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Enhancing the Quality of Education Through the Integration of STEM Technology Elements in Chemistry Lessons

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ABSTRACT

This study introduces a methodological framework for integrating STEM technologies into secondary school chemistry through project-based learning. The research aimed to boost students' interest and engagement in chemistry by involving them in a scientific project called "Water Purification Methods." Eighth-grade students from Kazakhstani secondary schools participated in a three-month study to create accessible water filtration systems using everyday materials, such as gravel, quartz, and activated carbon. A key aspect of the project was the use of ReLab.A Lite software and digital sensors, allowing students to measure and analyze water quality indicators before and after filtration. The software offered a platform for real-time visualization of chemical changes, enhancing students' understanding of scientific concepts through hands-on experimentation. Data analysis showed a clear reduction in chloride ions, potassium ions, ammonium compounds, and oxidation-reduction potential, confirming the effectiveness of the filtration methods. Besides scientific results, the project notably improved students' STEM skills, such as critical thinking, data interpretation, and digital tool usage. The questionnaire results further confirmed increased student motivation, interest in chemistry, and appreciation of its relevance to real-world issues. The findings support the integration of STEM-based project learning as an effective approach to building scientific literacy and interdisciplinary skills in schools.

Keywords: STEM education, chemistry education, water quality indicators, interdisciplinary connections, filtration

INTRODUCTION

In the current educational landscape of the Republic of Kazakhstan, new goals and objectives for teaching STEM subjects have been established through the integration of multiple related disciplines. STEM represents an integrated approach to education that closely connects schools, communities, workplaces, and the surrounding world. To support the advancement of education and science, Kazakhstan has implemented the State Program of Education Development until 2025 (2019). However, despite these efforts, several urgent challenges still exist within the national education system. This study examines how STEM technologies are applied to improve the competitiveness and development of the education system.

STEM, an abbreviation for Science, Technology, Engineering, and Mathematics, emphasizes the importance of these fields in today's world. As a result, STEM education has become a prominent educational trend

(Kazbekova & Ismagulova, 2022; Yesnazar et al., 2024). It uses interdisciplinary and practical methods, combining all four disciplines into a unified curriculum. The STEM teaching approach organizes the learning process across different disciplines, enabling students to gain a broad understanding of the world and reflecting the traditional separation of scientific fields. Using this method, students apply knowledge from one subject to solve problems in other areas. This modern STEM approach promotes creative thinking and broadens students' perspectives when addressing complex issues (Ontagarova & Zholymbayev, 2023).

Furthermore, the STEM approach boosts students' engagement, cognitive skills, and creativity. STEM education enables learners to manage the vast flow of information, apply their knowledge practically, take initiative, and work confidently with equipment and technology (Ryu et al., 2019). By studying the basic principles of the natural sciences, students gain an understanding of the links between different phenomena and uncover new scientific facts (Chiu, 2023). Additionally, it is important to highlight the vital role of STEM education in fostering and maintaining students' interest in STEM careers, as it helps shape their career goals within the STEM field (Ribeirinha et al., 2024).

The STEM approach plays a crucial role in chemistry teaching, as it not only improves students' understanding but also develops their critical thinking, creativity, and project-based learning skills. This is especially important in modern schools, where robotics, engineering, modeling, and design are becoming more central to the curriculum. Recent studies, especially those by Bybee (2013) and Kelley & Knowles (2016), emphasize the importance of interdisciplinary approaches in education, highlighting their role in developing students' holistic scientific thinking. Their research shows that STEM integration not only deepens understanding of individual disciplines but also reveals their connections, which is particularly crucial for chemistry. This subject naturally depends on mathematical calculations, technical advances, and engineering principles, making the STEM approach an effective teaching method. By promoting an interdisciplinary approach, STEM education not only enhances students' understanding of the material but also equips them with the skills necessary to solve real-world scientific and technological problems.

The investigation by Wei and Chen (2020) highlights the comprehensive nature of STEM education, proposing a holistic model that includes four key elements: subject knowledge, teaching strategies, learning expectations, and the educational system. This approach ensures that students not only grasp essential scientific concepts but also develop practical skills vital for effectively applying STEM principles. Incorporating diverse teaching strategies allows adaptation to different proficiency levels, while considering learning expectations helps create a motivating educational environment. Additionally, a systemic approach to education encourages the integration of disciplines, improving students' ability to solve complex problems. As a result, this model provides an effective framework for implementing STEM education more broadly.

The study by Sahito and Wassan (2024) explores challenges, issues, and solutions in natural sciences, with a focus on STEM education. The researchers analyze key aspects, including the objectives and complexities of STEM education, curriculum, inquiry, learning environments, technologies, learning models and integration, blended learning approaches, students' problem-solving skills, implementation and evaluation, research, current trends, and interdisciplinary collaboration.

Sanders (2009) examines strategies for incorporating STEM education into schools, with a focus on chemistry and highlighting the importance of an interdisciplinary approach. The study by Shojaee et al. (2019) highlights the growing recognition of project-based learning in STEM (STEM-PBL) due to its effectiveness in developing students' practical and analytical skills. The authors not only examine the benefits of this approach but also analyze students' perceptions by assessing the psychometric properties of the STEM-PBL attitude scale. This approach facilitates the objective evaluation of students' engagement, the identification of motivational factors, and the improvement of instructional strategies. Their findings confirm the importance of project-based learning in STEM education and its impact on the overall learning process.

The importance of this study lies in incorporating STEM education into the learning process, which enables students to handle large amounts of information effectively and apply their knowledge in real-world situations. This method enables students to develop additional practical skills that are essential in today's world. STEM education is a comprehensive approach that combines the study of natural sciences, including engineering, mathematics, and technology. In this framework, students explore the connections between various phenomena, enhance their logical thinking, and develop innovative solutions by constructing their own models. The interdisciplinary nature of STEM education encourages students' cognitive interest and active participation in learning. Additionally, implementing STEM education promotes critical and logical thinking, develops practical skills, and prepares students to adapt successfully to the modern challenges they face. The holistic nature of this approach increases student engagement, stimulates research activity, and fosters a long-term interest in the sciences.

In modern education, integrating STEM elements is seen as a way to enhance educational quality. The Chinese philosopher Confucius said: "I hear and I forget, I see and I remember, I do and I understand." This idea emphasizes the importance of active, hands-on participation in reinforcing acquired knowledge. In this context, the use of STEM technologies in education offers notable benefits (Sudarmin et al., 2019; Chiu & Li, 2023).

This study aims to enhance students' interest in learning by integrating STEM technologies into the educational process, particularly in chemistry lessons. As an illustrative example, the study examines a scientific project titled "Methods of Water Purification," in which students not only acquire theoretical knowledge but also apply it in practice. The study hypothesizes that if students independently design and build prototypes of water filtration devices using modern and accessible engineering tools and materials, this will not only enhance their understanding of chemistry but also develop practical skills.

Research Questions

1. Does involvement in a scientific project using STEM technologies influence students' interest in learning chemistry?
2. How effective are STEM methods in teaching the topic "Water purification methods" in terms of enhancing students' research skills?
3. How does the level of cognitive activity and student engagement change when using the STEM approach?

MATERIALS AND METHODS

The research relied on a thorough application of methods, including reviewing scientific literature, conducting experiments, assessing learning outcomes, and analyzing statistical data to test hypotheses and identify significant links between implementing STEM methods and students' academic performance. Key studies highlighting the didactic potential of STEM integration in chemistry education were examined, along with a comparative analysis of national educational standards and curricula to identify the requirements for developing interdisciplinary competencies.

This study employed a quasi-experimental design with non-randomized groups, which was necessary due to the inherent limitations of the school environment and the impracticality of random assignment. The experimental group consisted of 31 students from Grade 8B who received instruction incorporating STEM technologies through a scientific project titled "Water Purification Methods." The control group consisted of 30 students from Grade 8A, who were taught using traditional methods without STEM integration. The total sample comprised 61 eighth-grade students from a general secondary school. The quasi-experiment involved administering both pre- and post-intervention surveys to both groups to evaluate changes in students' interest in learning chemistry. Additionally, the experimental group completed a project-based assignment, which allowed for analyzing the impact of STEM-based instruction on students' cognitive engagement and research skills development. Within a project that implements the STEM approach, special focus was given to the engineering and mathematical components, which ensured the hands-on and interdisciplinary nature of the learning process.

The engineering aspect of the project was achieved through students developing water filtration units based on engineering design principles. In classroom settings, hands-on work involved purifying contaminated water using accessible and environmentally safe materials such as gravel, sand, activated carbon, and cotton, chosen for their filtration properties. Students identified the best order for the filtering layers and estimated their approximate thicknesses. They then assembled and tested filter prototypes by passing 250–500 mL of water through each model. The time it took for the water to pass through the filter was recorded, and the filtration efficiency was evaluated. Based on these results, the filter designs were adjusted to enhance purification quality.

The mathematical component was included during the analysis of experimental data. Students recorded the volume of filtered water (V = 250–500 mL) and the time it took to pass through the filtration unit (t, in seconds). Using these measurements, the filtration rate was calculated according to the formula:

$$v=V \backslash t$$

where v is the filtration rate (ml/s), V is the volume of water (ml), and t is the filtration time (s).

These calculations enabled a quantitative evaluation of the efficiency of various filter designs, facilitating their comparison.

Data Collection

Aligned with the goal of this study—to assess how STEM integration affects students' growing interest in chemistry—a mix of quantitative and qualitative methods was used to gather and analyze data. This method helped produce objective and statistically sound results.

In this study, the independent variable was the integration of STEM technologies into the structure and content of the educational process. Conversely, the dependent variable was students' knowledge level and its growth in response to the innovative methodologies applied. To guarantee objective and reliable results, the following data collection tools were used (see **Table 1**). To assess the influence of STEM integration, data analysis was conducted in several stages. Questionnaire responses collected before and after participation in STEM activities were statistically processed. Mean interest scores and standard deviations were calculated, and a paired Student's t-test was applied to examine the statistical significance of observed differences.

Interview transcripts underwent thematic content analysis. Key themes were identified to reflect students' perceptions of STEM methodologies and changes in their motivation and attitudes toward the subject. To improve the reliability of the analysis, independent verification of coding was performed. Observations were recorded systematically in the form of field notes. Particular attention was paid to indicators of student interest, such as frequency of participation in discussions, initiative-taking behavior, and independence in task completion. These findings were triangulated with questionnaire and interview results to ensure comprehensive interpretation. Overall, using a variety of tools for data collection and analysis offered a strong, multidimensional insight into how STEM integration affects students' engagement with research-based learning in chemistry.

The experimental component of the study was conducted using standard laboratory equipment (chemical glassware, reagents, measuring instruments) as well as the ReLab.Lite software system, a versatile digital tool designed to determine the composition of specific chemical compounds using sensors and optical microscopes. To implement project-based research tasks, a study was conducted on the topic "Water Purification Methods" using STEM technologies. The combination of classical laboratory techniques with STEM elements enabled the creation of a multifaceted environment for examining chemical phenomena through interdisciplinary interaction.

The study was carried out as a pedagogical experiment, with mandatory pre- and post-assessments of students' knowledge. Participants were divided into two groups: a control group and an experimental group, with each group including students with both low and high proficiency levels, based on pre-testing. The control group followed a traditional instructional approach, while the experimental group used STEM-based technologies to engage with the material. The project involved eighth-grade students from Secondary School No. 136 and Gymnasium School No. 50 named after A. Baitursynov in Shymkent, Kazakhstan.

Research Design

Project guidelines:

Project duration: 1 academic year (November 1, 2023 - May 31, 2024)

Participants: 8th-grade students

Target audience: teachers, parents, and 8th-grade students.

Key features of the project:

- By product type: informative, creative
- By number of participants: group-based.
- By duration: long-term.

The project aims to develop and test an accessible water purification method using easily available materials, while also assessing the effectiveness of various filtration components, including gravel, quartz, and activated carbon. This approach is expected to increase students' interest in chemistry, boost their intellectual skills, and involve them in scientific research activities.

Project objectives:

1. To create a pedagogically meaningful, scientifically innovative, and developmentally enriching environment within the school.
2. To carry out the project using STEM technologies.
3. To enhance students' research, engineering, teamwork, and analytical skills for assessing project results.

The project enables students to explore water properties through hands-on experimentation, providing them with practical insights into the nature of objects, phenomena, and their interrelationships with the surrounding environment.

Engaging in experiential learning helps students gain a deeper understanding of the world around them by increasing their awareness of the connections within living systems. This sensory-based, observational approach encourages environmental awareness and fosters a holistic view of the natural world. This project was implemented in three stages, as outlined in **Table 2**.

Table 1. Data collection tools

No.	Tool	Description	Purpose
1	Pre- and Post-Questionnaire	Likert-scale questionnaire (5-point scale) covering motivational, cognitive, and emotional aspects of interest in chemistry.	Quantitative assessment of changes in students' interest.
2	Semi-structured Interviews	Individual interviews with a selected sample (10–15 students), including open-ended questions about their experiences with STEM-based activities.	Identification of students' subjective perceptions and motivational drivers.
3	Researcher Observations	Systematic recording of students' behavior, engagement, and activity during STEM lessons and project implementation.	Supplementary validation and contextualization of quantitative data.

Table 2. Stages of project implementation

Stage	Stage description	Work direction
Stage 1 - Preparatory (November 2023)	Goal setting, theoretical study, and planning	Examining theoretical aspects of the issue in pedagogy. Reviewing the works of leading researchers in this field. Enhancing the subject-based developmental environment for the practical implementation of STEM technologies. Creating conditions that stimulate initiative, creativity, and collaborative activities based on STEM principles.
Stage 2 - Practical, main (December 2023 - April 2024)	Filter construction, experimentation, and data collection	Introducing STEM technologies and their application methods within the school setting. Collecting, compiling, and systematizing materials necessary for achieving project objectives. Integrating STEM elements into the educational process.
Stage 3 - Final (May 2024)	Results comparison, identification of the most effective methods.	Sharing experiences and project results via digital and information resources. Analyzing the outcomes of the implementation of STEM technologies in the organization of scientific activities.

Ethical Considerations

Ethical considerations in the research process were addressed by strictly following established bioethics principles. Approval to conduct the study was received from the school administration, and all participants in both the experimental and control groups provided written informed consent for participation, data analysis, and dissemination of the findings. Adherence to ethical principles not only protected participants but also promoted students' ecological responsibility and scientific integrity, thereby increasing the societal value of the research. The study was reviewed and approved by the Ethical Committee Board for the Evaluation of Scientific Research at Zhanibekov University, in accordance with the institution's established procedures and ethical standards (IRB approval number: 15-15/402 from March 12, 2025).

STEM Activity: Water Filtration

During the project on "Water Purification Methods," the ReLab software system was used to evaluate water quality indicators after filtration with digital sensors Lite. The study employed various filtration materials, including gravel, quartz, and activated carbon, as presented in **Table 3**. As part of the study, a comparative analysis was conducted to evaluate differences in filtration performance across structurally distinct filter designs. The comparison of the obtained data enabled the identification of specific features of each model. The final results are presented in **Table 4**. Analysis of the experimental data presented in **Table 4** enables a comparison of the efficiency of various filter setups. The highest filtration rate (5.00 mL/s) was recorded for the sand–activated charcoal combination, which results from a balanced combination of mechanical and sorption-based purification at a moderate layer density.

The gravel–sand setup produced an intermediate rate (4.17 mL/s), providing high flow but less effective at capturing fine particles. The lowest rate (3.00 mL/s) was found with the charcoal–cotton configuration, probably due to the denser upper layer that slows water flow. These results underscore the importance of thoughtful filter design, taking into account both the properties of the materials and their arrangement. The research team carried out the study in the school laboratory three times a week, combining theoretical learning with hands-on experimentation. The project lasted three months, providing an opportunity for thorough exploration of the topic and gathering reliable data.

Table 3. Filter composition

Filter composition	Function	Photo
Gravel	Used to filter out large sediments such as leaves and insects.	
Quartz	Removes suspended particles, as well as floating and sinking debris. Particles are eliminated through absorption or physical encapsulation.	
Activated carbon	Eliminates contaminants and impurities through chemical absorption. Organic compounds are adsorbed and retained. While it does not completely remove chlorine, filtration through activated carbon significantly reduces chlorine levels and decreases its reactivity.	

Table 4. Relationship between filter design parameters and filtration rate

Filter design	Water volume (mL)	Filtration time (s)	Rate (mL/s)
Sand + charcoal	250	50	5.0
Charcoal + cotton	300	100	3.0
Gravel + sand	500	120	4.17

The combination of theoretical and empirical approaches ensured the validity and reliability of the study's conclusions. A review of the regulatory framework and scientific literature provided the foundation for designing pedagogical models. At the same time, the integration of quantitative and qualitative diagnostic methods enabled a comprehensive assessment of the effectiveness of STEM-based strategies. Statistical data analysis confirmed the significance of the observed changes, aligning with the principles of evidence-based pedagogy.

RESULTS

Using a combination of questionnaires, interviews, and observations follows the principles of a comprehensive methodological approach, ensuring both the reliability and validity of the study. Each tool focuses on different aspects of student interest: the cognitive (knowledge, evaluation), emotional (attitudes, motivation), and behavioural (engagement, participation) components. This integrative approach not only enables the quantitative measurement of changes in students' interest but also offers deeper insights into the underlying mechanisms and factors that drive these changes within STEM education.

The study used a comprehensive data analysis approach, combining both quantitative and qualitative methods. For the quantitative part, descriptive and inferential statistical techniques were employed. Specifically, means and standard deviations were calculated for the variables "interest in chemistry," "attitude toward the subject," and "academic achievement." To determine the statistical significance of differences between the experimental and control groups, an independent samples t-test was performed ($p < 0.05$). Qualitative analysis involved examining students' responses to open-ended questions through content analysis. This included coding, categorization, and interpretation to detect shifts in interest and motivation. The questionnaire's reliability was evaluated using Cronbach's alpha ($\alpha = 0.82$), indicating strong internal consistency. Three primary variables were measured during the study, as summarized in **Table 5**.

Water used in daily life is rarely perfectly pure and maintains its natural properties, which, when disrupted, can have a negative impact on ecosystems and the functioning of living organisms. The quality standards for water intended for centralized supply systems are especially strict. The various characteristics of natural water sources enable their classification based on different criteria, allowing for the selection of the most suitable sources for specific consumer needs.

Table 5. Measured variables and instrument characteristics

Variable	Description	Measurement Instrument	Reliability (Cronbach's α)	Validity
Interest in Learning Chemistry	Motivation, engagement, and willingness to study chemistry	Questionnaire (5-point Likert scale)	0.82	Expert evaluation
Attitude Toward Chemistry	Perceived usefulness and personal relevance of chemistry	Questionnaire (Likert scale + open-ended questions)	0.79	Expert evaluation
Academic Achievement	Performance on assignments, participation in the project	Assessment rubrics, observation	-	-

Table 6. Classification of water resources based on various indicators

Indicator	Very pure	Pure	Slightly polluted	Moderately polluted	Heavily polluted	Extremely polluted
Temperature (°C)	20	25	25	30	30	30
pH	6,5-7,5	6,1-6,4 7,6-7,9	5,9-6,0 8,0-8,1	5,7-5,8 8,2-8,3	4,0-5,2 8,8-9,5	<4.0 >9.5
Chlorides (mg/dm³)	50	150	200	300	500	500
Potassium ions (mg/dm³)	50	150	200	300	500	500
Ammonia (mg/dm³)	0, 1	0, 2	0, 5	2, 0	5, 0	5, 0
Oxidation-Reduction Potential (ORP), (mV)	2	4	8	15	25	25

Figure 1. Independently constructed filtration device

Assessing the suitability of a water resource for drinking and household use requires a comprehensive analysis of several key indicators. Research shows that among existing methods for evaluating surface water, an integrated classification approach—combining multiple related parameters—is recognized as the most effective. This method guarantees a thorough assessment of water quality (see **Table 6**), a conclusion supported by expert consensus.

As part of the project implementation, members of the research team carried out a series of laboratory experiments using samples of contaminated water collected from Lake Kainar Bulak (Shymkent). The students independently designed and built filtration devices (**Figure 1**), followed by a comparative analysis of purification efficiency based on the following parameters:

- Physical: temperature, color, odor, taste.
- Chemical: ionic composition, pH level.
- Biological: coli index, E. coli bacterial count.

After filtering contaminated water, students performed a comparative analysis of the physicochemical properties of the original and purified samples. The study revealed the following changes: the temperature remained steady at +25.0°C both before and after filtration, indicating no thermodynamic effect from the filtration system. Additionally, there was a notable decrease in odor intensity and turbidity, with the purified water reaching a clarity level visually comparable to that of distilled water (**Figure 2**).

Figure 2. Contaminated and purified water

Figure 3a. pH of contaminated water

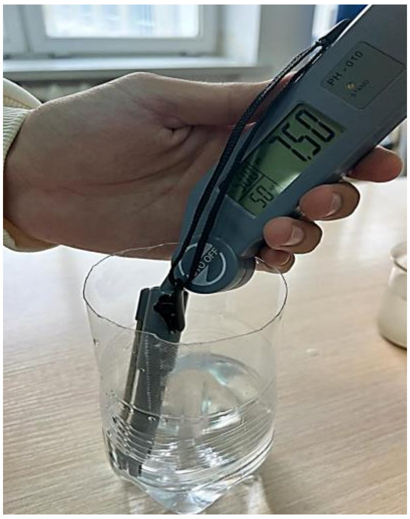

Figure 3b. pH of purified water

The use of the developed filtration device significantly improved the water's organoleptic qualities, making it clearer and odor-free while maintaining a stable temperature. A slight drop in pH (by 0.12 units) indicates partial removal of alkaline substances; however, the final pH still falls within the acceptable range for drinking water. These results confirm the effectiveness of the filtration system in purifying household water.

The initial water sample had a pH of 7.62, which decreased to 7.50 after filtration, indicating a mildly alkaline reaction in both cases (**Figure 3a**, **3b**). As part of the study, the ReLab software platform was integrated with the Lite system, which is used for the quantitative analysis of water sample chemical compositions. Based on the data shown in **Table 6**, the concentrations of the following components were evaluated.

• Chloride ions (Cl^-): a decrease in chloride content was observed in the purified water, confirmed by spectrometric data (**Figure 4**).

• Potassium ions (K^+): a slight decrease in concentration was observed, as shown in the graph (**Figure 5**).

• Ammonia and ammonium compounds (NH_3/NH_4^+): partial removal of these impurities was observed during filtration (**Figure 6**).

• Oxidation-reduction potential (ORP): A decrease in oxidation activity was observed after purification, indicating a decline in oxidation processes (**Figure 7**).

A comparative analysis of the initial and purified water samples showed statistically significant differences across all measured parameters ($p < 0.05$). The results, displayed through ReLab-generated graphs, confirm the effectiveness of the filtration technology used in reducing ionic and nitrogen-based contaminants.

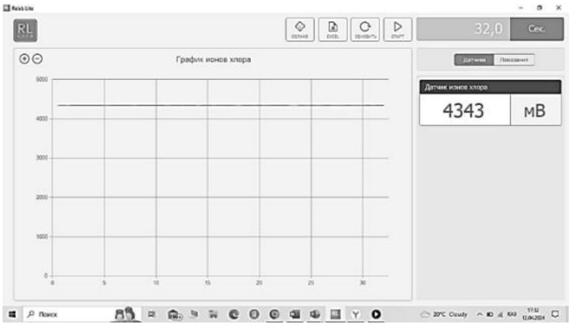

Figure 4a. Chloride ion (Cl-) concentration in contaminated water

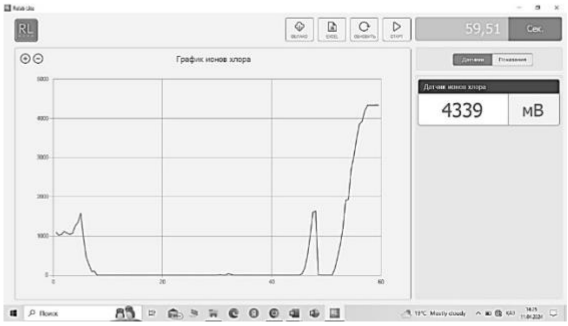

Figure 4b. Chloride ion (Cl-) concentration in purified water

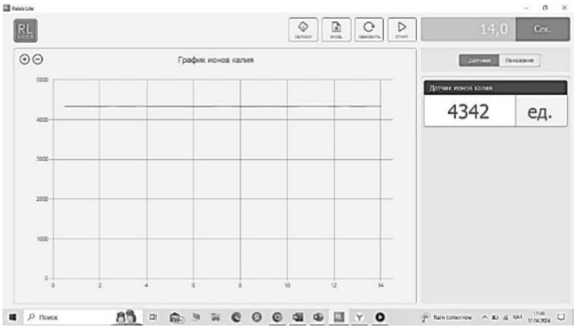

Figure 5a. Potassium ion (Cl-) concentration in contaminated water

Figure 5b. Potassium ion (Cl-) concentration in purified water

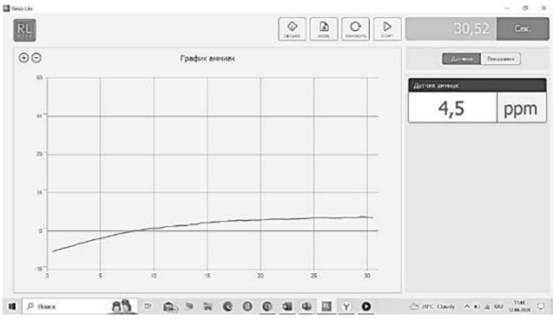

Figure 6a. Ammonia concentration in contaminated water

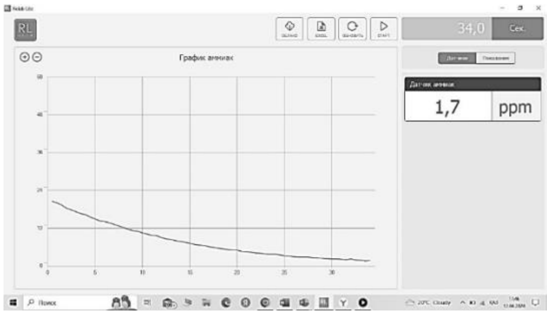

Figure 6b. Ammonia concentration in purified water

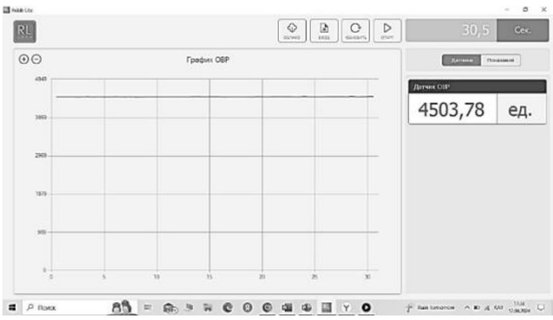

Figure 7a. Oxidation-reduction potential (ORP) in contaminated water

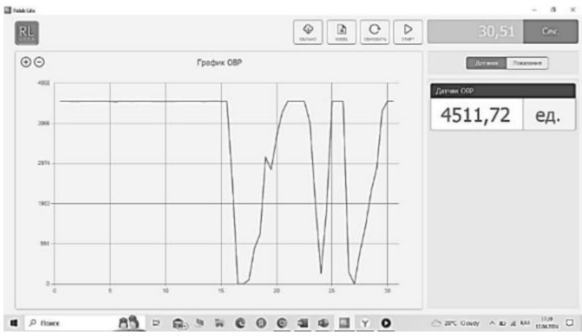

Figure 7b. Oxidation-reduction potential (ORP) in purified water

Figures 4a and **4b** show the changes in chlorine concentration in the tested medium before and after the purification process, respectively. Figure 4a displays a steady chlorine level throughout the measurement period, indicating no significant external influences and consistent sensor performance under stable conditions. In contrast, Figure 4b shows the changes in chlorine concentration after the purification process. While small fluctuations occur at the start of the measurements, the chlorine level stabilizes at lower values in the middle of the graph, suggesting effective removal of impurities. However, a sharp rise in chlorine concentration appears at later stages, which may indicate sensor malfunction, reintroduction of contaminants, or specific chemical reactions in the solution.

Figure 5a shows a stable potassium ion concentration with minimal fluctuations throughout the measurement period. This stability indicates a chemical equilibrium in the solution, with no external factors affecting ion levels. **Figure 5b** illustrates the changes in potassium ion concentration after purification. At the start and end of the measurements, potassium levels stay high, but in the middle, there are sharp drops, reaching a low point (~166 units). This suggests a significant decrease in potassium concentration during purification; however, the subsequent rebound in concentration may indicate inadequate filtration or secondary processes that impact ion levels.

Figure 6a shows a gradual increase in ammonia concentration throughout the measurements, indicating its accumulation in the solution. In contrast, **Figure 6b** demonstrates a significant reduction in ammonia levels following the purification process, confirming the effectiveness of the applied filtration method.

Figure 7a presents the dynamics of the oxidation-reduction potential (ORP), which remains stable throughout the measurement period. This stability indicates a consistent chemical composition of the solution with no significant external influences. However, **Figure 7b** initially displays a high and stable ORP value. As the experiment progresses, sharp fluctuations occur, followed by substantial drops and subsequent spikes. These variations indicate the impact of the purification process, resulting in temporary changes to the water's chemical composition.

Analyzing changes in impurity concentration before and after filtration provides valuable insights into water purification processes and helps identify potential chemical reactions that occur during filtration. Specifically, observing concentration spikes in certain substances at later measurement stages can lead to new discoveries about the interactions between solution components.

DISCUSSION

The goal of this study was to increase students' interest in learning chemistry by integrating STEM technologies into the educational process, specifically through the implementation of a scientific project titled "Water Purification Methods." The results confirm that using a STEM-based approach in chemistry teaching has a positive influence on both student engagement and the development of research skills and core competencies.

Data analysis showed that students in the experimental group exhibited higher levels of involvement, motivation, and interest in learning chemistry compared to those in the control group. These results are consistent with the findings of Bybee (2013), which highlight the effectiveness of STEM approaches in increasing interest in science subjects and encouraging students' cognitive engagement.

Furthermore, participating in the scientific project helped develop practical skills and research abilities. Students demonstrated the ability to apply theoretical knowledge in real situations, analyze experimental data, and make well-reasoned conclusions. These results confirm the educational value of project-based learning within the STEM framework and highlight the importance of active, hands-on teaching methods.

It is also noteworthy that participation in the STEM project supported not only the acquisition of subject-specific knowledge but also the development of key transversal skills, such as critical thinking, collaboration, and communication—competencies that align with current educational standards for 21st-century learners. The integration of STEM technologies into chemistry education not only fosters a deeper interest in the subject but also equips students with the skills necessary to solve real-world problems and adapt to a rapidly changing scientific and technological environment.

This study's findings highlight the importance and potential of expanding STEM education practices in school environments. A thorough review of scientific research shows that incorporating STEM technologies into chemistry education effectively improves learning outcomes. Current studies confirm that this method not only enhances students' academic performance but also helps develop the research skills necessary in the context of 21st-century scientific and technological progress. The data from our study help improve existing filtration technologies, including chemical, physico-chemical, and biological purification methods. Assessing the effectiveness of different water treatment approaches supports the development of new, combined technologies that are more efficient and effective.

Research by Wang et al. (2011) shows increasing interest in integrating STEM education, as a traditional, discipline-specific approach does not adequately develop systems thinking, which is vital for analyzing and solving real-world problems. Our study allows for the assessment of water contamination levels and the effectiveness of applied purification methods. The observed patterns of decreasing impurity levels, such as potassium ions, chlorine, and ammonia, confirm the potential to lessen the harmful effects of pollutants on the environment and aquatic ecosystems.

As shown in our study, students participate in hands-on chemistry lessons by building functional water filtration models using easily accessible engineering tools and materials. They create structures from plastic or cardboard, integrating various elements from existing filtration systems to enhance their effectiveness. Throughout the process, students consider material properties and select the most suitable structural components to design efficient filters. This practical, STEM-focused approach fosters an engineering mindset, increases interest in chemistry, and develops skills in working with modern technologies. Additionally, incorporating scientific projects, such as the study of "Water Purification Methods," strengthens students' engagement with STEM fields and encourages the development of applied problem-solving skills in real-world scenarios.

In the study by So et al. (2018), the researchers used a structure to analyze STEM-related activities displayed in elementary school students' science projects. The results showed a strong positive correlation between scientific activities and engineering and mathematical activities. The study by Beier et al. (2019) examined the effectiveness of project-based learning (PjBL) courses, showing that participation in these projects encourages STEM-related skills. Similarly, Thibaut et al. (2018) and Bicer et al (2020) demonstrated that implementing STEM education necessitates a shift toward integrative practices that connect theory with real-world applications, emphasizing collaborative work to enhance attitudes and critical thinking skills.

During the lessons conducted as part of our research, students independently built prototypes using available engineering tools and materials. They created models from plastic or cardboard, incorporating elements from existing devices while considering the properties of different materials. When selecting structural components, students strive for maximum functionality and efficiency in their models. This hands-on approach helps develop engineering thinking and technical skills. The integration of modern technologies into the educational process encourages greater interest in the subject and improves students' ability to apply scientific principles to practical challenges.

Moreover, Thibaut et al. (2018) demonstrated that integrated STEM education is an innovative approach to enhancing student achievement and increasing interest in STEM disciplines. However, the successful implementation of integrated STEM education largely depends on educators' competence, which, among other factors, includes their attitudes towards STEM instruction. Despite the importance, there is limited knowledge of the factors influencing teachers' attitudes towards teaching integrated STEM curricula.

Fitriyana et al. (2024) argue that high school chemistry teachers (HSCTs) and vocational school chemistry teachers (VSCTs) should have a positive attitude toward STEM, as it offers students a meaningful way to learn chemistry. Using a research survey method, their study examined the perceptions of in-service chemistry teachers regarding the potential of STEM-based instruction in high school and vocational chemistry schools. The findings showed that STEM-integrated instruction can be effectively added to high school and vocational chemistry lessons. However, researchers pointed out that many teachers lack practical experience in applying STEM methods in their chemistry classes. Therefore, there is an urgent need for professional development programs focused on STEM to help ensure the successful adoption of STEM-based chemistry education.

The study by Siregar et al. (2023) and Banton et al. (2023) investigated the effect of an integrated STEAM project delivered via mobile technology on the reasoning abilities of elementary school students. The results verify the effectiveness of mobile technology in education and provide recommendations for developing instructional models that enhance students' reasoning skills. Furthermore, the study indicates that such projects can serve as a framework for maintaining educational quality during challenging times, such as pandemics. The findings of our research within the "Water Purification Methods" project are of considerable scientific and practical importance, as they contribute to the development of effective methods for removing pollutants and ensuring the safety of drinking water.

The study by Fitriyana et al. (2021) explored chemistry teachers' initial perceptions and understanding of incorporating the STEM approach into high school chemistry lessons. The authors conclude that for effective STEM integration into chemistry education, it is essential to offer specialized workshops and training sessions. These professional development programs help teachers acquire the necessary skills and enhance their readiness to implement STEM-based teaching methods. We fully agree with this view. Digital tools are vital for deepening mastery of STEM subjects and developing professional skills among future educators. Additionally, our research within the "Water Purification Methods" project not only confirms the effectiveness of the chosen filtration techniques but also suggests new opportunities for their enhancement. The results can be applied in both basic and applied research, as well as in the development of innovative water purification technologies. This highlights the project's importance and relevance for both scientific progress and practical applications.

The findings reported by Philip et al. (2023) and Adjapong (2019)confirm the effectiveness of computer modelling in teaching stoichiometric chemistry and emphasize its potential as a key part of STEM education. By integrating elements of science (chemistry), technology (digital tools), engineering (process modelling), and mathematics (calculations and quantitative analysis), computer modelling promotes the overall development of students' cross-disciplinary skills.

Using a STEM-based approach in chemistry education not only boosts academic achievement but also encourages the development of critical thinking, problem-solving, research skills, and digital literacy among students. In this context, computer modelling proves to be an effective way to implement interdisciplinary learning, aligning with modern needs to prepare students for future careers in a digital economy.

CONCLUSION

Based on the research questions, the following conclusions can be drawn:

1. Student participation in research projects employing STEM technologies has a positive impact on their interest in learning chemistry. First, STEM-based project activities (Science, Technology, Engineering, and Mathematics) ensure an interdisciplinary character of education, allowing students to perceive the practical relevance of chemical knowledge when applied to engineering and technological tasks. Second, the use of modern digital tools—such as virtual laboratories, 3D modeling, and data analysis—makes the study of chemistry more illustrative, interactive, and closely aligned with real conditions of scientific research.

2. The conducted study demonstrated that the application of STEM methods in teaching the topic "Water Purification Methods" is highly pedagogically effective for developing students' research skills. Engagement in practice-oriented tasks, process modeling, and laboratory experiments enabled students to acquire essential competencies, including formulating hypotheses, designing research algorithms, and conducting critical analysis of the results obtained.

3. The research findings indicate that the STEM approach exerts a significant influence on students' cognitive activity and engagement in the educational process. An analysis of learning dynamics revealed that the introduction of interdisciplinary tasks, grounded in solving real-world problems, enhances students' interest in the subject matter and stimulates their initiative in seeking additional information sources. A positive trend is observed in the development of such indicators of cognitive activity as the pursuit of independent inquiry, readiness to experiment, and the ability to formulate research-oriented questions. At the same time, engagement manifests not only in increased attendance and classroom participation but also in students' greater willingness to collaborate in group projects, engage in discussions, and publicly present their results.

Through the integration of STEM technologies, students gained a comprehensive understanding of the natural properties of water, developed an ecological perspective on resources, and acquired practical skills in using modern digital platforms. They explored various methods of water purification and the composition of filtration systems, and subsequently designed and assembled water filters on their own. To evaluate and compare filtration outcomes, the ReLab system was employed. This lightweight software environment facilitated data processing, analysis, and discussion, enabling an objective assessment of the dynamics of key chemical indicators of water quality before and after filtration.

Future research can focus on creating specific methodological guidelines for integrating digital technologies into STEM teacher training programs. This may also help develop more engaging and effective teaching methods, improving the overall quality of STEM education.

The limitations of the scientific project "Water Purification Methods" mainly stemmed from resource and equipment shortages. Using school laboratories and educational materials might not fully replicate industrial water purification processes. Since the study took place in an educational environment, it was difficult to accurately model the complex processes found in actual water treatment systems.

In school laboratories, analyzing heavy metal content, microorganisms, and organic pollutants in water is challenging. Additionally, water quality can fluctuate based on sampling time, weather, temperature, and other factors, which can impact the reproducibility of results. The study was incorporated into the academic curriculum, limiting the duration of experiments and long-term monitoring of purified water quality. Some water treatment methods require extended observation periods, which are often not practical in school settings.

Thus, the study aims for a comprehensive integration of STEM components. Future work plans to strengthen the mathematical and engineering aspects by adding more advanced computational and optimization tasks. This improvement is likely to increase the project's educational value and better align it with the needs of a full-scale STEM model.

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COMPETING INTERESTS

The authors declare that they have no relevant financial or non-financial interests to disclose.

AUTHOR CONTRIBUTIONS

All the authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed by all the authors. All the authors read and approved the final manuscript.

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