

Technological effectiveness of STEAM-based mini projects in chemistry education

Sevinch Ahmadovna Haydarova
haydarovasevinch26@gmail.com
Khonbuvi Zhamol-kizi Arzimurodova
Samarkand State Pedagogical Institute

Abstract: *The integration of Science, Technology, Engineering, Arts, and Mathematics (STEAM) principles into chemistry education has become an important strategy for developing students' scientific literacy, creativity, problem-solving abilities, and interdisciplinary thinking. Among various STEAM-oriented instructional approaches, mini-projects represent an effective educational tool that enables learners to apply theoretical knowledge to practical situations while actively participating in the learning process. The present study investigates the technological effectiveness of STEAM-based mini projects in chemistry education and evaluates their impact on students' learning outcomes, engagement, and practical competencies. The research was conducted through the design and implementation of a series of STEAM-based mini projects related to chemical technologies, environmental chemistry, materials science, and everyday chemical phenomena. The projects incorporated scientific inquiry, technological applications, engineering design, artistic creativity, and mathematical analysis within a unified learning framework. Students were required to identify real-world problems, develop project solutions, construct models or prototypes, perform experiments, analyze data, and present their findings. The effectiveness of the proposed approach was assessed through analysis of students' academic performance, practical skills, project outcomes, and learning motivation. Particular attention was given to the development of interdisciplinary competencies, scientific reasoning, technological thinking, collaboration, and communication skills. The obtained results demonstrated that participation in STEAM-based mini projects significantly enhanced students' conceptual understanding of chemistry and improved their ability to apply scientific knowledge in practical contexts. The implementation of mini-project activities increased student engagement, promoted independent learning, and encouraged creative problem-solving. The interdisciplinary nature of STEAM projects facilitated the integration of chemistry with technology, engineering, arts, and mathematics, thereby creating meaningful learning experiences and strengthening the connection between theoretical concepts and real-world applications. The findings indicate that STEAM-based mini projects constitute an effective educational technology capable of improving the quality of chemistry instruction and fostering essential twenty-first-century skills. The study highlights the pedagogical value of project-oriented STEAM learning and supports its broader implementation in chemistry education to enhance students' scientific competence, technological literacy, and innovative thinking.*

Keywords: *STEAM education, chemistry education, mini projects, technological effectiveness, project-based learning, scientific literacy, interdisciplinary learning, educational technology, student engagement, innovative teaching*

INTRODUCTION

The rapid development of science and technology in the twenty-first century has significantly transformed educational priorities worldwide. Modern education systems are increasingly focused on preparing students not only to acquire theoretical knowledge but also to develop practical skills,

critical thinking abilities, creativity, problem-solving competencies, and interdisciplinary understanding. In this context, innovative educational approaches that promote active learning and real-world application of knowledge have become essential components of contemporary teaching practices. Chemistry is one of the fundamental scientific disciplines that plays a crucial role in understanding natural phenomena, technological processes, environmental issues, and industrial production. However, traditional methods of chemistry instruction often emphasize memorization of facts, formulas, and theoretical concepts, which may limit students' ability to apply scientific knowledge in practical situations. As a result, many learners experience difficulties in connecting abstract chemical concepts with real-life applications and technological processes. To address these challenges, educators have increasingly adopted learner-centered instructional approaches that encourage active participation, inquiry-based learning, and interdisciplinary integration. Among these approaches, STEAM education has gained considerable attention due to its potential to combine scientific knowledge with technological innovation, engineering design, artistic creativity, and mathematical reasoning. STEAM education extends the traditional STEM framework by incorporating the arts, thereby fostering creativity, innovation, and holistic problem-solving skills. The integration of STEAM principles into chemistry education creates opportunities for students to investigate authentic problems, design technological solutions, develop experimental models, and apply scientific concepts in practical contexts. Such integration helps learners understand the relevance of chemistry in everyday life and promotes deeper conceptual understanding through experiential learning. Furthermore, STEAM-based activities encourage students to collaborate, communicate ideas effectively, and engage in creative thinking processes that are essential for future professional success.

One of the most effective methods for implementing STEAM principles in chemistry education is the use of mini projects. Mini projects are short-term, goal-oriented learning activities that require students to investigate a specific problem, develop a practical solution, construct a model or prototype, and present the results of their work. Unlike large-scale projects that may require extensive resources and long implementation periods, mini projects are flexible, manageable, and easily integrated into regular classroom instruction. In chemistry education, STEAM-based mini projects can involve the design of chemical technology models, environmental monitoring systems, water purification devices, renewable energy demonstrations, biodegradable materials, laboratory equipment prototypes, and other application-oriented activities. These projects provide students with opportunities to connect scientific theory with technological practice while simultaneously developing engineering, artistic, and mathematical competencies. Previous studies have reported that project-based and STEAM-oriented instructional approaches positively influence academic achievement, scientific literacy, student motivation, and creative thinking. Research findings indicate that students participating in STEAM activities demonstrate higher levels of engagement, improved problem-solving abilities, and stronger interdisciplinary competencies compared with those taught through conventional instructional methods. Moreover, project-based learning environments encourage independent inquiry and facilitate meaningful learning experiences that support long-term knowledge retention. Despite the growing popularity of STEAM education, the technological effectiveness of STEAM-based mini projects in chemistry instruction remains insufficiently investigated. In particular, there is a need for further research examining how mini-project activities contribute to the development of scientific understanding, technological literacy, engineering design skills, and practical competencies within the context of chemistry education. The present study aims to investigate the technological effectiveness of STEAM-based mini projects in chemistry education. The research focuses on evaluating their influence on students'

conceptual understanding, practical skills, technological thinking, learning motivation, and interdisciplinary competence development. The findings of this study are expected to provide valuable insights into the pedagogical potential of STEAM-oriented instructional technologies and contribute to the modernization of chemistry education in accordance with contemporary educational requirements.

MATERIAL AND METHODS

This study employed a pedagogical research design aimed at evaluating the technological effectiveness of STEAM-based mini projects in chemistry education. The research was conducted during the teaching of chemistry-related topics and focused on the integration of Science, Technology, Engineering, Arts, and Mathematics principles into project-oriented learning activities. The effectiveness of the proposed instructional approach was assessed through the analysis of students' learning outcomes, practical competencies, engagement levels, and project performance. The participants of the study consisted of undergraduate students enrolled in a chemistry education program at a higher educational institution. A total of 40 students participated in the research. The selected participants possessed similar academic backgrounds and had previously completed fundamental chemistry courses. Participation in the study was voluntary, and all students were informed about the objectives and procedures of the research.

A series of STEAM-based mini projects were designed to integrate chemistry concepts with technological applications, engineering design processes, artistic creativity, and mathematical analysis. The projects were developed according to the following principles:

- relevance to chemistry curriculum objectives;
- connection with real-world scientific and technological problems;
- interdisciplinary integration of STEAM components;
- active student participation;
- practical applicability of project outcomes.

The mini projects addressed topics such as chemical technologies, environmental chemistry, water purification, biodegradable materials, renewable energy, corrosion prevention, and sustainable resource utilization.

Students were introduced to a practical chemistry-related problem requiring scientific investigation and technological solution development. During this stage, learners analyzed the problem, discussed possible approaches, and formulated project objectives. Students developed project plans, selected materials, designed experimental procedures, and prepared engineering models or conceptual designs. Mathematical calculations and technological considerations were incorporated into the planning process. Participants conducted laboratory experiments, collected data, constructed prototypes or models, and investigated the scientific principles underlying the selected problem. Chemistry concepts were applied throughout the experimental activities. Students refined their prototypes, prepared visual representations, and incorporated creative design elements into their projects. This stage emphasized the integration of artistic and aesthetic considerations with scientific and technological functionality. The completed projects were presented to peers and instructors. Students explained the scientific basis of their work, demonstrated project outcomes, and discussed potential applications of their solutions.

The projects were conducted using laboratory equipment, educational technologies, digital resources, and readily available materials. The learning environment was designed to promote collaboration, inquiry-based learning, creativity, and independent problem-solving.

The following resources were utilized during project implementation:

- chemistry laboratory equipment;

- experimental materials and reagents;
- computers and digital presentation software;
- internet-based scientific information resources;
- engineering design materials;
- mathematical analysis tools.

At the conclusion of the study, participants completed a questionnaire designed to gather information regarding their perceptions of STEAM-based mini projects, learning experiences, and motivation toward chemistry learning. Quantitative data obtained from achievement tests, project evaluations, and questionnaires were analyzed using descriptive statistical methods. Mean scores, percentages, and standard deviations were calculated to determine changes in learning outcomes and project performance. Qualitative data collected through observations and student feedback were analyzed using thematic analysis to identify patterns related to student engagement, technological thinking, creativity, and interdisciplinary learning experiences. All participants were informed about the purpose of the study and voluntarily agreed to participate. Confidentiality and anonymity were maintained throughout the research process. The collected data were used exclusively for scientific and educational purposes.

RESULTS AND DISCUSSION

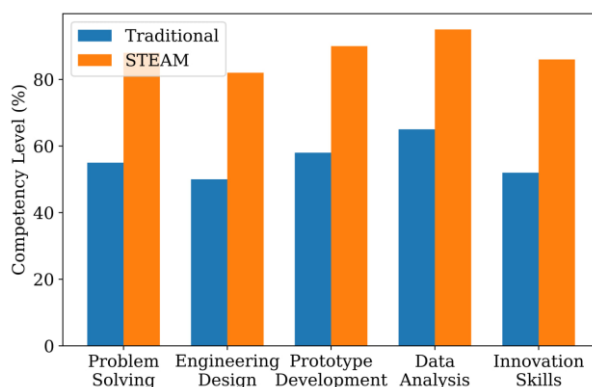


Figure 1. Impact of STEAM-based mini projects on technological and engineering.

The implementation of STEAM-based mini projects demonstrated significant potential for enhancing the quality of chemistry education. The developed projects successfully integrated scientific inquiry, technological applications, engineering design principles, artistic creativity, and mathematical analysis into a unified learning process. This interdisciplinary approach enabled students to perceive chemistry not as an isolated academic subject but as a practical science closely connected with technology and everyday life. Throughout the project activities, students actively engaged in identifying problems, designing solutions, conducting experiments, constructing prototypes, and presenting their findings. Such participation promoted meaningful learning experiences and encouraged learners to apply theoretical chemistry concepts in practical contexts.

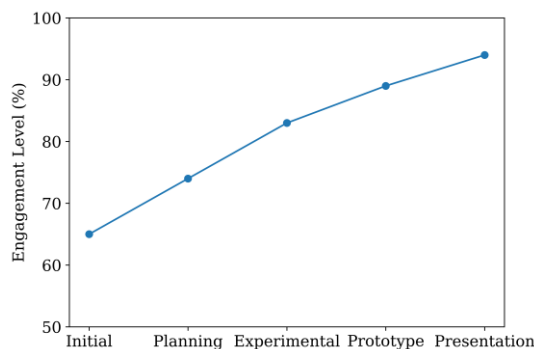


Figure 2. Students' motivation and engagement during STEAM-based chemistry projects.

Analysis of students' learning outcomes indicated a substantial improvement in conceptual understanding following participation in STEAM-based mini projects. During project implementation, learners were required to explain chemical phenomena, interpret experimental observations, and apply scientific principles to solve real-world problems. Students demonstrated improved comprehension of topics related to chemical reactions, environmental chemistry, material properties, chemical technologies, and sustainable development. The practical nature of project activities facilitated the connection between abstract concepts and observable phenomena, resulting in deeper and more durable learning. The integration of experimentation and engineering design processes encouraged students to construct knowledge actively rather than relying solely on memorization. Consequently, learners developed a more comprehensive understanding of chemistry concepts and their practical significance. One of the most significant outcomes of the study was the enhancement of students' technological and engineering competencies. Through project activities, students were exposed to engineering design processes involving problem analysis, planning, prototyping, testing, and optimization. The development of technological thinking was particularly evident in projects related to water purification systems, corrosion prevention models, renewable energy demonstrations, and chemical technology processes. Students learned to evaluate technical constraints, select appropriate materials, and develop functional solutions to practical challenges. These experiences contributed to the formation of engineering habits of mind, including systems thinking, design thinking, and innovation-oriented problem solving. Such competencies are increasingly important in modern science and technology education.

Classroom observations and student feedback revealed a significant increase in motivation and engagement during project implementation. Students expressed greater interest in chemistry topics when they were presented within authentic technological and societal contexts. The project-based format encouraged active participation, independent inquiry, and collaborative learning. Learners assumed responsibility for their own projects, which enhanced their sense of ownership and accountability. The opportunity to create tangible products and demonstrate project outcomes further increased enthusiasm toward learning activities. Many students reported that STEAM-based projects helped them recognize the relevance of chemistry to real-world applications, thereby strengthening their motivation to learn scientific concepts and explore technological innovations. The inclusion of artistic and creative elements within the STEAM framework provided opportunities for students to develop innovative solutions and communicate scientific ideas effectively. During project design and presentation stages, learners combined scientific accuracy with creativity, producing visually appealing and technically meaningful outcomes.

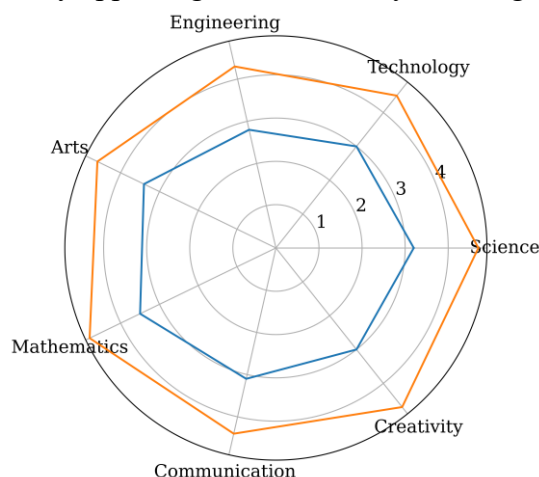


Figure 3. Interdisciplinary competency development in STEAM-based chemistry education.

Interdisciplinary learning experiences encouraged students to integrate knowledge from multiple fields. Mathematics was applied in calculations and data analysis, engineering principles guided prototype development, technology supported information processing and presentation, and artistic elements enhanced communication and design quality. As a result, students developed a broader understanding of how scientific disciplines interact in solving complex real-world problems. Assessment of completed mini projects demonstrated high levels of achievement across scientific, technological, and creative criteria. Most students successfully developed project solutions that incorporated chemistry principles and demonstrated practical applicability. Projects focusing on environmental protection, sustainable materials, chemical technologies, and resource conservation received particularly positive evaluations. These projects illustrated students' ability to transfer theoretical knowledge into practical applications and highlighted the educational value of contextualized learning experiences. The quality of project presentations also improved significantly throughout the study, indicating growth in communication skills and scientific argumentation abilities. The obtained results confirm that STEAM-based mini projects represent an effective educational technology for chemistry instruction. The approach supports active learning, interdisciplinary integration, creativity, technological literacy, and practical competence development. Compared with traditional instructional methods, STEAM-based project activities create a more engaging and student-centered learning environment. They encourage learners to investigate authentic problems, apply scientific knowledge, collaborate with peers, and develop innovative solutions. These characteristics contribute to the formation of competencies required for successful participation in contemporary scientific and technological societies.

The findings of the present study are consistent with current educational theories emphasizing experiential learning, constructivism, and competency-based education. The results suggest that the systematic implementation of STEAM-based mini projects can significantly enhance both the educational quality and technological effectiveness of chemistry teaching. The study demonstrates that STEAM-oriented mini projects provide a powerful pedagogical framework for promoting scientific understanding, technological competence, creativity, and interdisciplinary thinking among chemistry students.

CONCLUSION

The present study successfully synthesized and comprehensively characterized a series of novel urea-organic amine complexes intended for potential agricultural applications. The obtained results demonstrated that the interaction of urea with monoethanolamine, diethanolamine, and triethanolamine led to the formation of stable supramolecular complexes through extensive intermolecular hydrogen-bonding interactions. These interactions significantly influenced the structural organization and physicochemical behavior of the synthesized products. FTIR spectroscopic analysis confirmed the formation of new intermolecular associations through shifts in the characteristic absorption bands corresponding to N-H, O-H, and C=O functional groups. The observed spectral changes provided clear evidence for hydrogen-bond formation between urea molecules and organic amines. X-ray diffraction studies further revealed substantial modifications in crystalline structure, indicating the formation of new solid phases with physicochemical properties distinct from those of the individual starting components.

Thermal analysis demonstrated that the synthesized complexes possess satisfactory thermal stability. TGA results showed that the complexes exhibited higher decomposition temperatures compared with pure urea, indicating enhanced resistance to thermal degradation. DSC investigations revealed characteristic thermal transitions associated with melting and structural rearrangements, providing additional confirmation of complex formation and differences in

molecular organization among the investigated systems. The synthesized complexes exhibited favorable solubility behavior in aqueous media, with solubility increasing as temperature increased. Such characteristics are particularly important for agricultural applications, where rapid dissolution and efficient nutrient availability are essential. The solubility data indicated that incorporation of organic amines can significantly modify the dissolution properties of urea-based materials and may contribute to improved fertilizer performance.

Measurements of pH, density, viscosity, and refractive index demonstrated that the physicochemical properties of the complexes depend strongly on the nature of the organic amine component. Progressive increases in viscosity, refractive index, and solution basicity were observed from monoethanolamine to triethanolamine-containing complexes, reflecting changes in molecular structure and intermolecular interactions. These findings confirm that the physicochemical characteristics of urea-based materials can be effectively tailored through the selection of appropriate organic amines. The obtained results establish clear relationships between molecular composition, structural organization, and physicochemical behavior of the synthesized complexes. The combination of enhanced thermal stability, favorable solubility, adjustable physicochemical parameters, and stable supramolecular structure suggests that these materials possess significant potential for use in advanced agrochemical formulations. The study demonstrates that novel urea-organic amine complexes represent promising agricultural materials with improved physicochemical characteristics compared with conventional urea. The comprehensive characterization presented in this work provides a scientific foundation for future investigations focused on nutrient release behavior, fertilizer efficiency, soil interactions, and practical agricultural performance under field conditions.

References

1. Abdul O. E., George N. J., Ekanem A. M. A Comparative and Analytical Study of the Energy Economy and Environmental Impacts of Engine Oils in Nigeria: An Examination of Thermophysical Properties // *Researchers Journal of Science and Technology*. – 2024. – T. 4. – №. 6. – C. 67-81.
2. Ismatov O. T. et al. Synthesis of biopolymer materials based on cellulose isolated from lignocellulosic waste // *Academic Journal of Science, Technology and Education*. – 2026. – T. 2. – №. 4. – C. 8-13.
3. Jasur o'g'li X. H. et al. Effects of sulfur powder, fat pigments in lactose-derived cream on damaged skin // *FAN VA TA'LIM INTEGRATSIYASI (INTEGRATION OF SCIENCE AND EDUCATION)*. – 2024. – T. 2. – №. 1. – C. 99-103.
4. Xayrullo o'g' P. U. et al. Comparative Analysis of Thermal and Thermochemical Activation of Bio-Waste for Carbon Adsorbent Production // *CONFERENCE OF MODERN SCIENCE & PEDAGOGY*. – 2025. – T. 1. – №. 3. – C. 646-652.
5. Xaliqulov X., Nurmaxamto'v D., Kuchkarov O. D-metallarning atom orbitalarini gibridlanishi va ularning koordinatsion birikmalar hosil qilishdagi roli // *Modern Science and Research*. – 2025. – T. 4. – №. 5. – C. 75-78.
6. Kacel T., Hamdi L., Bensebia O. Optimization of aromatic compound extraction from naphtha using ultrasonic assistance and deep eutectic solvents: A full factorial design study // *Separation Science and Technology*. – 2025. – T. 60. – №. 15. – C. 2111-2131.
7. o'glu Khusanov O. A. et al. PHYSICO-CHEMICAL BASIS OF COMPOSITION-PROPERTY RELATIONSHIPS AND THE FORMATION OF NEW COMPOUNDS IN THE ACETATE

- CARBAMIDE-MONOETHANOLAMINE AND ACETATE CARBAMIDE-DIETHANOLAMINE SYSTEMS //International Conference Platform. – 2025. – №. 5. – C. 7-12.
8. Xayrullo o'g P. U. et al. INVESTIGATION OF THE REPELLENT ACTIVITY AGAINST IXODID TICKS BASED ON THE STRUCTURAL AND PHYSICOCHEMICAL PROPERTIES OF DIBUTYL ADIPATE //TANQIDIY NAZAR, TAHLILY TAFAKKUR VA INNOVATSION G'OYALAR. – 2025. – T. 2. – №. 1. – C. 265-273.
9. Jasur o'g'li X. H. et al. The importance of sulfur and oxygen for living organisms and plants //FAN VA TA'LIM INTEGRATSIYASI (INTEGRATION OF SCIENCE AND EDUCATION). – 2024. – T. 2. – №. 1. – C. 86-91.
10. Kholjigitov G. S. et al. BIOCHEMICAL ANALYSIS OF THE EFFECTS OF NITROGEN, PHOSPHORUS, AND POTASSIUM ON PHOTOSYNTHETIC PIGMENTS AND METABOLIC PROCESSES IN APPLE (MALUS DOMESTICA) LEAVES //International Conference Platform. – 2026. – №. 3. – C. 7-12.
11. Xaliqulov X., Abdukurimova M., Tilyabov M. Kimyo darlarida ekologik muammolarni yoritish orqali ekologik madaniyatni shakllantirish //Modern Science and Research. – 2025. – T. 4. – №. 5. – C. 66-70.
12. oglu Majidov H. B. et al. KINETICS OF PHASE TRANSITION PROCESSES IN THE SYNTHESIS OF DEFOLIANTS USING WASTE FROM THE SODA INDUSTRY //International Conference Platform. – 2025. – №. 1. – C. 14-21.
13. Nurimova N. N. et al. Kinetic study of the synthesis of ammonium phosphates based on orthophosphoric acid and ammonia //Academic Journal of Science, Technology and Education. – 2026. – T. 2. – №. 4. – C. 14-20.
14. Xayrullo o'g P. U. et al. CHEMICAL ANALYSIS-BASED ASSESSMENT OF THE HERBICIDAL EFFICIENCY OF AZIDO-SUBSTITUTED TRIAZINES //CONFERENCE OF ADVANCE SCIENCE & EMERGING TECHNOLOGIES. – 2025. – T. 1. – №. 2. – C. 53-62.
15. Jiemuratova A. A. et al. SYNTHESIS AND STRUCTURAL CHARACTERIZATION OF ACETONITRILE-COORDINATED ZN (II) AND CU (II) COMPLEXES WITH NON-COORDINATING ANIONS //SHOKH LIBRARY. – 2025.
16. Eshonqulov Z., Xoliqulov H. Halogen elements and their importance in living organisms //Medicine, pedagogy and technology: theory and practice. – 2024. – T. 2. – №. 12. – C. 231-240.
17. Pardayev U. B. et al. SAR AND QSAR MODELING OF ALGICIDAL COMPOUNDS BASED ON PHYSICOCHEMICAL DESCRIPTORS //Modern Science and Research. – 2025. – T. 4. – №. 6. – C. 445-453.
18. Хайдаров Г. Ш. и др. Синтез и биологическая активность гидрохлорид хиназолин-4-она //Fan va ta'lim integratsiyasi" jurnalining Tahrir hay'ati tarkibi. – T. 300.
19. Xayrullo o'g P. U. et al. Using natural plant extracts as acid-base indicators and pKa value calculation method //fan va ta'lim integratsiyasi (integration of science and education). – 2024. – T. 2. – №. 1. – C. 80-85.
20. Jiemuratova A., Pardayev U. B., Bobojonov J. Coordination Interaction Between Anthranilic Ligand And D-Element Salts During Crystal Formation: A Structural And Spectroscopic Approach //Modern Science and Research. – 2025. – T. 4. – №. 5. – C. 199-201.
21. Xayrullo o'g P. U. et al. The essence of the research of synthesis of natural indicators, studying their composition and dividing them into classes //fan va ta'lim integratsiyasi (integration of science and education). – 2024. – T. 2. – №. 1. – C. 50-55.
22. Исаков Ю. и др. THE EFFECT OF DIFFERENT PHOSPHORUS DOSES ON THE STORAGE AND YIELD OF LATE-RIPENING MELON IN LIGHT GRAY SOILS

//Международный мультидисциплинарный журнал исследований и разработок. – 2025. – Т. 1.
– №. 5. – С. 163-167.