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

SCIENTIFIC JOURNAL OF PEDAGOGY AND ECONOMICS

№5
2025

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

CENTRAL ASIAN ACADEMIC
RESEARCH CENTER

SCIENTIFIC JOURNAL OF PEDAGOGY AND ECONOMICS

PUBLISHED SINCE 1944

5 (417)

September – October 2025

ALMATY, 2025

Scientific Journal of Pedagogy and Economics
ISSN 2518-1467 (Online),
ISSN 1991-3494 (Print).
Owner: «Central Asian Academic Research Center» LLP (Almaty).
The certificate of registration of a periodical printed publication in the Committee of information of the Ministry of Information and Communications of the Republic of Kazakhstan **No. 3620-Ж,** issued on 05.06.2025
Thematic focus: *«publication of the results of new achievements inthe field of fundamental sciences»*
Periodicity: 6 times a year.
http://www.bulletin-science.kz/index.php/en/

Scientific Journal of Pedagogy and Economics
ISSN 2518-1467 (Online),
ISSN 1991-3494 (Print).
Меншіктенуші: «Орталық Азия академиялық ғылыми орталығы» ЖШС (Алматы қ.).
Қазақстан Республикасының Ақпарат және коммуникациялар министрлігінің Ақпарат комитетінде 05.06.2025 ж. берілген **№ 3620-Ж** мерзімдік басылым тіркеуіне қойылу туралы куәлік.
Тақырыптық бағыты: *«іргелі ғылым салалары бойынша жаңа жетістіктердің нәтижелерін жариялау»*
Мерзімділігі: жылына 6 рет.
http://www.bulletin-science.kz/index.php/en/

Scientific Journal of Pedagogy and Economics
ISSN 2518-1467 (Online),
ISSN 1991-3494 (Print).
Собственник: ТОО «Центрально-азиатский академический научный центр» (г. Алматы).
Свидетельство о постановке на учет периодического печатного издания в Комитете информации Министерства информации и коммуникаций и Республики Казахстан **№ 3620-Ж,** выданное 05.06.2025 г.
Тематическая направленность: *«публикация результатов новых достижений вобласти фундаментальных наук».*
Периодичность: 6 раз в год.
http://www.bulletin-science.kz/index.php/en/

CONTENTS

PEDAGOGY

ECONOMICS

МАЗМҰНЫ

ПЕДАГОГИКА

ЭКОНОМИКА

СОДЕРЖАНИЕ

ПЕДАГОГИКА

ЭКОНОМИКА

SCIENTIFIC JOURNAL OF PEDAGOGY AND ECONOMICS
ISSN 1991-3494
Volume 5. Number 417 (2025), 133–145

https://doi.org/10.32014/2025.2518-1467.1028

UDC 37.016:5:004

© A. Kopbossyn[1*], A. Orynbekova[2], N. Serikbayeva[2], 2025.
[1]Al-Farabi Kazakh National University, Almaty, Kazakhstan;
[2]Shakarim University, Semey, Kazakhstan.
E-mail: kopbossyn_amandyk2@kaznu.edu.kz

STEM TECHNOLOGY IN INTERDISCIPLINARY NATURAL SCIENCE TEACHING

A. Kopbossyn — PhD student, Al-Farabi Kazakh National University, Almaty, Kazakhstan,
E-mail: *kopbossyn_amandyk2@kaznu.edu.kz*, https://orcid.org/0009-0001-1097-2765;
A. Orynbekova — PhD, Senior Lecturer of Shakarim University, Semey, Kazakhstan,
E-mail: a.orynbekova@shakarim.kz, https://orcid.org/0000-0002-2156-1793;
N. Serikbayeva — PhD, acting Associate Professor of Shakarim University, Semey, Kazakhstan,
E-mail: nurgul.sgpi@mail.ru, https://orcid.org/0000-0002-7490-7639.

Abstract. The integration of STEM (Science, Technology, Engineering, and Mathematics) technologies into school curricula has become one of the key global priorities in modern education. This approach aims to enhance students' scientific literacy, foster critical and creative thinking, develop problem-solving skills, and prepare them to meet the demands of the 21st-century labor market and innovation-driven economy. STEM education goes beyond strengthening individual subject competencies; through interdisciplinary integration, it connects theoretical knowledge with practical experience, promotes research-oriented and teamwork skills, and plays a crucial role in expanding students' scientific worldview and shaping their technological culture. The article aims to identify the pedagogical and methodological foundations for applying STEM technologies in school settings and to analyze effective strategies for improving interdisciplinary teaching. The study is based on international systematic reviews and empirical research published between 2019 and 2025 and employs comparative and content analysis methods. Within the context of Kazakhstan's educational system, the research examines methodological practices and specific features of STEM integration. The findings demonstrate that implementing STEM strengthens conceptual links between disciplines, enhances students' ability to connect scientific ideas, develops their capacity for complex problem analysis and decision-making, and increases learning motivation and civic engagement. The article also highlights opportunities and challenges of introducing STEM in resource-limited schools and provides practical recommendations for curriculum development, teacher professional growth, and aligning STEM initiatives with Kazakhstan's national goals of digitalization and educational modernization.

Keywords: STEM education, interdisciplinary learning, natural science subjects, project based pedagogy, systems modeling

© А. Копбосын[1*], А. Орынбекова[2], Н. Серикбаева[2], 2025.
[1]Әл-Фараби атындағы Қазақ Ұлттық университеті, Алматы, Қазақстан;
[2]Шәкәрім университеті, Семей, Қазақстан.
E-mail: kopbossyn_amandyk2@kaznu.edu.kz

STEM ТЕХНОЛОГИЯСЫН ЖАРАТЫЛЫСТАНУ ПӘНДЕРІН ПӘНАРАЛЫҚ ОҚЫТУДА ҚОЛДАНУ

А. Копбосын — PhD студент, Әл-Фараби атындағы Қазақ Ұлттық Университеті, Алматы, Қазақстан,
E-mail: kopbossyn_amandyk2@kaznu.edu.kz, https://orcid.org/0009-0001-1097-2765;
А. Орынбекова — PhD, Шәкәрім университетінің аға оқытушысы, Семей, Қазақстан,
E-mail: a.orynbekova@shakarim.kz, https://orcid.org/0000-0002-2156-1793;
Н. Серикбаева — PhD, Шәкәрім университетінің қауымдастырылған профессор м.а, Семей, Қазақстан,
E-mail: nurgul.sgpi@mail.ru, https://orcid.org/0000-0002-7490-7639.

Аннотация. STEM (Science, Technology, Engineering, and Mathematics – ғылым, технология, инженерия және математика) технологияларын мектеп бағдарламасына енгізу – қазіргі білім берудің жаһандық басым бағыттарының бірі. Бұл тәсіл оқушылардың ғылыми сауаттылығын арттыруға, сыни және шығармашылық ойлау қабілеттерін дамытуға, күрделі мәселелерді шешу дағдыларын қалыптастыруға және XXI ғасырдың еңбек нарығы мен инновациялық экономикасының талаптарына бейімделуіне мүмкіндік береді. STEM-білім беру тек жекелеген пәндік құзыреттерді дамытумен шектелмей, пәнаралық интеграция негізінде оқушылардың теориялық білімін тәжірибемен ұштастыру арқылы зерттеушілік және командалық жұмыс дағдыларын жетілдіруге ықпал етеді. Сонымен қатар, ол оқушылардың ғылыми дүниетанымын кеңейтіп, технологиялық мәдениетін қалыптастыруда шешуші рөл атқарады. Мақалада мектеп жағдайында STEM технологияларын қолданудың педагогикалық және әдіснамалық негіздері айқындалып, пәнаралық оқытуды жетілдіру жолдары талданады. Зерттеу 2019–2025 жылдары жарияланған халықаралық жүйелі шолулар мен эмпирикалық зерттеулерге сүйеніп, салыстырмалы және мазмұндық талдау әдістері арқылы жүргізілді. Қазақстанның білім беру жүйесінің контексті негізінде STEM интеграциясының әдістемелік тәжірибелері мен практикалық ерекшеліктері қарастырылды. Зерттеу нәтижелері STEM технологияларын енгізу пәндер арасындағы ұғымдық байланысты күшейтетінін, оқушылардың ғылыми идеяларды байланыстыру қабілетін арттыратынын, олардың проблемаларды кешенді талдау және шешу дағдыларын дамытатынын, сондай-ақ оқу мотивациясын және белсенді азаматтық ұстанымын қалыптастыратынын көрсетті. Мақалада ресурстары шектеулі мектептерде STEM-ді енгізудің

мүмкіндіктері мен қиындықтары айқындалып, оқу бағдарламаларын жетілдіру, мұғалімдердің кәсіби дамуын қолдау және STEM бастамаларын білім беруді цифрландыру мен жаңғыртудың ұлттық басымдықтарымен үйлестіруге бағытталған нақты әдістемелік ұсынымдар жасалды.

Түйін сөздер: STEM-білім беру, пәнаралық оқыту, жаратылыстану пәндері, жобалық оқыту, жүйелік модельдеу

© А. Копбосын[1*], А. Орынбекова[2], Н. Серикбаева[2], 2025.
[1]Казахский Национальный университет им. аль-Фараби, Алматы, Казахстан;
[2]Университет Шакарима, Семей, Казахстан.
E-mail: kopbossyn_amandyk2@kaznu.edu.kz

STEM-ТЕХНОЛОГИИ В МЕЖДИСЦИПЛИНАРНОМ ОБУЧЕНИИ ЕСТЕСТВЕННЫМ НАУКАМ

А. Копбосын — PhD студент, Казахский Национальный университет им. аль-Фараби, Алматы, Казахстан,
E-mail: kopbossyn_amandyk2@kaznu.edu.kz, https://orcid.org/0009-0001-1097-2765;
А. Орынбекова — PhD, старший преподаватель университета Шакарима, Семей, Казахстан,
E-mail: a.orynbekova@shakarim.kz, https://orcid.org/0000-0002-2156-1793;
Н. Серикбаева — PhD, и. о. ассоциированного профессора университета Шакарима, Семей, Казахстан,
E-mail: nurgul.sgpi@mail.ru, https://orcid.org/0000-0002-7490-7639.

Аннотация. Интеграция STEM-технологий (Science, Technology, Engineering, and Mathematics — наука, технология, инженерия и математика) в школьные программы является одним из ключевых глобальных приоритетов современного образования. Этот подход направлен на повышение научной грамотности учащихся, развитие критического и творческого мышления, формирование навыков решения сложных проблем и адаптацию к требованиям рынка труда и инновационной экономики XXI века. STEM-образование не ограничивается развитием отдельных предметных компетенций: через междисциплинарную интеграцию оно способствует объединению теоретических знаний с практическими умениями, развитию исследовательских и командных навыков. Кроме того, оно играет важную роль в расширении научного мировоззрения учащихся и формировании технологической культуры. Цель статьи — определить педагогические и методологические основы применения STEM-технологий в школьных условиях и проанализировать пути совершенствования междисциплинарного обучения. Исследование основано на международных систематических обзорах и эмпирических исследованиях, опубликованных в 2019–2025 годах, и реализовано с использованием сравнительного и контент-анализа. В контексте образовательной системы Казахстана проанализированы методические практики и особенности интеграции STEM. Результаты исследования показывают, что внедрение STEM усиливает понятийные связи между дисциплинами, развивает способность учащихся устанавливать

взаимосвязи между научными идеями, формирует навыки комплексного анализа и решения проблем, а также повышает учебную мотивацию и гражданскую активность. В статье определены возможности и трудности внедрения STEM в школах с ограниченными ресурсами и представлены практические рекомендации по совершенствованию учебных программ, профессиональному развитию учителей и согласованию STEM-инициатив с национальными целями цифровизации и модернизации образования.

Ключевые слова: STEM-образование, междисциплинарное обучение, естественнонаучные предметы, проектное обучение, системное моделирование

Introduction. The accelerating pace of scientific and technological progress requires education systems worldwide to cultivate learners who are not only proficient in discrete academic disciplines but also capable of integrating knowledge across domains. The traditional compartmentalization of subjects such as physics, chemistry, biology, and mathematics often results in fragmented understandings, where students struggle to apply theoretical knowledge to real-world problems (Holley & Park, 2020). In response, STEM education—an integrative approach combining Science, Technology, Engineering, and Mathematics—has become a central paradigm for educational reform at the school level.

STEM is more than a curricular framework; it is a pedagogical philosophy that emphasizes interdisciplinary connections, project-based tasks, inquiry, engineering design, and modeling. By engaging students in authentic problem-solving, STEM nurtures higher-order thinking, creativity, and adaptability—skills critical for addressing complex global challenges such as climate change, biodiversity loss, and the transition to sustainable energy systems (Cole et al., 2024).

One of the defining features of STEM education is its capacity to foster interdisciplinary learning. Interdisciplinary learning occurs when students connect knowledge, skills, and methods from multiple subjects to construct a unified understanding of phenomena. For example, a school project on water quality can integrate chemistry (measuring pollutants), biology (studying ecosystems), physics (using sensors for data collection), and mathematics (analyzing datasets). Such tasks exemplify the holistic perspective that STEM aims to develop, where disciplinary boundaries dissolve in the pursuit of solving real-world problems (Sezen-Barrie et al., 2023).

Recent systematic reviews indicate that STEM-based approaches such as project-based learning (PjBL), inquiry-based learning (IBL), engineering design, and socioscientific reasoning consistently yield positive outcomes for interdisciplinary integration (Restaino et al., 2024). Project-based approaches provide the backbone for cross-disciplinary work, while inquiry and modeling strengthen systems reasoning. Engineering design offers students opportunities to apply knowledge practically, and socioscientific issue frameworks connect natural sciences with civic reasoning and ethical analysis. Together, these approaches cultivate not only knowledge but also skills, values, and agency.

From 2019 to 2025, the number of school-focused integrated STEM studies expanded rapidly, particularly in North America and Southeast Asia. These studies explored a wide variety of topics—climate, water, waste/circular economy, biodiversity, and energy—with strong emphasis on sustainability and problem-based contexts. Evidence shows that students engaged in STEM projects demonstrate stronger conceptual understanding, higher motivation, and increased capacity to act as responsible citizens (Hakim et al., 2023).

Technology plays a pivotal role in enabling interdisciplinary integration. Low-cost green kits, digital platforms such as iNaturalist, modeling tools, and BIM-based simulations have expanded the scope of classroom STEM (Herodotou et al., 2024). However, adoption remains uneven: climate and water-related projects often leverage technology, whereas energy and justice/policy contexts are less technologically integrated (Cole et al., 2024). This unevenness signals both a challenge and an opportunity for curriculum designers to broaden the technological dimension of interdisciplinary STEM.

In Kazakhstan, educational modernization has prioritized competence-based learning through the Жаңартылған білім мазмұны (Updated Content of Education). While this curriculum includes elements supportive of cross-subject integration, practical STEM-based interdisciplinary implementation remains limited. Teachers frequently report insufficient methodological preparation, lack of interdisciplinary teaching resources, and infrastructure gaps such as limited laboratory equipment and digital tools (Izzah et al., 2023).

At the same time, government initiatives such as Digital Kazakhstan and the growing emphasis on innovation-driven economic development provide fertile ground for scaling STEM initiatives. Pilot projects in Nazarbayev Intellectual Schools (NIS) and BINOM Schools, for example, demonstrate how interdisciplinary projects can be embedded in natural science education. Yet systematic research on the methodological foundations for STEM-based interdisciplinarity in Kazakhstan's schools is scarce. This represents a significant gap, particularly as policymakers seek to align national education goals with global trends in digitalization and sustainability.

Against this backdrop, the present article explores the role of STEM technology in fostering interdisciplinary connections in teaching natural science subjects at school. It aims to: (1) clarify the theoretical and pedagogical foundations of interdisciplinary integration within STEM education; (2) review and synthesize international evidence on how STEM practices foster interdisciplinary competencies in natural science subjects; (3) analyze the opportunities and challenges of STEM implementation in Kazakhstan's school system; and (4) offer methodological recommendations for educators, curriculum developers, and policymakers seeking to strengthen interdisciplinary teaching. The article is structured as follows: Section 2 presents the theoretical framework underpinning interdisciplinary STEM learning; Section 3 reviews global experiences and case studies (2019–2025); Section 4 situates the discussion within the Kazakhstani educational context; Section 5 discusses methodological and policy implications; Section 6 concludes with recommendations.

Literature Review

Global Expansion of Integrated STEM Research (2019–2025)

The past decade has witnessed rapid growth in research on STEM integration at the school level, particularly where sustainability and interdisciplinarity intersect. Systematic mapping of studies between 2019 and 2025 indicates a sharp acceleration in publications after 2020, with North America and Southeast/East Asia leading in output. This surge reflects global recognition that disciplinary silos cannot adequately prepare students for complex socio-ecological challenges such as climate change, biodiversity decline, or circular-economy transitions. Despite regional diversity, a common theme emerges: integrated STEM is most effective when framed around real-world issues. Studies repeatedly demonstrate that when students investigate authentic contexts—such as water pollution, renewable energy, or disaster preparedness—they more readily perceive how physics, chemistry, biology, and mathematics interconnect (Sezen-Barrie et al., 2023).

Interdisciplinary Approaches in STEM Education

A variety of instructional designs underpin interdisciplinary STEM learning. Each has distinctive features and outcomes (see Table 1 for a summary):

• Project-Based Learning (PjBL): Functions as the backbone for interdisciplinary integration. Students engage in extended projects where natural sciences converge with mathematics and engineering, producing artifacts or reports relevant to real communities.

• Inquiry-Based Learning (IBL): Encourages scientific reasoning through experimentation and evidence-based analysis, blending disciplinary tools into unified investigations (Holley & Park, 2020).

• Engineering Design: Requires students to design solutions such as renewable-energy devices or water-filtration systems, combining principles from physics, chemistry, and mathematics (Jefferson et al., 2020).

• Modeling and Systems Thinking: Enables students to construct and refine models of socio-ecological systems, reinforcing cross-subject coherence (Sezen-Barrie et al., 2023).

• Socioscientific Issues (SSI): Promotes civic reasoning and ethical reflection while applying natural science knowledge, e.g., debating biofuels or climate policies (Zhu & He, 2022).

Thematic Focus Areas in Integrated STEM

Analysis of 42 empirical interventions shows strong clustering of STEM–ESD research around certain themes. Climate dominates, accounting for nearly one-third of studies, followed by water and waste/circular economy. Biodiversity and energy each constitute smaller but significant clusters, while disaster preparedness, built environment, and justice/policy are comparatively underrepresented (Cole et al., 2024; Restaino et al., 2024). This distribution is summarized in Figure 1.

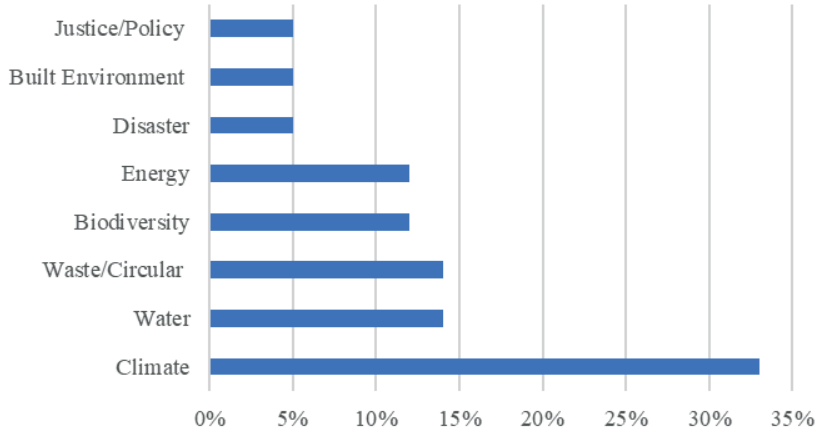

Figure 1. Distribution of Integrated STEM–ESD Studies by Theme (2019–2025)

The pattern demonstrates two key points. First, environmental science is the dominant disciplinary anchor, showing the natural alignment between STEM and sustainability. Second, gaps remain in energy literacy and justice-oriented education, where interdisciplinary potential is high but underexplored.

Technology as a Lever for Integration

Technology serves as both enabler and challenge in interdisciplinary STEM. Low-cost kits, sensors, and mobile apps make it possible to connect chemistry experiments with physics measurements and mathematical modeling (Sharif et al., 2021). Citizen-science platforms such as iNaturalist extend biology and geography into authentic data practices, blending ICT and statistical reasoning (Herodotou et al., 2024). However, studies caution that advanced tools such as BIM-based simulations or serious games risk imposing excessive cognitive load unless scaffolded carefully. Technology use also remains uneven: while water and waste/circular projects exhibit high integration rates (~67%), energy and justice/policy projects show minimal technological application (Cole et al., 2024). This indicates a design gap where accessible technologies could be deployed to strengthen underrepresented interdisciplinary areas.

Outcomes of Interdisciplinary STEM

Syntheses across four outcome domains—cognitive, affective, skills, and agency—show consistent positive effects when STEM is implemented in interdisciplinary forms (Maass et al., 2022). Table 1 summarises the dominant approaches, subjects integrated, and strongest outcomes reported across representative studies.

Table 1. Summary of Interdisciplinary STEM Approaches and Outcomes

Approach	Subjects Integrated	Strongest Outcomes	Representative Studies
Project-Based Learning	Physics, Chemistry, Biology, Math, ICT	Broad gains: cognition, affect, skills, agency	Dung et al., 2023
Inquiry-Based Learning	Science, Math, ICT	Cognitive literacy, critical thinking	Holley & Park, 2020

Engineering Design	Physics, Chemistry, Math	Problem-solving, design skills	Jefferson et al., 2020; Wang et al., 2025
Modeling & Systems Thinking	Biology, Chemistry, Math, ICT	Systems reasoning, explanation coherence	Sezen-Barrie et al., 2023; Cuong et al., 2025
Socioscientific Issues	Natural sciences + civic reasoning	Agency, values, literacy	Zhu & He, 2022

Challenges in Implementing Interdisciplinary STEM

Despite promising outcomes, recurring barriers limit widespread adoption: curriculum alignment, teacher preparation, assessment gaps, and equity issues. Table 3 (in the Discussion) synthesises common challenges and corresponding remedies with supporting studies.

Synthesis

The literature demonstrates that STEM fosters interdisciplinary connections most effectively through authentic, problem-based contexts supported by project work, inquiry, modeling, and engineering design. Technology integration amplifies these effects but requires careful scaffolding. The gaps in energy literacy, justice-oriented education, and underrepresentation of certain regions (including Central Asia) suggest directions for future work. This review thus establishes a clear rationale for exploring how Kazakhstan can adopt and adapt STEM methodologies to strengthen interdisciplinary teaching in natural sciences.

Materials and methods.

Research Design

This article employed a systematic review methodology to synthesize recent international evidence on the role of STEM education in fostering interdisciplinary connections across natural science subjects. Following the PRISMA 2020 framework, the review identified, screened, and coded peer-reviewed publications between January 2019 and April 2025. The design is qualitative-interpretive, with quantitative mapping of trends (e.g., topics, approaches, outcomes).

Databases and Search Strategy

Three major databases were used: Scopus, Web of Science Core Collection, and SpringerLink. Searches were conducted with Boolean operators and keyword blocks. The full search string blocks are summarised in Table 2.

Table 2. Search Strategy and Keywords

Keyword Block	Search Terms
Integration	"integrated STEM" OR "STEM education" OR "STEAM" OR "engineering design" OR modeling OR "inquiry-based learning" OR "project-based learning"
Sustainability / ESD	sustainab* OR ESD OR "climate change" OR energy OR water OR biodivers* OR circular OR "waste" OR hazard* OR "built environment" OR justice OR policy*
Education Context	school OR K–12 OR "secondary education" OR "high school" OR "middle school" OR teacher OR "pre-service" OR undergraduate*

Inclusion and Exclusion Criteria

To ensure relevance, the following criteria were applied:

• Inclusion: (i) studies focused on STEM education at school or early undergraduate level; (ii) explicit reference to interdisciplinary teaching or sustainability/ESD contexts; (iii) reported empirical data (quantitative, qualitative, or mixed); (iv) published in 2019–2025.

• Exclusion: (i) higher-education studies focused solely on advanced disciplinary training; (ii) commentaries, opinion pieces, or purely conceptual papers without implementation guidance; (iii) non-English publications.

Screening Process

Searches yielded 232 records. After removing duplicates (n = 34), 198 records remained. Title/abstract screening excluded 56 articles for lacking ESD or interdisciplinary focus. Full-text screening excluded 93 additional studies for methodological or contextual reasons. The final dataset included 49 studies, of which 42 were empirical interventions and 7 were conceptual/methodological. The PRISMA-style flow of study selection is depicted in Figure 2.

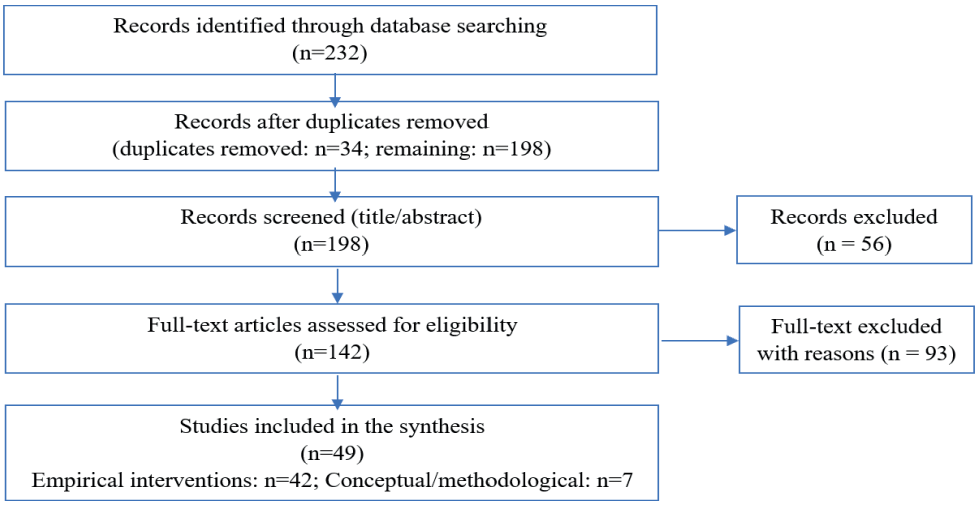

Figure 2 - PRISMA-Style Flow Diagram of Study Selection

Data Extraction and Coding

A structured codebook was developed, piloted on 10% of the sample, and refined iteratively. Extracted variables included: bibliographic information; subject anchors; STEM approaches; sustainability topics; technology use; education level; outcomes; and presence/absence of teacher professional development. Coding was performed manually by two reviewers with cross-checking to ensure reliability.

Data Analysis

Analysis combined descriptive statistics (frequency counts, distributions) and qualitative synthesis. Trends were visualised in figures (e.g., thematic distribution in Figure 1), and a challenge–remedy map is provided in Table 3.

Reliability and Validity

To enhance reliability, dual coding and consensus discussions were used. Validity was strengthened by triangulating data across multiple databases and by aligning coding with established frameworks (e.g., PRISMA 2020, ESD competencies).

Results and discussion

Interdisciplinary STEM as a Driver of Holistic Learning

The synthesis of 49 studies demonstrates that STEM education is most impactful when designed to foster interdisciplinary connections across natural science subjects (see Table 1). Evidence consistently indicates that approaches such as PjBL, IBL, engineering design, and modeling provide opportunities for students to integrate knowledge from physics, chemistry, biology, and mathematics in authentic contexts (Sezen-Barrie et al., 2023). For instance, water-quality monitoring projects link biology (ecosystems), chemistry (pollutants), physics (sensors), and mathematics (data analysis), thereby giving students a systems-level perspective. Renewable-energy tasks similarly converge physics, engineering, and mathematics while promoting sustainable thinking (Hakim et al., 2023; Wang et al., 2025).

Theoretical Implications

Three theoretical perspectives are reinforced by the evidence: (1) Constructivism—students actively build knowledge through meaningful, cross-disciplinary tasks (Holley & Park, 2020); (2) Systems Thinking—modeling activities underscore the interconnectedness of socio-ecological systems (Sezen-Barrie et al., 2023); and (3) Socioscientific Reasoning—engagement with issues such as climate policy or biofuel use links scientific literacy with civic and ethical reasoning (Zhu & He, 2022).

Practical Implications for Schools

From a practical standpoint, the review identifies several design principles that schools can adopt: embed real-world contexts; use scaffolds for complex tasks and simulations; integrate technology strategically; and diversify assessment to capture interdisciplinary competencies (see Table 1 for approaches and Table 3 for implementation remedies).

Challenges and Remedies

Recurring challenges and evidence-based remedies are synthesised in Table 3.

Table 3. Challenges and Remedies in Interdisciplinary STEM

Challenge	Remedy / Strategy	Supporting Studies
Curriculum alignment	Co-produce locally relevant units with explicit links to standards	Restaino et al., 2024
Teacher preparation	Provide professional development with video reflection and interdisciplinary co-teaching	Maass et al., 2022
Assessment misalignment	Develop rubrics for evaluating models, designs, and arguments	Sezen-Barrie et al., 2023
Technology and cognitive load	Introduce low-cost kits first; scaffold complex simulations with stepwise examples	Sharif et al., 2021
Equity and access barriers	Provide transport, multilingual materials, and budget support for disadvantaged schools	Herodotou et al., 2024
Short intervention duration	Extend to multi-week or semester-long projects	Park & Kim, 2020

Implications for Kazakhstan

For Kazakhstan, the findings offer several context-specific implications. The Жаңартылған білім мазмұны curriculum encourages competencies and cross-subject integration, yet implementation often remains surface-level. Interdisciplinary STEM provides a concrete framework for operationalising these goals. Policy and practice priorities include: embedding interdisciplinary projects aligned with national issues (e.g., Aral Sea restoration; renewable energy in steppe regions; biodiversity in national parks); PD focused on co-teaching and interdisciplinary design (piloted in NIS and scaled to rural schools); targeted equity supports via low-cost kits and mobile technologies; and infrastructure alignment through Digital Kazakhstan initiatives.

Contribution to Research and Policy

This discussion advances three contributions: (i) for research, it consolidates fragmented evidence into a design-ready framework and highlights underexplored domains (energy literacy; justice education); (ii) for practice, it provides actionable remedies, emphasising technology scaffolding and assessment redesign; and (iii) for policy, it aligns global evidence with Kazakhstan's education reforms.

Limitations and Future Directions

The evidence base is uneven across regions, with few studies from Central Asia, Africa, and Latin America. Instruments for measuring agency and long-term outcomes are limited. Future research should conduct longitudinal studies of student agency and transfer; expand to underrepresented geographies; develop validated assessment tools for interdisciplinary competencies; and investigate cost-effectiveness of technology integration in low-resource contexts.

Conclusion. This article examined the role of STEM education in fostering interdisciplinary connections in the teaching of natural science subjects at school. Drawing on a systematic review of studies published between 2019 and 2025, as well as contextual insights from Kazakhstan's education system, the study demonstrated that STEM technologies and pedagogies can transform fragmented subject instruction into coherent, problem-centred learning experiences.

Key Findings. First, STEM is inherently interdisciplinary when implemented through project-based learning (PjBL), inquiry-based learning (IBL), modeling, engineering design, and socioscientific issue (SSI) reasoning (Table 1). These pedagogies consistently lead to stronger conceptual understanding, systems thinking, and problem-solving skills, while also fostering student motivation and civic agency. Second, technology is a critical enabler of interdisciplinarity; however, adoption is uneven across themes, suggesting opportunities for targeted design. Third, recurring challenges—curriculum alignment, teacher preparation, assessment, equity, and cognitive load—can be addressed via co-produced units, structured PD with reflection, rubric-based assessments, stepwise technology scaffolds, and equity-oriented supports (Table 3).

Implications for Kazakhstan. Embedding authentic projects related to national priorities—such as renewable energy, Aral Sea restoration, biodiversity protection, and digital transformation—can enhance both disciplinary learning and real-world

problem-solving. Teacher preparation is the most pressing lever, complemented by equitable access to low-cost technologies and alignment with Digital Kazakhstan.

Contribution to Knowledge. The study (i) synthesises global evidence under constructivist, systems-thinking, and socioscientific reasoning lenses; (ii) offers design-ready recommendations for schools and teachers; and (iii) provides a policy-relevant roadmap for aligning curriculum, teacher development, and technology integration.

Final Reflection. STEM is not just a content framework but a unifying methodology for interdisciplinary education in natural sciences. Its successful implementation requires deliberate design, systemic support, and contextual adaptation, but its potential to empower students as knowledgeable, skilled, and active citizens is unparalleled.

References

Azevedo H., Soares-Silva I., Fonseca F., Alves P., Silva D., & Azevedo M.M. (2022) Impact of educational gardens and workshop activities on 8th-grade student's perception and knowledge of plant biology. Education Sciences, 12(9). — P. 619. DOI: *https://doi.org/10.3390/educsci12090619* (in Eng.).

Besalti M., & Smith G.G. (2024) High school students' motivation to learn climate change science through educational computer games. Simulation & Gaming, 55(3). — P. 527-551. DOI: https://doi.org/10.1177/10468781241235754 (in Eng.).

Celestino T. (2023) High school sustainable and green chemistry: Historical–epistemological and pedagogical considerations. Sustainable Chemistry, 4(3). — P. 304-320. DOI: *https://doi.org/10.3390/suschem4030022* (in Eng.).

Cole L.B., Priscilla L., Zangori L., Kania-Gosche B., & Burken J. (2024) Raising the Green Roof: Enhancing Youth Water Literacy through Built Environment Education. Sustainability, 16(10). — P. 4262. DOI: https://doi.org/10.3390/su16104262 (in Eng.).

Cuong T.V., Dung N.V.V., Tinh T.T., & Hau N.H. (2025) Mathematical modelling for monitoring tree growth in school green initiatives in vietnam. International Journal of Ecosystems & Ecology Sciences, 15(2). — P. 203-208. DOI: https://doi.org/10.31407/ijees15.226 (in Eng.).

Dung T.M., Nga N.T., & Thanh L.T. (2023) Interdisciplinary Education in the Context of Protection of Water Resources: A Case Study in Vietnam. Journal of Education and E-Learning Research, 10(3). — P. 569-577. DOI: https://doi.org/10.20448/jeelr.v10i3.4986 (in Eng.).

Gandolfi H.E. (2024) (Re) considering nature of science education in the face of socio-scientific challenges and injustices: insights from a critical-decolonial perspective. Science & Education. — P. 1-27. DOI: https://doi.org/10.1007/s11191-024-00536-w (in Eng.).

Hakim A., Efwinda S., Damayanti P., Syam M., Mutmainah O., & Norsaputra A. (2023) Improving climate literacy of high school students through physics teaching materials based on STEM. Jurnal Pendidikan IPA Indonesia, 12(4). — P. 526-537. DOI: *https://doi.org/10.15294/jpii.v12i4.43188* (in Eng.).

Herodotou C., Ismail N., I. Benavides Lahnstein A., Aristeidou M., Young A.N., Johnson R.F., ... & Ballard H.L. (2024) Young people in iNaturalist: a blended learning framework for biodiversity monitoring. International Journal of Science Education, Part B, 14(2). — P. 129-156. DOI: https://doi.org/10.1080/21548455.2023.2217472 (in Eng.).

Holley D., & Park S. (2020) Integration of Science Disciplinary Core Ideas and Environmental Themes through Constructivist Teaching Practices. EURASIA Journal of Mathematics, Science and Technology Education, 16(5). DOI: https://doi.org/10.29333/ejmste/115583 (in Eng.).

Izzah S.N., & Wardani S. (2023) Analysis of Science Concept Mastery, Creative Thinking Skills, and Environmental Attitudes After Ethno-STEM Learning Implementation. International Journal of Instruction, 16(3). DOI: https://doi.org/10.29333/iji.2023.16342a (in Eng.).

Jefferson M.T., Rutter C., Fraine K., Borges G.V., de Souza Santos G.M., Schoene F.A., &

Hurst G.A. (2020) Valorization of sour milk to form bioplastics: Friend or foe?. Journal of chemical education, 97(4). — P. 1073-1076. DOI: https://doi.org/10.1021/acs.jchemed.9b00754 (in Eng.).

Maass K., Sorge S., Romero-Ariza M., Hesse A., & Straser O. (2022) Promoting active citizenship in mathematics and science teaching. International journal of science and mathematics education, 20(4), P. 727-746. DOI: https://doi.org/10.1007/s10763-021-10182-1(in Eng.).

Park W.Y., & Kim C.J. (2020) The impact of project activities on the cultivation of ecological citizenship in a high school climate change club. Asia-Pacific Science Education, 6(1), P. 41-69. DOI: https://doi.org/10.1163/23641177-BJA00005 (in Eng.).

Restaino,C., Eusden S., & Kay M. (2024) Taking the next step in wildfire education: integrating multiple knowledge forms into co-produced high school fire science curricula. Fire Ecology, 20(1), P. 62. DOI: https://doi.org/10.1186/s42408-024-00296-6 (in Eng.).

Sezen-Barrie A., Stapleton M.K., Marbach-Ad G., & Miller-Rushing A. (2023) Epistemic Discourses and Conceptual Coherence in Students' Explanatory Models: The Case of Ocean Acidification and Its Impacts on Oysters. Education Sciences, 13(5). — P. 496. DOI: https://doi.org/10.3390/educsci13050496 (in Eng.).

Spencer J. L., Maxwell D.N., Erickson K.R.S., Wall D., Nicholas-Figueroa L., Pratt K.A., & Shultz G.V. (2021) Cultural relevance in chemistry education: Snow chemistry and the Iñupiaq community. Journal of chemical education, 99(1). — P. 363-372. DOI: *https://doi.org/10.1021/acs.jchemed.1c00480* (in Eng.).

Wang H.H., Knobloch N.A., Nelson B.J., & Thies S.L. (2025) Exploring a Co-Teaching Model to Teach Energy and Food Systems in STEM Integration Through the Lens of Pedagogical Content Knowledge. Education Sciences, 15(3). — P. 318. DOI: https://doi.org/10.3390/educsci15030318 (in Eng.).

Zhu Y., & He A. (2022) The effects of a collaborative argumentation intervention on Chinese students' socioscientific issues decision-making. The Journal of educaTional research, 115(6). — P. 317-332. DOI: https://doi.org/10.1080/00220671.2022.2150996 in Eng.).

Publication Ethics and Publication Malpractice in the journals of the Central Asian Academic Research Center LLP

For information on Ethics in publishing and Ethical guidelines for journal publication see http://www.elsevier.com/publishingethics and http://www.elsevier.com/journal-authors/ethics.

Submission of an article to the journals of the Central Asian Academic Research CenterLLP implies that the described work has not been published previously (except in the form of an abstract or as part of a published lecture or academic thesis or as an electronic preprint, see http://www.elsevier. com/postingpolicy), that it is not under consideration for publication elsewhere, that its publication is approved by all authors and tacitly or explicitly by the responsible authorities where the work was carried out, and that, if accepted, it will not be published elsewhere in the same form, in English or in any other language, including electronically without the written consent of the copyright-holder. In particular, translations into English of papers already published in another language are not accepted.

No other forms of scientific misconduct are allowed, such as plagiarism, falsification, fraudulent data, incorrect interpretation of other works, incorrect citations, etc. The Central Asian Academic Research Center LLP follows the Code of Conduct of the Committee on Publication Ethics (COPE), and follows the COPE Flowcharts for Resolving Cases of Suspected Misconduct (http:// publicationethics. org/files/ u2/New_Code.pdf). To verify originality, your article may be checked by the Cross Check originality detection service http://www.elsevier.com/editors/plagdetect.

The authors are obliged to participate in peer review process and be ready to provide corrections, clarifications, retractions and apologies when needed. All authors of a paper should have significantly contributed to the research.

The reviewers should provide objective judgments and should point out relevant published works which are not yet cited. Reviewed articles should be treated confidentially. The reviewers will be chosen in such a way that there is no conflict of interests with respect to the research, the authors and/ or the research funders.

The editors have complete responsibility and authority to reject or accept a paper, and they will only accept a paper when reasonably certain. They will preserve anonymity of reviewers and promote publication of corrections, clarifications, retractions and apologies when needed. The acceptance of a paper automatically implies the copyright transfer to the Central Asian Academic Research Center LLP.

The Editorial Board of the Central Asian Academic Research Center LLP will monitor and safeguard publishing ethics.

Правила оформления статьи для публикации в журнале смотреть на сайте:

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

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

Подписано в печать 31.10.2025.
Формат 60x881/8. Бумага офсетная. Печать - ризограф.
46,0 п.л. Тираж 300. Заказ 5.

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