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Integrating science education in Kazakhstan: Teacher preparedness and the development of 21st -century skills

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Abstract

This study investigates the implementation of interdisciplinary science education in Kazakhstan, focusing on teacher and student teacher preparedness, challenges, and the development of 21st-century skills such as critical thinking, creativity, and problem-solving. Kazakhstan has made progress in STEM education, particularly in robotics, coding, and designing interdisciplinary courses. However, the transition from STEM to STEAM, which incorporates arts and humanities, faces significant challenges. This research draws from surveys conducted with student teachers and in-service teachers, identifying gaps in familiarity with STEM principles, limited interdisciplinary teaching, and resource constraints. Findings highlight the need for structured teacher training programs, targeted course resources, and robust support systems to overcome these barriers. This study offers valuable insights for designing and implementing interdisciplinary science teacher education and professional development courses, aligning Kazakhstan's education system more closely with global STEAM standards. Additionally, this work contributes to the global discourse on STEAM education, providing recommendations for strengthening teacher education and interdisciplinary learning.

Keywords: 21st century skills, Creativity, Critical thinking, Curriculum development, Educational reform, Interdisciplinary learning, Kazakhstan, Problem-solving, STEAM education, Teacher preparedness.

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1. Introduction

The rapid pace of technological advancement is a defining feature of modern society, transforming societies, economies, industries, and, consequently, educational demands. As scientific and technological innovations reshape the needs of the workforce, nations that prioritize technological education and skill development enhance their competitiveness in the global economy. STEM education, encompassing science, technology, engineering, and mathematics, has become central to preparing students across all grade levels for evolving industries [1]. At the same time, tackling complex or "wicked" challenges related to sustainability and environmental issues has become increasingly difficult due to the separation of scientific and practical knowledge [2]. Trans- and interdisciplinary education, which integrates all or any other school subjects, including the arts, humanities, and social sciences into STEM to form STEAM education, represents an effort to address these complex challenges and foster essential 21st-century skills, such as problem-solving, creativity, and critical thinking [3]. Integrated science education is recognized as a key driver for addressing challenges in an ever-changing world and promoting economic growth [4].

Kazakhstan, like many other nations, has recognized the strategic importance of STEM and STEAM education and has been actively working to reform its educational system to align with global standards. The country has made significant strides toward integrating STEAM into its curriculum, aiming to prepare students with the skills required for future job markets and a complex, ever-changing world. However, Kazakhstan faces notable challenges in implementing effective STEAM education, including teacher preparedness, curriculum support, and resource limitations [5]. Many educators report feeling unprepared to teach content through an interdisciplinary approach, and the lack of clear curriculum guidance has complicated integration efforts. Resource limitations, such as inadequate materials and technological infrastructure, further hinder teachers' ability to fully adopt and apply the STEAM approach. Addressing these issues is crucial to achieving Kazakhstan's goal of fostering an education system that equips students with the critical skills needed for a technology-driven global economy and complex real-world challenges.

The development of STEM education in Kazakhstan since 2014 has provided a strong foundation for exploring the preparedness and challenges faced by student teachers and educators in implementing integrated learning [6]. Early initiatives, such as the "Knowledge of the World" and "Natural Science" courses, along with project-based learning and private organizations promoting STEM, have established a foundation for formal STEM education. The 2016–2019 State Program for Education and Science further advanced these efforts with STEM-focused curricula. Since then, STEM education in Kazakhstan has rapidly expanded, introducing elective courses in robotics, establishing robotics laboratories, and promoting robotics clubs. By 2023, 2,500 schools offered robotics courses, 1,100 schools had robotics labs, and over 32,000 students participated in robotics clubs across 1,626 schools. Additionally, 757 new STEM classrooms were opened in 2023. This development is summarized in Figure 1.

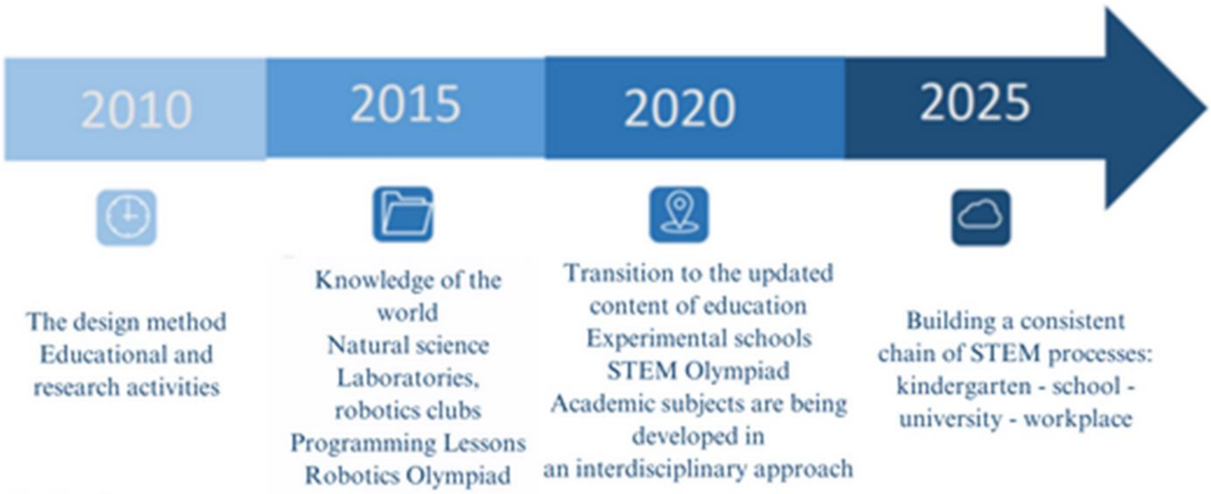

Figure 1.
The development of STEM education in Kazakhstan illustrates key milestones, from the early introduction of foundational STEM courses and activities in 2010 to the integration of interdisciplinary approaches in 2020, and the establishment of a consistent STEM pipeline from kindergarten through higher education projected for 2025.

In alignment with these developments, the Kazakh government has embedded 21st-century skills in the State Standards for secondary education, highlighting essential competencies such as critical thinking, problem-solving, functional literacy, ICT skills, and both individual and collaborative work skills. These skills, as shown in Figure 2, are designed to align with global educational goals, preparing students for a rapidly changing world and meeting employer expectations. To support these reforms, the government provides teacher retraining and advanced programs, alongside specialized STEM degrees at institutions like Nazarbayev University and Al-Farabi Kazakh National University. Gonzalez and Kuenzi [7] indicate that STEM-related learning is gaining traction in Kazakhstan [7], with 85,095 students enrolling in STEM courses between April 2022 and March 2023, 40% of whom were women.

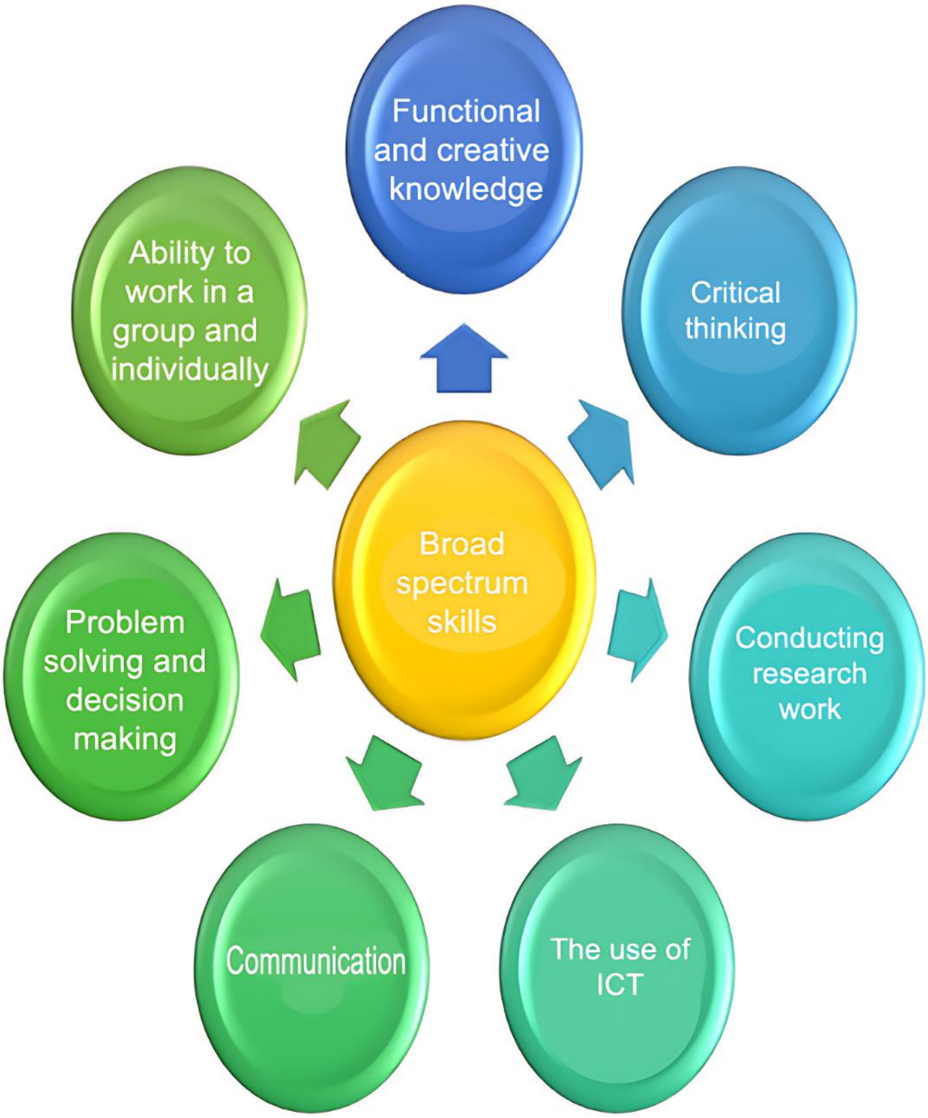

Figure 2.
Comprehensive range of 21st-century skills in Kazakhstan's State Standards for secondary education.

In recent years, the "Modernization of Teacher Education" project, implemented from September 2021 to May 2024 by the World Bank and the Ministry of Science and Higher Education in collaboration with Häme University of Applied Sciences (Finland), Nazarbayev University (Kazakhstan), and Jyväskylä University of Applied Sciences (Finland), has further strengthened teacher education in Kazakhstan. This project developed 30 higher and postgraduate pedagogical programs, underscoring the importance of a research-based approach in high-quality teacher training [8]. In Finland, for example, research-based teaching is central to higher education, fostering competence-based learning outcomes and applying research and active learning methods in educational processes.

The enhanced model of teacher education emerging from this project includes the "STEAM and CLIL initiative," where CLIL stands for Content and Language Integrated Learning. In this context, the "A" in STEAM may represent the English language as part of the humanities, aligning it with the broader concept of Arts in STEAM. Through this initiative, 100 teachers from various universities in Kazakhstan were trained to integrate English language learning into STEM education.

This study builds upon these developments, drawing on insights from the "Modernization of Teacher Education" project and the "STEAM and CLIL" initiative to design an elective course, "Physics in STEM," for the Physics student teacher education program. The purpose of this study is to explore the perspectives of both pre-service student teachers and practicing teachers on integrated science education in Kazakhstan, with a focus on their experiences, ideas, and challenges in implementing integrated learning. Specifically, this research aims to address the following research questions:

1. What is the level of familiarity and self-assessed competency of student teachers in 21st-century skills, such as interdisciplinarity, practical problem solving, creativity, and critical thinking, within the context of STEAM education?

2. How do school and university teachers perceive and implement STEM education, situational tasks, and interdisciplinary connections in their teaching, and what challenges do they face in integrating these elements into STEM/STEAM education?

These questions aim to provide a nuanced understanding of the current state of integrated science education in Kazakhstan, identifying ways to strengthen teacher education programs in developing interdisciplinary competencies and ensuring effective classroom implementation. The insights into the development of STEAM-related competencies in teacher education provide recommendations to support Kazakhstan's educational reform and align it with global STEAM education standards.

2. Literature Review

This study's theoretical framework is grounded in the development of three essential skills within STEAM education: critical thinking, creativity, and problem-solving. These skills collectively enable students to navigate complex, real-world, and working life challenges, making them indispensable for success in STEAM and other fields in a rapidly changing world.

Critical thinking is a foundational skill that enables individuals to challenge assumptions, analyze information, evaluate evidence, and form logical conclusions. According to Facione [5] critical thinking involves a persistent focus on achieving detailed and precise results. Observation and strict attention to details allow individuals to gather and interpret relevant information accurately. Ennis [4] emphasizes the importance of engaging students in processes that transform gained information into deep understanding by connecting it to their prior knowledge and experiences. Through critical thinking, students interpret, compare, analyze, and consider the significance of various points, which helps them break down complex problems and make informed decisions [9].

Logical reasoning allows individuals to structure their thoughts coherently, leading to sound conclusions. Halpern [8] suggests that critical-thinking skills should be taught with a focus on the structure of problems or arguments, emphasizing the core elements of reasoning rather than content-specific details themselves. Students need practice that is spaced over time, using diverse examples and corrective feedback, to build the habit of spontaneously noticing relevant aspects. Instruction should be designed to help students retrieve these skills independently of any specific content area Alpyssov et al. [10].

Paul and Elder [11] argue that generalization and evidence evaluation are key to applying knowledge across diverse contexts. A critical thinker identifies problems, gathers and assesses relevant information, uses abstract concepts to interpret it effectively, and reaches well-reasoned conclusions, testing them against established criteria and standards. Effective critical thinkers also communicate clearly and collaborate with experts from other disciplines to solve complex problems.

In the context of STEAM education, critical thinking empowers students to systematically assess scientific and technological issues, preparing them to make well-reasoned decisions in both educational and professional settings [12].

Students' familiarity with creativity as a feature of STEAM training underscores its perceived importance and the emphasis on adaptability, originality, and collaborative problem-solving within their educational experiences. Amabile [1] defines creativity as "the production of novel and useful ideas in any domain," highlighting that it is not limited to traditionally artistic subjects. In STEAM education, this broad view of creativity is particularly significant, as it encourages students to find innovative solutions to complex, "wicked" real-world problems.McLaughlin et al. [13].

Torrance [14] identifies originality the ability to generate unique ideas as a core component of creativity, which drives students to explore fresh perspectives and develop unconventional approaches to complex challenges. This trait encourages students to view problems from new angles rather than relying solely on established solutions. Flexibility, as described by Runco and Jaeger [15] enhances this to adaptability, allowing individuals to shift between different ideas and perspectives, which is a crucial skill also in interdisciplinary approaches to learning.

According to Csikszentmihalyi [2] "flow" is a state in which people are so absorbed in an activity that nothing else seems to matter; the experience itself is so enjoyable that people engage in it for its own sake. In this flow state, individuals achieve high productivity and deep engagement, fully immersing themselves in creative tasks and enhancing the quality of their problem-solving efforts.

Mumford et al. [16] argue that effective problem-solving frequently requires a blend of analytical thinking and the creative generation of novel solutions. This balance is essential in interdisciplinary learning, where students benefit from both structured analysis and the freedom to experiment with innovative ideas. Within STEAM education, fostering creativity encourages students to explore and elaborate on diverse solutions to scientific and technological problems. Diverse subjects in STEAM education promote multiple representations and transformations between them, aligning with the Lesh transformation principle [17]. Engaging students in this approach fosters adaptability and resilience, as they learn to shift perspectives and apply knowledge flexibly across varied contexts, which is essential for deep conceptual understanding and demonstrating that understanding.

Problem-solving is an integrative skill that draws on both critical thinking and creativity, enabling students to identify issues, evaluate possible solutions, and implement effective strategies. Jonassen [9] suggests that problem-solving is inherently linked to real-world applications, particularly within STEAM, where students often tackle complex open challenges that lack straightforward answers. Mayer [18] emphasizes that successful problem-solving requires both content knowledge and cognitive strategies, allowing students to apply theoretical concepts in practical situations. In the problem-solving process within STEAM education, the diverse domains of knowledge work together to support each phase: information is gathered through scientific methods, experimental setups and concrete models are designed in engineering, results are elaborated through multiple representations, applied in technology, and analytically and critically evaluated through mathematical methods [19]. This integrated approach enhances students' ability to address complex problems effectively and holistically, enabling them to consider all aspects of a problem and apply interdisciplinary skills in a cohesive manner.

The theoretical framework outlined here forms the basis of this study, which aims to explore how STEAM education in Kazakhstan can better promote critical thinking, creativity, and problem-solving skills, aligning with international educational standards. By examining the perspectives of both student teachers and practicing teachers, this research seeks to identify strengths and gaps in Kazakhstan's current approach to integrated education, particularly within teacher training programs. The insights gained are intended to inform the development of more effective teacher training courses and activities, ensuring that Kazakhstani teachers are equipped not only with STEAM knowledge but also with the pedagogical skills necessary to foster critical thinking, creativity, and problem-solving in their students.

3. Materials and Methods

To ensure validity in the survey design, a group of experts carefully developed two structured surveys. The first survey assessed student teachers' awareness, experiences, and competencies in STEAM education. The second survey focused on teachers' experiences and perceptions related to the integration of STEM subjects in teaching, with an emphasis on physics education. The differentiation between STEM and STEAM surveys for teachers and students was purposefully made to account for the distinct roles, expectations, and educational contexts of each group, thereby enhancing the relevance and accuracy of the data collected. For students, the focus on STEAM emphasizes a holistic approach, including the integration of arts and humanities to foster creativity, critical thinking, and problem-solving skills. Assessing students' awareness, experiences, and skills in STEAM helps identify how interdisciplinary learning impacts their development across multiple dimensions. For teachers, however, the survey focuses on STEM to examine their experiences and perceptions regarding the integration of core science, technology, engineering, and mathematics subjects in teaching. This narrower focus acknowledges that teachers are often expected to develop foundational STEM skills in students before integrating broader interdisciplinary approaches. Additionally, it highlights potential areas where teachers may need support in mastering core STEM content and pedagogical approaches, particularly in subjects like physics, which are crucial for a STEM foundation and later STEAM integration.

The survey for students comprised 15 questions, designed to gather both demographic data and insights into students' educational experiences. The demographic questions (e.g., university, year of study, gender, and age) helped contextualize the responses. The core of the student survey focused on the following areas:

1. Familiarity with STEM Education. These questions assessed students' knowledge of selected STEM principles, such as interdisciplinarity, practice orientation, creativity, critical thinking, and project-based learning.

2. Skills Assessment. Respondents were asked to evaluate their own critical and creative thinking skills, with multiple-choice options.

3. Problem-Solving and Project Experience. Additional questions explored students' experience in solving situational, interdisciplinary, and complex problems during their studies. The survey also inquired about the frequency of participation in projects and their readiness to lead project activities for schoolchildren.

The survey targeted both school teachers and educators from pedagogical universities, aiming to assess their use of the STEM approach, the challenges they face, and the benefits they perceive from its implementation. The survey included a mix of multiple-choice and open-ended questions, structured around the following key themes:

1. Use of STEM approach in Teaching

Teachers were asked whether they actively use the STEM approach in their physics classes, with response options ranging from non-use to occasional or full integration.

2. Perceived Benefits of STEM education

Participants were prompted to identify three main reasons for the appeal of STEM education, including aspects such as interdisciplinarity, real-life application of scientific knowledge, development of critical thinking skills, and fostering creativity and teamwork.

3. Challenges in STEM Implementation

The survey also asked teachers to reflect on the specific challenges they encounter when integrating STEM into their teaching practices. Respondents could choose from predefined options or provide their own answers in an open text format.

4. Support Needs and Didactic Material Development

Additional questions focus on the need for methodological assistance when implementing STEM, as well as on which aspects of symbolic representation in didactic materials for physics require further refinement.

The survey for students was distributed online to 3rd year science student teachers in three universities: Atyrau University named after [20].Caspian University of Technology and Engineering, and Kairat and Utemisov [21] West Kazakhstan University. Participation was voluntary, and respondents were assured of the confidentiality of their answers. The aim was to gather comprehensive data on students' STEM-related educational experiences and competencies. The survey for teachers was distributed online to a convenience sample of school teachers from the western region of Kazakhstan and educators from pedagogical universities. Also, this participation was voluntary, and all responses were anonymized to ensure confidentiality.

4. Results and Discussion

The student survey was answered by 71 students, including 37 females and 34 males, all at the third-year stage of teacher education. The teacher survey was completed by 120 secondary school physics teachers and 18 university teachers. The collected data provided valuable insights into the current state of STEAM integration in science education and informed the subsequent analysis of teachers' support needs and best practices.

The responses of student teachers to questions about selected STEAM features related to 21st-century skills are presented in Table 1. A majority (57%) indicated familiarity with the interdisciplinary nature of STEAM, reflecting a relatively strong understanding of this concept, though 21% remained unfamiliar, suggesting further potential for integrating interdisciplinary approaches in their training. Familiarity with both practice-oriented and project-based learning showed moderate levels: 44% of student teachers reported familiarity with practice-oriented learning (with 37% somewhat familiar and 19% unfamiliar), while 48% indicated familiarity with project-based learning (41% somewhat familiar). These findings suggest that many student teachers recognize the importance of both practical orientation and project-based methods in STEAM, though these approaches may benefit from greater emphasis in teacher training programs.

Familiarity with creativity as a skill targeted in the context of STEAM was lower, with only 16% feeling knowledgeable about it. Nearly half (49%) were somewhat familiar, and 35% were unfamiliar. This gap indicates a need for increased emphasis on creative thinking and its role in addressing complex STEAM-related challenges. Critical thinking exhibits the highest rate of unfamiliarity, with over half (52%) of respondents feeling unfamiliar. Only 12% felt they fully understood critical thinking within a STEAM context. This highlights an area for development, as analytical and critical thinking are foundational 21st-century skills essential for effective problem-solving and decision-making.

Table 1.
Student teachers' responses regarding their awareness of 21st-century skills-related features of STEM learning.

Feature	**Counts n=71 (%)**		
	Unfamiliar	**Somewhat familiar**	**Known**
Interdisciplinarity	15 (21)	16 (22)	40 (57)
Practice orientation	13 (19)	26 (37)	32 (44)
Creativity	25 (35)	35 (49)	11 (16)
Critical thinking	37 (52)	25 (36)	9 (12)
Project oriented	8 (11)	29 (41)	34 (48)

Table 2 displays the frequency and percentage of respondents who identified each critical and creative thinking skill as their primary self-assessed competency within STEAM education. In the survey, respondents were asked to select the one skill in each category, critical thinking and creative thinking, that they felt was their strongest competency.

Table 2.
Student teachers identify their primary self-assessed competency in critical thinking and creative skills within the context of STEAM education.

Skill Type	**Option**	**Counts n = 71**	**(%)**
Critical Thinking Skills	Strong observational skills and attention to detail	30	43
	Ability to interpret, analyze, and compare information	9	11
	Capacity to generalize, evaluate, and form sound conclusions	16	23
	Logical reasoning and structured thinking	11	16
	Intellectual curiosity and a broad perspective	5	7
Creative Skills	Flexibility in adapting to new ideas and approaches	16	22
	High productivity and efficient execution of creative tasks	17	24
	Originality in generating unique and innovative ideas	11	16
	Strong ability to solve complex problems creatively	21	30
	Consistently creative mindset and approach to challenges	6	8

Nearly half of the respondents (43%) selected strong observational skills and attention to detail. This was the most commonly chosen critical thinking attribute. This result suggests that attention to detail is perceived as a key strength among respondents, particularly relevant in STEAM fields where accuracy is foundational. About a quarter of respondents (23%) identified the capacity to generalize, evaluate, and form sound conclusions as their primary skill, indicating a notable confidence in synthesizing and reasoning with information—essential for applying scientific knowledge effectively. The skill of logical reasoning and structured thinking was selected by 16% of respondents, reflecting moderate confidence in logical structuring of thought processes. Structured thinking is essential in STEAM fields, where systematic approaches are often required to solve complex problems. A smaller proportion (11%) chose analytical ability to interpret, analyze, and compare information, suggesting that fewer respondents see interpretation and comparison as their strongest abilities. Given the critical role of analysis in STEAM, this indicates a potential area for further skill enhancement. Intellectual curiosity and a broad perspective was chosen by only 7%. This skill was the least frequently selected, indicating that intellectual curiosity is not widely perceived as a primary strength. Developing a broader, inquisitive approach could benefit interdisciplinary understanding and innovation.

Strong ability to solve complex problems creatively was the most commonly chosen creative skill, with 30% of respondents selecting it. The emphasis on creative problem-solving suggests that respondents are inclined to approach challenges with inventive solutions, a critical skill in tackling interdisciplinary STEAM issues. Another significant amount, 24% of respondents, identified high productivity and efficient execution of creative tasks as their main strength, reflecting an ability to execute ideas effectively. This skill complements creative problem-solving, indicating that respondents can implement solutions efficiently. With 22% choosing flexibility in adapting to new ideas and approaches, respondents showed a reasonable level of confidence in adjusting to new ideas, a valuable trait in STEAM as it often involves shifting approaches based on novel information. Originality in generating unique and innovative ideas was selected by 16% of respondents, suggesting that originality, while present, is not as prominent. Innovation is essential for advancing STEAM fields, pointing to an opportunity for growth in generating unique ideas. Only 8% of respondents identified a consistently creative mindset and approach to challenges as their main skill, indicating that a consistently creative approach to problem-solving may be an area for improvement. Cultivating a creative mindset can support resilience and flexibility in complex situations.

The responses of student teachers to questions concerning their experiences with situational and project-based tasks in interdisciplinary learning processes, as well as the quality of these tasks, are presented in Table 3.

A majority of the student teachers, 53 (75%), reported that they had not encountered situational problems in the interdisciplinary learning process, while only a small portion (8%) indicated they had encountered these problems often. Interdisciplinary communication challenges were experienced more frequently, with 20 (28%) of student teachers encountering them often, while the largest group of 30 students (43%) encountered them only rarely. High-quality interdisciplinary tasks were reported as often encountered by 25 (35%) of the student teachers, though the majority, 40 student teachers (57%), indicated these tasks were only encountered rarely. Active learning in projects appeared to be less common, with 48 (67%) of the student teachers stating they encountered it rarely and only 6 (9%) saying they experienced it often.

Table 3.
Student teachers' responses to question of how often they have encountered various kinds of tasks during their studies.

Task	**Counts n=71 (%)**		
	Yes, often	**In rare cases**	**No. I haven't**
Situational problems in the interdisciplinary learning process	6 (8)	12 (17)	53 (75)
Interdisciplinary communication challenges	20 (28)	30 (43)	21 (29)
High-quality interdisciplinary tasks	25 (35)	40 (57)	6 (8)
Active learning on projects	6 (9)	48 (67)	17 (24)

Student teachers found it difficult to answer the question, 'Do you believe that problem-solving activities can develop students' research skills?' A total of 26 student teachers (37%) selected this option. Thirteen student teachers (18%) believed it was possible, 11 (16%) believed it was partially possible, and 21 (29%) believed it was not possible. Nine student teachers (13%) felt they were already able to instruct project-based activities for schoolchildren. Thirty-three (46%) did not feel ready, and 29 (41%) found it difficult to answer.

The Table 4 presents the percentage and number of school and university teachers who reported their frequency of using STEM technologies and situational tasks in teaching physics. Teachers were asked whether they use these approaches widely, in rare cases, not at all, or were uncertain ("cannot tell"). The results reveal differing levels of engagement with STEM technologies and situational tasks between school and university educators.

Table 4.
Responses of School and University Teachers on the Use of STEM Technologies and Situational Tasks in Teaching Physics.

Question	**Answer option**	**School Teachers n=120 (%)**	**University Teachers n=18 (%)**
Q1: Do you use STEM Approach in teaching physics	Yes, I use it widely	15 (12)	1 (6)
	I use it in rare cases	65 (54)	10 (56)
	Not using /unable to use	39 (33)	1 (6)
	Cannot tell	1 (1)	6 (32)
Q2: Do you use situational tasks in the learning process	Yes, I use it widely	79 (66)	10 (56)
	I use it in rare cases	38 (32)	7 (39)
	Not using /unable to use	2 (2)	1 (5)
	Cannot tell	1 (1)	0 (0)

In response to the question, "Do you use STEM approaches in teaching physics," 12% of school teachers reported that they "use it widely," while 54% indicated they "use it in rare cases." Additionally, 33% of school teachers stated they are "not using or are unable to use" STEM technologies, and 1% selected the "Cannot tell" option. Among university teachers, 6% reported "using it widely," and 56% indicated they "use it in rare cases." A further 6% reported "not using or unable to use" STEM technologies, and a notable 32% selected the "Cannot tell" option.

Table 5.
School and university teachers' main reasons for the attractiveness of the STEM approach: Frequency and percentage of school and university teachers selecting each reason as a primary factor contributing to the appeal of the STEM approach in education. Respondents could select up to three reasons why they find the STEM approach attractive.

Reason	School Teachers n = 120 (%)	University Teachers n = 18 (%)
1) Integrated learning by topic, not by subject;	54 (38)	11 (39)
2) Applied scientific and technical knowledge in real life;	28 (20)	3 (11)
3) Developing critical thinking and problem solving skills;	35 (25)	4 (14)
4) Building self-confidence;	4 (3)	0 (0)
5) Active communication and teamwork;	4 (3)	0 (0)
6) Development of interest in technical disciplines;	4 (3)	1 (4)
7) Creative and innovative approaches to projects;	4 (3)	0 (0)
8) Development of motivation for technical creativity through the activities of children, taking into account the age and individual characteristics of each child;	2 (1)	3 (11)
9) Early career guidance;	2 (1)	0 (0)
10) Preparing children for the technological discoveries of life.	1 (1)	6 (21)
Cannot tell	3 (2)	0 (0)

For the question, "Do you use situational tasks in the learning process," 66% of school teachers indicated that they "use it widely," while 32% reported "using it in rare cases." Only 2% of school teachers reported "not using/unable to use" situational tasks, and 1% selected "cannot tell." Among university teachers, 56% reported that they "use it widely," with 39% indicating they "use it in rare cases." Only 5% of university teachers stated they are "not using/unable to use" situational tasks, and none selected "cannot tell."

The Table 5 shows the preferences of school and university teachers regarding the attractiveness of STEM approach across various aspects.

Both school and university teachers highly value the integrated learning approach by topic, with 38% of school teachers and 39% of university teachers selecting this as an attractive feature of the STEM approach. A notable 20% of school teachers consider the real-life application of scientific and technical knowledge an appealing aspect, compared to 11% of university teachers. Developing critical thinking and problem-solving skills is valued by 25% of school teachers and 14% of university teachers, indicating it is an important feature for both groups, though slightly more so for school teachers.

Several reasons, including building self-confidence, active communication, teamwork, interest in technical disciplines, and creative and innovative project approaches, were selected by only a small percentage of school teachers (3% each) and almost none of the university teachers.

Some differences appear in areas such as motivation for technical creativity, which was chosen by 11% of university teachers and 1% of school teachers. Similarly, "preparing children for technological discoveries in life" was selected by 21% of university teachers, compared to just 1% of school teachers.

A small percentage of school teachers, 2%, indicated uncertainty ("cannot tell") regarding the appeal of the STEM approach, whereas no university teachers selected this option.

The data reveals a shared preference among school and university teachers for integrated learning by topic. However, university teachers show a relatively higher interest in aspects such as preparing children for future technological advancements, while school teachers prioritize skills like critical thinking and the real-life application of knowledge. These results suggest differences in how each group perceives the impact of STEM education on students’ future readiness and engagement with technology.

Table 6 shows teachers' perspectives on interdisciplinary integration, research skill development, and support needs in STEM education. The data reflect the extent to which both school and university teachers emphasize interdisciplinary connections, view problem-solving as a tool for building research skills, and identify a need for additional support in implementing STEM technologies.

Table 6.
Responses from School Teachers and University Teachers on Attention to Interdisciplinary Connections, Formation of Research Skills, and Need for Methodological Support in STEM education.

Question	Answer Option	School Teachers n = 120 (%)	University Teachers n = 18 (%)
Q5: Do you think that you focus enough attention on interdisciplinary connections when solving physics problems?	Yes, I emphasize the broad attention	93 (77)	15 (83)
	I focus insufficient attention	24 (20)	3 (17)
	I don't pay attention	2 (2)	0 (0)
	Cannot tell	1 (1)	0 (0)
Q6: Do you think that when solving problems, the research skills of the trainees are formed?	Yes	89 (74)	13 (72)
	No	5 (4)	0 (0)
	Partially	24 (20)	4 (22)
	Cannot tell	2 (2)	1 (6)
Q7: Do you need methodological help and support in implementing STEM education?	Yes	81 (67)	13 (72)
	No	8 (7)	2 (11)
	Partially	29 (24)	3 (17)
	Cannot tell	2 (2)	0 (0)

A significant majority, 93 of both school teachers (77%) and 15 university teachers (83%), indicated that they pay broad attention to interdisciplinary connections when solving physics problems, suggesting a strong awareness of the importance of integrating diverse fields in STEM education. A smaller proportion, 24 (20%) of school teachers and 3 (17%) of university teachers, reported focusing insufficient attention on interdisciplinary connections. This indicates that while most educators acknowledge its importance, a notable portion may feel either limited by curriculum constraints or in need of additional support to fully integrate interdisciplinary perspectives. Only 2 (2%) of school teachers reported not paying attention to interdisciplinary connections, and no university teachers selected this option, suggesting that almost all educators are at least aware of the relevance of interdisciplinary approaches in STEM. The "Cannot tell" option was chosen by 1 (1%) of school teachers, indicating minimal uncertainty among respondents regarding their approach.

As many as 89 (74%) of school teachers and 13 (72%) of university teachers believe that problem-solving activities contribute significantly to developing students' research skills, reflecting a shared understanding of the role of hands-on problem-solving in building essential skills for scientific inquiry. A minority, 24 (20%) of school teachers and 3 (22%) of university teachers, felt that research skills were only partially formed during problem-solving, highlighting potential limitations in current methods or resources. Only 5 (4%) of school teachers responded "No," suggesting that very few educators see problem-solving as unrelated to research skill development. No university teachers selected this option. A small number of respondents, 2 (2%) of school teachers and 1 (6%) of university teachers, were uncertain, indicating some ambiguity about how effectively problem-solving activities translate into research skills for students.

A substantial majority of 81 (67%) of school teachers and 13 (72%) of university teachers expressed a need for methodological help and support in implementing STEM education, indicating a widespread demand for resources, training, or structured guidance to enhance STEM teaching practices. A smaller percentage of respondents, 29 (24%) of school teachers and 3 (17%) of university teachers, reported a partial need for support, suggesting that some educators may already have a foundation in STEM methodology but could benefit from further assistance. Only 8 (7%) of school teachers and 2 (11%) of university teachers reported no need for support, indicating that a small minority feel adequately equipped to implement STEM technologies without additional help. Minimal uncertainty was observed, with only 2 (2%) of school teachers and no university teachers indicating "Cannot tell," showing a clear stance on the necessity of methodological support among most respondents.

The data suggest that both school and university teachers recognize the value of interdisciplinary approaches in physics and see problem-solving as a key method for developing students' research skills. However, there remains a clear need for methodological support in implementing STEM technologies, particularly among school teachers, as indicated by the high percentage seeking assistance. This points to a shared interest in fostering interdisciplinary connections and research skills but also highlights gaps in resources or training needed to fully implement effective STEM methodologies in educational settings.

The responses to the question "What problems do you experience when implementing STEM education?" reveal several key challenges teachers face when integrating STEM/STEAM into their teaching. Here is a breakdown of the main issues identified:

1. Teachers emphasize the importance of ensuring that all students develop STEM literacy, highlighting that STEM/STEAM should be accessible and beneficial for everyone. This reflects a broader challenge in making STEM concepts understandable and relevant to diverse learners, regardless of their initial skill levels or interests.

2. Multiple responses indicate that additional time is needed to work effectively with students on STEM/STEAM activities. The complexity and interdisciplinary nature of STEM projects require extended time for planning, instruction, and hands-on learning, which is often challenging within typical class schedules.

3. Teachers express difficulties in facilitating interdisciplinary projects that allow students to practice research skills. This involves coordinating students to work in teams, setting up long-term projects, and fostering systematic relationships between disciplines, which requires significant planning and resources.

4. A recurring theme is the absence of adequate equipment in classrooms, with multiple teachers reporting that they lack the tools and technology needed for effective STEM instruction. Without the right resources, it becomes challenging to create interactive and hands-on STEM experiences that support learning.

5. Teachers note a lack of standardized or unified instructional methods for teaching STEM, which can lead to inconsistencies in how STEM/STEAM concepts are taught and assessed. This lack of a cohesive approach may hinder teachers' ability to implement best practices and share successful strategies with one another.

6. There is a perceived gap in the availability of materials that are both understandable and accessible for students. Teachers suggest that existing resources may not be suited for all learning levels, which can make it difficult to teach complex STEM concepts in a way that resonates with every student.

7. Some teachers acknowledge gaps in their own knowledge of STEM education, which may affect their confidence and ability to deliver STEM lessons effectively. This suggests a need for additional professional development or training programs to ensure teachers feel well-equipped to incorporate technology into their teaching.

In summary, teachers face both logistical and resource-related challenges in implementing STEM education. Time constraints, a lack of equipment, and the absence of unified teaching methods are common obstacles, along with the need for accessible student materials and further teacher training. Addressing these issues through targeted support, resources, and training could help teachers integrate STEM/STEAM more effectively, making it more accessible and impactful for students across varying levels of literacy and interest.

5. Conclusion

The findings indicate a varied level of preparedness and familiarity among student teachers with essential STEAM competencies. While many student teachers recognize the importance of interdisciplinary learning, particularly in understanding the interconnectedness of STEAM subjects in practical problems, their familiarity with critical thinking and creativity remains limited. Specifically, a small proportion demonstrated confidence in critical thinking skills, with an emphasis on Facione [5] of observation and attention to detail rather than intellectual curiosity, logical reasoning, or analytical abilities [8]. Similarly, for creativity, student teachers highlighted strengths in task-focused problem-solving, as described by Torrance [14] but many lacked the ability to sustain a consistently creative mindset and to generate unique, innovative ideas, qualities essential for fostering creativity in STEAM education [11, 22].

Notably, situational problem-solving and project-based activities, which could effectively cultivate these competencies, were reported as rarely experienced in their studies, aligning with previous findings by Jonassen [9] and Lawrence [22] on the critical role of realistic, interdisciplinary tasks in educational programs. Despite their awareness of practical and project-oriented approaches, student teachers seldom encountered these methods in their own training, indicating a need to strengthen their integration into teacher education programs [23].

Both school and university teachers demonstrate awareness of the importance of STEM and STEAM approaches, but discrepancies exist in their use of situational tasks. School teachers reported more frequent use of situational problems in classroom practice than university teachers, a difference that may arise from curriculum constraints, resource limitations, or differing educational goals [16]. Furthermore, while teachers consistently prioritize critical thinking and problem-solving skills, creativity is less emphasized in an integrated learning approach, suggesting that traditional STEM methods may not fully support the holistic skill development required in STEAM.

6. Summary and Recommendations

The study emphasizes a significant need to improve competencies in critical thinking and creativity among student teachers. Current findings indicate a preference for observation-based critical thinking skills over broader analytical or logical abilities, as well as a tendency to favor task-focused creativity over sustained creative ideation. Situational problem-solving, which encourages both critical thinking and creativity through real-world, interdisciplinary applications, is seldom used in teacher education. These results suggest that more targeted training is necessary to develop a strong, interdisciplinary approach in STEAM education. Student teacher courses should focus on practical exercises involving reflection, open-ended questioning, and peer discussions to support these skills, as emphasized by Paul and Elder [11] and Facione [5]. Incorporating complex, real-world problem scenarios across multiple disciplines would allow student teachers to apply theoretical knowledge in realistic contexts. This approach aligns with recommendations from Lawrence [22] and Jonassen [9] for deepening interdisciplinary understanding through situational problems.

Teacher professional development programs should emphasize the benefits of STEAM over traditional STEM, especially in fostering creativity. STEAM-focused resources and frameworks would help teachers understand how to embed creative thinking into science education, which is vital for interdisciplinary and innovative learning [15]. The programs should include resources, workshops, and training on designing interdisciplinary, situational, and project-based learning tasks that foster critical thinking, creativity, and problem-solving. Structured guidance would help teachers confidently integrate STEAM concepts and methods into their teaching.

Offering teachers opportunities to collaborate on interdisciplinary projects and share effective practices locally, nationally, and internationally would reinforce integrated learning. Professional development sessions that include group activities and interdisciplinary team teaching would support the application of STEAM principles and allow teachers to benefit from each other's experiences.

This approach will better equip both pre-service and in-service teachers with the skills necessary for STEAM education, ultimately supporting Kazakhstan's goal to align its educational system with global standards and prepare students for complex, technology-driven challenges. The integration of critical thinking, creativity, and interdisciplinary problem-solving skills within teacher education will enhance both teaching efficacy and student outcomes, aligning with broader educational reform goals [14].

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