеграцию задач экспериментального проектирования в химическое образование, подчеркивая их роль в том, чтобы сделать предмет более интересным и практически значимым.

Хотя они ограничены размером выборки и продолжительностью исследования, положительные результаты предполагают потенциал для более широкого применения. Будущие исследования должны изучить долгосрочные эффекты и масштабируемость этого метода в различных образовательных средах.

Ключевые слова: химическое обучение, проектирование экспериментов, школьное образование, академическая успеваемость, методика преподавания.

Теруге 03.08.2026 ж. жіберілді. Басуға 14.09.2026 ж. қол қойылды.
Электронды баспа
6,45 МБ
Шартты баспа табағы 49,9
Компьютерде беттеген З. Ж. Шокубаева
Корректорлар: А. Р. Омарова, Д. А. Қожас
Тапсырыс № 4597

Сдано в набор 03.08.2026 г. Подписано в печать14.09.2026 г.
Электронное издание
6,45 МБ, Усл.п.л. 49,9.
Компьютерная верстка З. Ж. Шокубаева
Корректоры: А. Р. Омарова, Д. А. Қожас
Заказ № 4597

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