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PEDAGOGICAL CONDITIONS AND DIDACTIC OPPORTUNITIES FOR DEVELOPING PRE-SERVICE PRIMARY SCHOOL TEACHERS' SKILLS IN USING STEAM TECHNOLOGY

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ABSTRACT
This article examines the pedagogical conditions and didactic opportunities for developing pre-service primary school teachers' skills in applying STEAM technology. It highlights the growing importance of practice-oriented education in contemporary pedagogy and analyzes the pedagogical conditions and didactic possibilities involved in shaping future primary school teachers' competence in using STEAM technology. The study explores the potential of interdisciplinary integration, design thinking, contextual teaching, and the broader STEAM approach in teacher preparation.

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Keywords: *STEAM, primary education, pre-service teacher, interdisciplinary integration, design thinking, contextual teaching, pedagogical conditions, didactic opportunities, critical thinking, innovative education.*

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Introduction

Contemporary pedagogy increasingly emphasizes practice-based education aimed at equipping pre-service teachers with the professional knowledge and skills they need, while also helping them understand where, how, and for what purpose these should be applied.

Worldwide, the extensive use of scientific and technological achievements in education is widely recognized as one of the key factors ensuring the consistent and sustainable development of every sphere of society and the state, thereby securing a nation's future. From this standpoint, training highly competent and competitive specialists, together with the broad introduction of innovative, modern, interactive, and creative teaching methods into the educational process, plays a crucial role in developing students' capacity

for scientific inquiry, grounded in their motivational, cognitive, operational, reflective, and self-assessment indicators[1].

Methods

Implementing STEAM technology involves several key requirements[2]:

1. Applying the technology across all levels of education. The technology should be introduced into school and university education systems simultaneously, which requires updating and harmonizing primary, secondary, and higher education curricula. In American schools, for instance, STEAM has already been incorporated into the primary curriculum, while specialization is provided for at the secondary and upper levels; schools also run collaborative programs with universities and business partners. Local general-education institutions maintain a dedicated subject area called "Technology," within which particular attention is devoted to programming, biology, physics, and mathematics. It is equally important to introduce, or further develop, project-based practical activities, problem-solving exercises, and the design of technological and engineering structures.

2. Reforming teacher training and retraining systems is one of the key conditions for the development of contemporary education, since today's teachers must possess the knowledge, skills, and competencies required to work effectively within new curricula. To this end, many countries are developing and implementing dedicated support programs for teachers, with active participation not only from government agencies but also from commercial organizations. In particular, in the United States and the countries of the European Union, state-level platforms — including centers such as the National STEAM Centre — support teacher training and professional development by offering methodological resources, didactic materials, and innovative approaches that assist universities and schools in the teaching process.

3. Establishing close cooperation among schools, universities, and industry is one of the key strategic directions of the modern education system. Integrating student projects and school teachers into the research and educational programs of universities supports the continuous professional development of teachers and, in turn, contributes positively to raising the overall quality of education. At the same time, strengthening cooperation with urban industry, the community, and local governance bodies when defining educational goals and objectives is important, since this approach increases the social responsibility of the education system and directs it toward addressing pressing societal problems. As a result, the educational process becomes more practical, adaptable, and professionally oriented, creating conditions for the broad-scale development of innovative activity.

Furthermore, practice-based teaching directly affects an individual's activity and emotional intelligence; it encompasses a system of tools, forms, and methods that ensure students' active participation under conditions close to a genuine professional environment. It encourages learners to acquire integrated scientific, technical, engineering, artistic, and mathematical knowledge through group learning and experimental research, and it serves to build the complex competencies demanded by contemporary society[3].

STEAM education serves to cultivate critically thinking individuals, enhance scientific literacy, and nurture innovators, with pre-service teachers acting as the principal and decisive agents of this process.

[1]Schleicher A. World-Class: How to Build a 21st-Century School System. Moscow: Natsionalnoe Obrazovanie Publishing, FIOKO, 2019. 24 p. (in Russian).

[2]Active learning narrows achievement gaps for underrepresented students in undergraduate science, technology, engineering, and math. Proceedings of the National Academy of Sciences, March 2020, vol. 117, no. 12, art. 201916903. DOI: 10.1073/pnas.1916903117.

[3]Cortázar C., Nussbaum M., Harcha J., Alvares D., López F., Goñi J., Cabezas V. Promoting critical thinking in an online, project-based course. Computers in Human Behavior, 2021, vol. 119, art. 106705.

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According to The National STEAM School Education Resources Toolkit[4], pre-service teachers must observe a number of important methodological and professional principles in order to effectively implement the STEAM approach — principles that help organize the educational process on an integrated, practice-oriented, and innovative basis.

These principles are not necessarily applied uniformly in every situation, yet each provides important guidance:

1. Inquiry-based learning. This approach encourages investigation and problem-solving. Through this type of learning, students acquire essential life skills such as social interaction, inquiry, discussion, and the ability to accept failure. Pre-service teachers, for example, create active learning environments that foster critical thinking based on problem-driven scenarios.

2. Teaching students to solve real-world problems. Students attempt to solve genuine problems drawn from business and society. Such problems, by demonstrating their relevance, increase motivation and interest.

3. Integrated education — the practice of teaching two or more subjects together. This approach develops interdisciplinary skills and increases students' interest. A teacher may, for example, teach physics through an engineering-design approach, that is, through the stages of designing a product or system.

4. Use of technology. Purposeful use of technology improves the quality of education, engages students in the learning process, and increases their confidence in using technology. Rather than simply demonstrating ready-made technology, for instance, a teacher may assign students to program it themselves.

5. Differentiation of the learning process. The learning process is adapted to each student's needs and abilities, ensuring that every student's development is supported regardless of their starting level. A teacher may, for example, adjust lesson content based on a formal and informal assessment of students' abilities.

6. Linking education to twenty-first-century skills. Teachers focus on developing skills such as critical thinking, creativity, communication, and collaboration, since these are essential to students' future careers.

These principles ensure that pre-service teachers thoroughly master contemporary natural-scientific knowledge, advanced technologies, modeling, and practice-oriented educational strategies. Such an integrative approach helps shape teachers as creative, innovative thinkers with deep professional competence. As a result, a teacher becomes not merely a specialist who delivers subject content, but a leading agent who develops students' capacity for independent inquiry, problem-solving, and creative thinking. It is therefore essential, in preparing pre-service primary school teachers, to ensure the pedagogical conditions that support the effective organization of learning activities (Figure 1).

Preparing teaching staff to develop and implement STEAM technology in practice is one of the key factors in modernizing contemporary education. According to recent research, a teacher's readiness to create and apply pedagogical technologies is recognized as a fundamental condition for the effective implementation of innovative pedagogical activity. This is because a pre-service primary school teacher's readiness for innovative activity is determined by their professional and personal qualities, their orientation toward professional growth, their capacity for the independent and active mastery of new knowledge and materials, their ability for creative self-expression, and their potential to develop innovative methods and tools for pedagogical practice[5].

[4]The Australian Government Department of Education. Best Practice Guide: Elements of Successful School-Industry STEAM Partnerships. The National STEAM School Education Resources Toolkit, 2019.

[5]Pisarenko V.I. The System of Innovative Humanitarian Education in a Technical University: Monograph. Ed. by A.V. Nepomnyashchiy. Taganrog: TTI SFU Publishing House, 2007. 376 p. (in Russian).

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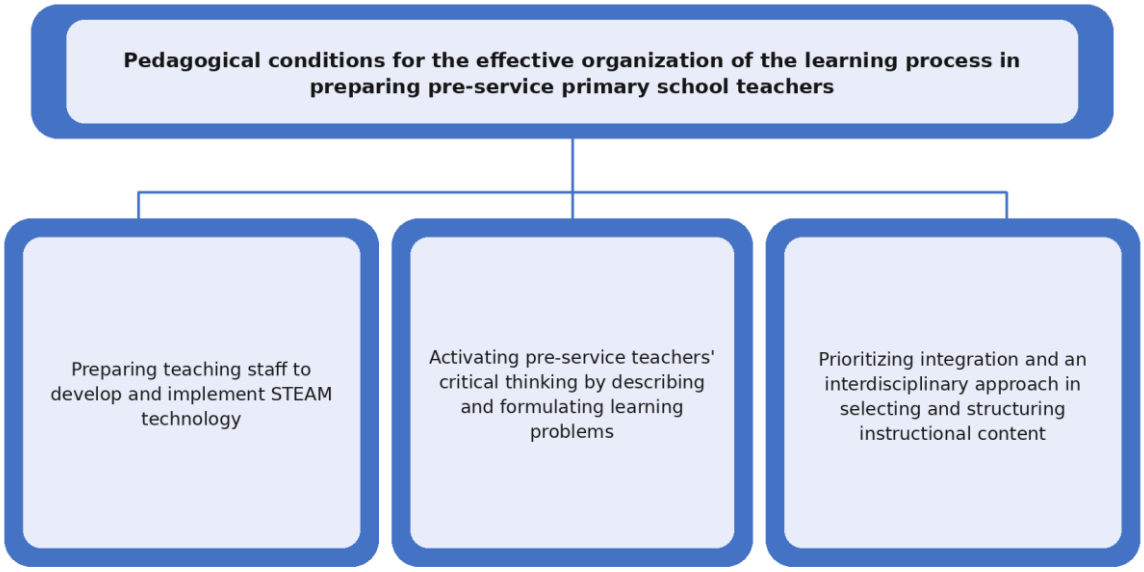


Figure 1. Pedagogical conditions for the effective organization of the learning process in preparing pre-service primary school teachers

Activating students' critical thinking by describing and clearly formulating a learning problem is an important pedagogical mechanism. As M. Makhmutov notes, the ideas of problem-based learning and critical thinking express the need to combine a critical approach to education with problem-oriented, developmental learning[6]. In other words, a teacher should not simply limit themselves to presenting ready-made, scientifically grounded conclusions, but should also guide students toward posing a problem, formulating it, and proposing hypotheses. Because the process of substantiating a hypothesis involves weighing alternative views and the possibility of refutation, a critical approach is particularly important at this stage. This view is likewise supported by D. Shakirova, who emphasizes the need to synthesize elements of problem-based learning with methods for developing critical thinking, interpreting the latter as an integrative form of logical reasoning[7]. Furthermore, in contemporary research the concepts of "problem solving" and "problem-solvers" are regarded as core principles for understanding the essence of critical thinking.

Prioritizing integration and an interdisciplinary approach in selecting and structuring instructional content is an important didactic factor in ensuring educational effectiveness. In developing curricula, selecting content and organizing it in a structurally sound manner brings together knowledge from different disciplines and ensures thematic connections, thereby achieving the integration of subjects. The need to adapt to continuous change in education and practice has broadened the contemporary requirements placed on professional training in higher education, recognizing interdisciplinary mobility — and not merely a set of competencies — as an essential skill for specialists. In this regard, interdisciplinary integration serves as a logical and necessary foundation for the professional and personal development of future specialists.

As noted above, "...the primary goal of STEAM technology is to develop learners' capacity for critical and creative thinking, shaping them into creative individuals capable of solving real-life problems. Interdisciplinary integration is the principal didactic criterion for achieving this goal, allowing knowledge to be formed as a coherent system by linking the technical and natural sciences with the arts"[8].

[6] Makhmutov M.I. Problem-Based Learning: Fundamental Questions of Theory. Moscow: Pedagogika, 2005. 368 p. (in Russian).
[7] Shakirova D.M. Developing critical thinking in schoolchildren and students: model and technology. Educational Technologies and Society, 2006, no. 9, pp. 284–292. (in Russian).
[8] Tilavova S. Methods for developing the environmental competence of pre-service primary education teachers based on the STEAM approach. Teacher and Lifelong Education (scientific-methodological journal). Nukus, 2025, no. 1, pp. 308–312. (in Uzbek).

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Results

Moreover, contemporary pedagogical research emphasizes that introducing this technology into the educational process significantly enhances the levels of learning, motivation, and thinking. It is therefore essential to prepare pre-service teachers specifically within this integrative approach, since the effectiveness of the process depends directly on the competence of the teachers who apply it in practice. The didactic opportunities for developing pre-service primary school teachers' skills in using STEAM technology are analyzed below (Table 2).

Table 2.

Didactic opportunities for developing pre-service primary school teachers' skills in using STEAM technology

Concept	Didactic opportunities	Role in preparing pre-service primary school teachers
Interdisciplinary integration	Presenting instructional material as a coherent whole; applying knowledge at the intersection of different subject areas.	Develops the skill of designing lessons on an integrative basis across various fields and subjects, systematizing knowledge, and engaging student interest.
Design thinking	Fostering creative, real-life, and project-based problem-solving; cultivating creative and critical thinkers.	Develops the ability to design real-life, creative, project-based lessons, along with facilitation, collaboration, and active-inquiry skills.
Contextual teaching	Narrowing the gap between theory and practice; strengthening interest and retention by connecting knowledge with life.	Develops the ability to explain topics through real-life situations and needs, helping students adapt to the cultural and social environment.
Experiential and constructivist learning	Practical orientation; learning through experience; teamwork; moving from passivity to creativity, and from "learning by reading" to "learning by building."	Reinforces an activity-based approach, an understanding of constructivism, process management, "learning to teach," and independent thinking.

According to S. B. Tilavova, a researcher who has studied the integrative characteristics of the technology, interdisciplinary integration is one of the core principles of STEAM education: whereas subjects are taught separately in traditional education, this approach presents them in unified form within a single theme. Such an integrative approach enables students to understand knowledge in various contexts, apply theoretical knowledge in practice, and develop interdisciplinary thinking skills for solving complex problems. At the same time, integrated teaching increases primary school students' interest in the learning material and helps them develop a holistic worldview[9].

The main didactic advantages of interdisciplinary integration can be described as follows:

Thematic integration. Here, "...academic subjects are taught not separately, but united around a single theme. In this process, interdisciplinary connections and the project method are applied together, creating opportunities to closely link the natural sciences with technology and engineering, and

[9]Tilavova S. Methods for developing the environmental competence of pre-service primary education teachers based on the STEAM approach. Teacher and Lifelong Education (scientific-methodological journal). Nukus, 2025, no. 1, pp. 308–312. (in Uzbek).

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mathematics with art"[10]. For example, when teaching the topic "Weather and Seasons" in primary school, natural science content can be integrated with art, allowing children to create drawings or handicrafts depicting the seasons with their own hands. As a result, they simultaneously acquire scientific concepts and creative skills.

Applying scientific knowledge to real life. During practical exercises, learners create models and conduct experiments using modern technologies or simple everyday tools, thereby observing how the laws they have studied manifest in real life. When teaching the topic "Air Pressure," for instance, instead of merely explaining formulas and rules, a teacher can demonstrate the concept of pressure practically — by inflating a balloon and observing its expansion, or through the classic glass-and-water experiment — thus connecting the topic to everyday life.

Developing critical and problem-based thinking. When presenting a topic, critical thinking can be developed through questions such as "Why did this happen?" and "Which solution is more effective?" Teaching students to analyze and correct errors after each trial further reinforces their problem-solving skills.

Creativity and an innovative approach. "...since the approach also incorporates art and design, it serves to develop creative thinking. Children imagine themselves in the roles of discoverers, scientists, engineers, and designers, striving toward research and discovery"[11], which encourages unconventional thinking. During project work in particular, proposing various ideas and creating new products through manual work and an artistic approach enhances creativity, while the process simultaneously combines engineering thinking (structural stability, calculating dimensions) with artistic taste (attractive design detailing).

Collaboration and communication skills. "...STEAM lessons are usually conducted in the form of team project work. While working in a group, students learn to communicate with one another, exchange ideas, and defend their own opinions. Each child contributes to the shared goal by fulfilling an assigned role within the team"[12]. As a result, primary school students develop communication, teamwork, and leadership skills, while pre-service teachers strengthen their ability to organize collective activities.

Discussion

These considerations clearly show that it is extremely important for pre-service primary school teachers to possess the skill of designing STEAM lessons on the basis of interdisciplinary integration, since this skill enables them to convey knowledge systematically at the intersection of different disciplines and to organize lessons capable of engaging every student's interest.

In preparing pre-service primary school teachers to use STEAM technology, developing design-thinking and contextual-teaching skills is of particular relevance. These are discussed in detail below.

According to a group of researchers who have studied this topic, "...design thinking means applying the approach characteristic of designers to problem-solving within the educational process. Its essence lies in deeply understanding and analyzing the problem, generating new ideas, creating a prototype, and then testing and refining it. It is an excellent methodological framework for developing STEAM education"[13]. Design thinking helps organize the learning process creatively, in a manner oriented toward real life and

[10]Tilavova S. Methods for developing the environmental competence of pre-service primary education teachers based on the STEAM approach. Teacher and Lifelong Education (scientific-methodological journal). Nukus, 2025, no. 1, pp. 308–312. (in Uzbek).
[11]Henriksen D., Mehta R., Mehta S. Design Thinking Gives STEAM to Teaching: A Framework That Breaks Disciplinary Boundaries. In: Khine M.S., Areepattamannil S. (eds.). STEAM Education: Theory and Practice, 2019, pp. 54–78.
[12]Tilavova S. Methods for developing the environmental competence of pre-service primary education teachers based on the STEAM approach. Teacher and Lifelong Education (scientific-methodological journal). Nukus, 2025, no. 1, pp. 308–312. (in Uzbek).
[13]Henriksen D., Mehta R., Mehta S. Design Thinking Gives STEAM to Teaching: A Framework That Breaks Disciplinary Boundaries. In: Khine M.S., Areepattamannil S. (eds.). STEAM Education: Theory and Practice, 2019, pp. 54–78.

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based on projects. A teacher who applies it skillfully moves away from the traditional model of "delivering ready-made knowledge" and instead directs students toward active inquiry and creation. The design-thinking algorithm consists of the following sequence (Figure 3).

Problem posing (defining the task): the problem (task) to be solved within the lesson or project is identified. The teacher presents the problem simply and clearly, generating motivation among students.

Discussion (empathy and idea exchange): the problem is discussed in detail within groups, and various solutions are proposed.

Design (planning the idea): following discussion, a detailed plan is developed for the chosen solution, a list of necessary materials is compiled, and the sequence of work is determined.

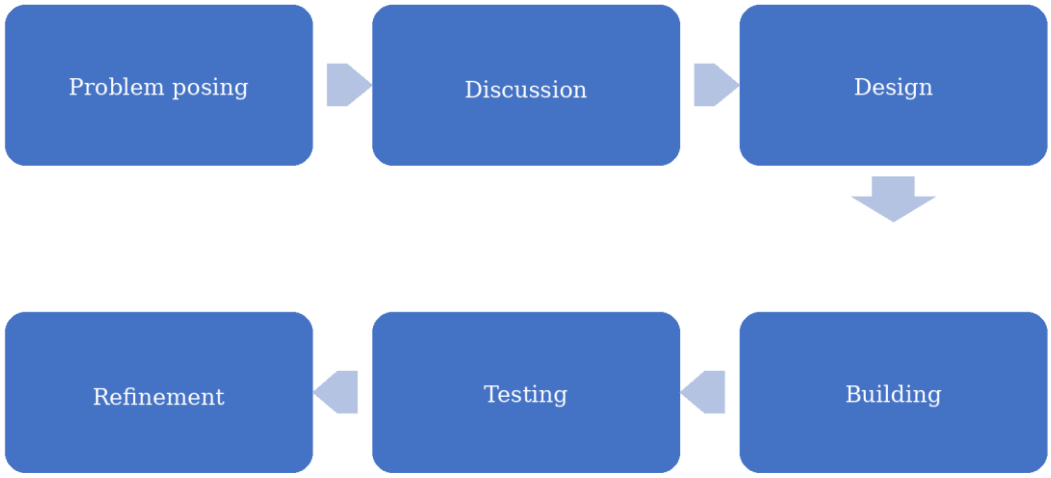


Figure 3. The design-thinking algorithm in STEAM education

Building (creating a prototype): groups begin creating a prototype of their idea. For primary school students, the prototype may take the form of a simple item, model, or mock-up made from basic materials.

Testing: the completed prototypes are tested in practice. Results are evaluated by the students themselves and by other group members, and the strengths and weaknesses of each solution are identified.

Refinement (development): based on the test results, groups make adjustments to improve their prototypes; that is, students draw conclusions from their mistakes and further perfect the product.

For pre-service primary school teachers to be able to apply design thinking effectively in the lesson process, they must first gain hands-on experience testing various pedagogical projects in practice. While working on a "Making Mathematics Engaging" project, for example, students can use the design-thinking algorithm to create an interactive game or a handmade didactic tool for younger learners. In doing so, they work systematically through the stages of identifying the problem (analyzing the difficulties students encounter in mathematics), generating ideas, creating a prototype (for example, a mathematical domino game), and testing it during a lesson. As a result, not only is a practically useful product created, but pre-service teachers also develop important professional competencies: planning a lesson around a project, solving problems, applying a creative approach, and analyzing and refining their own work.

Research indicates that contextual teaching is an approach based on explaining instructional material through real-life phenomena, professional activity, or problems, its essence being to convey a topic by connecting it with situations familiar to students from everyday life[14]. When teaching addition and subtraction in primary school mathematics, for example, rather than relying solely on abstract examples, a teacher can organize the lesson around real-life situations such as a shopping scenario, in which students perform addition and subtraction operations directly while selecting goods and paying for them. As a result,

[14]Yarmatov R.B., Akramova Z.B. Mechanisms for developing the professional competencies of pre-service primary school teachers through emotional intelligence. Promising Research in Education, 2025, no. 4, part 2, pp. 193–197. (in Uzbek).

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students grasp mathematical concepts more easily and more deeply through real-life context, which enhances the practical significance of the knowledge and reinforces its retention.

Contextual teaching is especially important within STEAM technology, since integrative projects are, in most cases, aimed at solving real-life problems. Its didactic advantages are reflected in increased student interest, the transfer of knowledge (its application beyond the textbook or classroom to other situations), and heightened motivation and engagement.

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