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The effectiveness of STEAM technologies on improving the professional competence of natural science students

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Introduction: STEAM technologies make it easier to use professional skills by combining an interdisciplinary approach to learning. The study problem concerns the absence of specialized approaches to learning physics using STEAM technologies that would enable a rethinking of how professional knowledge is acquired. The goal of this work is to check out the benefits of STEAM technologies in boosting the professional skills of natural science students.

Methods: The study employed modeling, comparison, survey methods, TOWS analysis, Student's t-test, and McNemar's test. To achieve the research objective, 71 students preparing to become physics teachers were involved.

Results and discussion: During the training, the use of digital platforms PhET Interactive Simulations and Khan Academy, group learning and student modeling of educational topics were provided for. The key results consisted in improved student performance attributable to the use of STEAM technologies. This was manifested in an improvement in theoretical knowledge from 4.2 points to 4.6 points; practical knowledge from 3.8 points to 4.8 points; and project activity from 3.5 points to 4.8 points. It was found that the skills obtained by students were characterized by the formation of critical thinking and creative skills. In solving situational problems using STEAM technologies, the greatest advantage was associated with the use of an interdisciplinary approach (28%), flexibility in processing information (26%). TOWS analysis made it possible to determine the primary influence of STEAM education on solving professional tasks. The practical significance of the article is related to improving the professional competence of future teachers through the use of STEAM technologies.

KEYWORDS

interdisciplinary approach, project-based learning, flexible learning, creative skills, situational tasks

1 Introduction

Improving the quality of the educational process depends on the choice of teaching strategies, which should be focused on understanding the principles of professional activity. One such approach is STEAM education, which combines science, technology, engineering, arts, and mathematics for a comprehensive understanding of educational topics (Ayanwale et al., 2024; Zhan et al., 2024). It is focused on the professional and psychological training of students for professional activities. Based on this, students' cognitive activity is developed, which affects the relevance of the chosen topic.

STEAM education is a universal approach to training students of different specializations, which contributes to a holistic perception of professional activities (Arpaci et al., 2023). STEAM education aims to use creativity and unconventional solutions to achieve academic goals. Among students, this is achieved through cognitive flexibility and a full understanding of the possibilities of certain disciplines for solving professional tasks (Nariman et al., 2025). The functions of STEAM education are aimed at integrated learning, problem solving, cognitive flexibility, and student motivation (Sun et al., 2023; Rosyida et al., 2025). This allows for a deeper understanding of professional opportunities and ways to solve professional problems. Project activities allow for the demonstration of leadership and communication skills. This ensures the training of focused specialists who meet modern competencies (Wu, 2022; Rohmah et al., 2025).

In the study of natural sciences, the STEAM approach, through its scientific component, affects the acquisition of research skills. Technological aspects impact the understanding of the specifics of using modern technologies; engineering aspects are focused on the development of logical thinking (Başaran and Erol, 2023). Artistic aspects contribute to the development of creativity; mathematical aspects contribute to the development of abstract thinking. This allows for more accurate application of skills in practice, which is associated with continuous development. However, the introduction of STEAM technologies into the educational process can cause difficulties (Liu and Tseng, 2024). First and foremost, adaptation problems are related to the lack of the necessary methodological basis, which may exclude the emphasis on professional materials (Camacho-Tamayo and Bernal-Ballen, 2023). The lack of a systematic approach to teaching is another gap in the implementation of STEAM technologies, which is more focused on the implementation of individual educational activities. This can also affect the intensity of one aspect of STEAM education, which excludes comprehensive education. Problems in education may also arise as a result of a lack of sufficient teaching tools (digital platforms, equipped laboratories, etc.), which prevents the integration of different disciplines within a single educational approach (Lestari et al., 2023; Usembayeva et al., 2024). One of the problematic aspects may be the psychological unwillingness of students to accept this format of education, which requires additional training. It is possible to eliminate difficulties in applying STEAM technologies in education through a well-thought-out educational approach, which will ensure the selection of appropriate educational concepts and directions to improve student performance (Martins and Baptista, 2024). Education should be systematic, allowing students to acquire the necessary knowledge. Education should be focused not only on acquiring professional knowledge, but also on developing critical and creative thinking (Awwalina et al., 2025).

Despite the widespread development of STEAM-technologies in the educational process, the issues of its application to the teaching of natural science disciplines are insufficiently studied. Attention should be paid to the development of specific training programs. The problems of researching STEAM technologies in education are related to the lack of specific mechanisms that would be focused specifically on students of natural science disciplines. There are also gaps in revealing the characteristics of students' personal development under the influence of an interdisciplinary

approach. The application of STEAM-technologies in teaching will improve students' knowledge and strengthen their training. This is due to the development of interdisciplinary thinking and the possibility of solving real-life problems based on research skills. The aim of this article is to identify the advantages of STEAM technologies for the development of professional competence in students of natural science disciplines.

The research hypothesis is that the systematic implementation of STEAM technologies is focused on developing professional skills, critical thinking skills, and creative skills for the realization of professional competence.

To achieve the research goal, the authors set the following tasks:

- To develop approaches to teaching students using the opportunities offered by STEAM technologies;
- To determine student performance before and after training using STEAM technologies;
- Determine the level of development of critical thinking and creative skills that have been formed during the learning process;
- Assess the significance of STEAM technologies for solving situational problems, which allows for a broader understanding of professional skills;
- Assess the positive and negative aspects of learning with STEAM technologies using TOWS analysis.

2 Literature review

The use of STEAM technologies as a vehicle for project-based learning is examined in the following group of studies. Applying STEAM technologies facilitates project-based learning, which serves as a tool for developing students' professional skills. This approach enabled the development of students' thinking to a level of 82.71 out of 100 and increased students' knowledge development by 25%, confirming its effectiveness (Hasani et al., 2024). The development of student confidence can be achieved through STEAM approaches, which implies improving information perception skills. The combination of different subjects in the learning process contributes to the solution of professional tasks. A focus on independent learning allows for more detailed analysis of information, which increases the value of its perception (Maričić and Lavicza, 2024). Creative and innovative skills can be developed in students through the use of STEAM technologies. This occurs due to the absence of restrictions in the learning process, the exchange of experiences between students, and the use of a variety of technologies for learning. Such learning is more meaningful, which develops flexibility in the perception of information (Leavy et al., 2023). It is possible to ensure the development of an innovative educational process with the help of STEAM technologies, which allow the use of virtual and augmented reality technologies. In this way, the scientific space becomes more focused on each student, which improves the quality of education. In education, STEAM technologies allow for the combination of pedagogical, psychological, and social methods that develop student activity (Dembitska et al., 2023). The qualitative development of professional skills is possible by involving students in group work, developing their interest in learning, and forming

research skills. Independent work by students helps improve social and emotional competence and communication skills, which contribute to the solution of scientific problems. This is focused on a creative approach, which allows for the generation of different ideas and the search for unusual approaches to their solution (Jakavonyte-Staškuvienė and Ponomarioviene, 2023). Project-based learning supported by STEAM technologies promotes students' overall development, manifested in the cultivation of creative thinking and communication skills. This yielded a high level of knowledge among 63% of students, consistent with expected outcomes. The process involved solving authentic learning tasks using an interdisciplinary approach (Rosady Putri et al., 2025). Implementing project-based learning with STEAM develops problem-solving skills and fosters creative thinking. The use of a team-based approach supports deeper data analysis, enabling research activity within the learning process (Oanh and Dang, 2025).

STEAM technologies in the learning process influence the development of critical thinking. The use of STEAM technologies contributes to the development of project skills that are focused on improving professional opportunities. The approach used improves student learning outcomes and develops critical thinking. With the help of STEAM technologies, students can adapt to using new approaches to solving tasks (Chistyakov et al., 2023). STEAM education is an effective tool for improving communication skills, as it allows students to develop critical thinking, creativity and communication skills. In this way, students can focus on understanding real professional problems that can be solved using their knowledge and technological skills (Firmansyah and Aslan, 2025). The effectiveness of STEAM education depends on the choice of tools that influence the development of professional activity. To this end, students need to develop critical thinking skills, which will enable them to see problems in a complex way for the implementation of educational projects. Professional skills for future teachers may be related to the formation of methodological competence, which includes understanding the principles of project implementation and case methods. It is important to develop digital literacy skills, which will improve teaching approaches in the future. Communication skills can be developed through interaction with other students, which is linked to the manifestation of one's own opportunities (Amanova et al., 2025). Project-based thinking in students can be developed using STEAM approaches in education. This allows gaps in knowledge to be filled by solving real-world problems. An interdisciplinary approach enables professional problems to be solved based on an understanding of educational concepts, which are implemented through the perception of interrelationships between different subjects. Such training will be effective if the right goals are set, the stages of work are planned, and the sequence of tasks and approaches to solving them are distributed (Yulianti et al., 2025).

Challenges in implementing STEAM technologies in the educational process are examined in the following group of studies. Full-scale use of STEAM technologies may be constrained by insufficient instructional time. This may be linked to teachers' limited experience with such approaches, which impedes the effective integration of interdisciplinary mechanisms to enhance student competence (Laili and Nisa', 2025). Difficulties with STEAM-based instruction may also arise from unequal access

to technology among students, which affects the study of complex physics concepts. This can reduce student motivation and hinder engagement with the updated learning process (Prayogi and Verawati, 2024). Furthermore, STEAM technologies face implementation barriers because many teachers are not prepared to adopt them in physics instruction on an ongoing basis. One contributing factor is the difficulty of assessing students who more frequently work in teams (Duong et al., 2024).

An analysis of scientific works has shown that STEAM education receives a great deal of attention in research. However, gaps in its study are associated with a lack of focus on specific student specializations and approaches to its implementation. Research is largely focused on assessing the skills that can be developed in students through such training. However, it would be possible to achieve greater depth in the research by studying the reasons for the emergence of these skills and comparing the results before and after the study.

3 Methodology

3.1 Research design

Obtaining accurate research results was linked to the initial introduction of STEAM technologies into the educational process (Figure 1).

Expanding the use of STEAM technologies based on interactive platforms involved implementing practical and theoretical classes using an interdisciplinary approach. This included using PhET Interactive Simulations to develop practical skills and Khan Academy to study theoretical materials. With the help of the PhET Interactive Simulations platform, practical classes were implemented, which made it possible to conduct various experiments in laboratory conditions. The process involved a combination of physics, chemistry, mathematics and biology classes. With the help of virtual experiments, students were able to study a variety of processes, which manifested itself in the opportunity to study complex technical processes and interact with hazardous substances. For example, this allowed them to study the laws of gravity and kinematics using a visual example. The Khan Academy platform was focused on studying scientific materials using video lectures, which allow students to learn information from a basic to a more professional level. The programme allows you to perceive information visually and select topics for individual study. Based on this approach, it is also possible to choose interactive exercises in accordance with the students' level of knowledge.

The formation of group learning for the development of team skills was aimed at developing independence and communication skills. Group learning facilitated the exchange of knowledge and the use of reasoned approaches to solving learning topics. This was reflected in the students' understanding of their role and their assessment of their own knowledge and that of other students.

The students' modeling of educational topics using STEAM opportunities was related to the creation of educational projects. The creation of projects was focused on developing critical thinking and creative skills in students. This involved student using planning approaches, analyzing existing information and searching for new

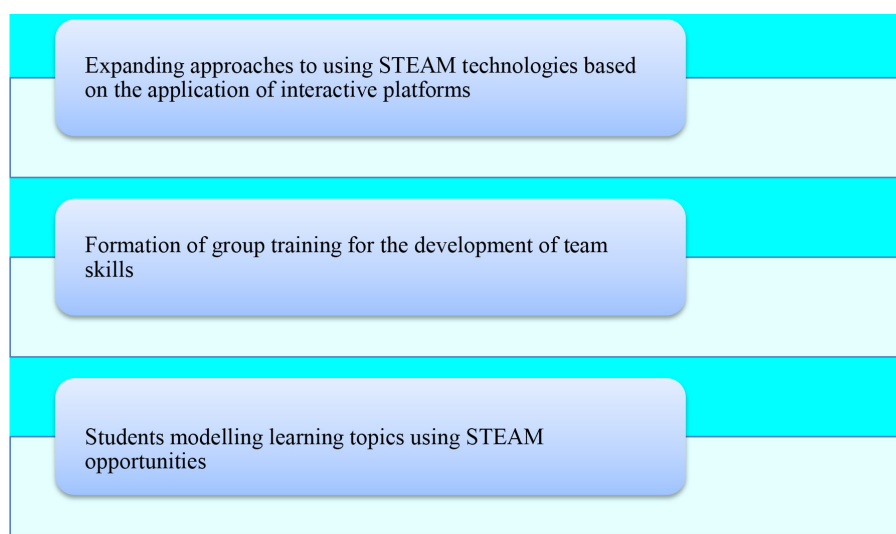


FIGURE 1
Approaches to teaching students using STEAM technologies.

information to develop research skills, modeling final results and presenting them. The STEAM teaching format was used for 12 weeks, which involved 8 classes per week, each lasting 45 min.

After the training, the students' results were assessed, focusing on the acquisition of theoretical and practical knowledge and skills. The results were compared before and after the study to assess the effectiveness of STEAM education. The assessment of students' knowledge was carried out by teachers, which involved analyzing the results of students after the control exam and in the process of solving situational tasks. The exam included detailed questions, which were different in all exam papers and included a theoretical description and practical tasks. The quality of situational task solutions was assessed throughout the entire training period, which allowed for the exclusion of inappropriate results influenced by accompanying factors (stress, anxiety, etc.). In the process of assigning scores to students, the ability to analyze the presented professional situations, as well as the understanding of the relationship between theoretical and practical aspects of professional specialization, were taken into account. The assessment of project activities involved students using unconventional approaches to solving situational problems in groups and presenting the information they had studied. The maximum score that students could achieve was 5, which corresponded to a high level of knowledge.

Among students specializing in education, skills that developed under the influence of STEAM education were identified. To this end, a survey was conducted among students to assess the skills that, in their opinion, were more pronounced. The assessment was based on the following skills: critical thinking (strong observation skills and attention to detail, ability to interpret, analyze and compare information, ability to generalize, evaluate and form reasoned conclusions. Developed logical reasoning and structured thinking, intellectual curiosity and broad horizons were also assessed. The skill of developing creative skills was considered. This includes flexibility in adapting to new ideas and approaches, high

productivity and effective performance of creative tasks, originality in creating unique and innovative ideas, the use of a creative approach to solving complex professional problems, and the use of creative thinking to solve situational tasks (Appendix 1). The survey among students was conducted based on an understanding of the principles of using STEAM technologies in education and their connection with the developed abilities of students. The skills acquired by the students, which were assessed by teachers, were verified based on the students' performance, which was evaluated at the previous stage of the study (through observation during the performance of situational tasks and the results of the control exam). The relevance of the questionnaire questions was assessed by the teachers and 7 psychologists. This allowed for the elimination of questions that were not relevant to the learning objective and focused on the development of critical thinking and creative skills. A comprehensive evaluation eliminated 4 questions because they were generalizations and indirectly related to the identification of critical thinking and creative skills. Cronbach's Alpha corresponded to 0.88, which confirmed the reliability of the presented questions of the questionnaire.

Determining the benefits of STEAM technologies was necessary for students to understand the approaches that have an impact on improving professional performance. The results were obtained through a survey of students focused on understanding the educational experience gained through STEAM technologies (Appendix 1). Thus, an assessment was made of students' understanding of STEAM technology-oriented learning, which contributed to the resolution of situational, interdisciplinary problems for the development of professional skills.

The identification of positive and negative aspects of STEAM education was linked to the use of TOWS analysis (Tang et al., 2025). TOWS analysis included an assessment of threats and opportunities (external factors) and strengths and weaknesses (internal factors) of such education. The use of TOWS analysis was necessary to understand existing

gaps in education and to address them in future research in order to improve educational programmes. The results obtained based on the TOWS analysis were focused on identifying non-standard approaches that could be used to solve educational problems.

The survey was conducted using Google Forms. Responses were collected over a period of 24 h, allowing respondents to consider their answers carefully and provide accurate data. During the survey, respondents were selectively asked to justify their answers based on specific examples from their training. The reliability of the answers was verified using Cronbach's alpha, which showed a value of 0.81 within the scope of the survey, which is higher than the required minimum value of 0.7. The survey results were analyzed by nine teachers who did not participate in teaching the students. The analysis was based on factor analysis, which made it possible to assess the relevance of the responses to the questions asked. The analysis focused on studying the factors that influenced the respondents' answers and were directly related to the assessment of the skills that were more developed in the STEAM training process, based on the students' opinions, and determining the advantages of STEAM technologies for solving situational problems. Factor analysis made it possible to assess the quality of respondents' answers and their use for further calculations.

The limitations of the study are related to the involvement of third-year students, but the absence of other groups of students, which could have contributed to obtaining more detailed results. This limitation will be eliminated in further studies by involving students from other educational institutions, which will help expand the sample for additional surveys.

3.2 Sample

Seventy one students (34 men, 37 women) who were training to become physics teachers were invited to participate in the study. This involved applying a purposive method to the sample of respondents, relating it to the course of study and the natural sciences. This approach treated the respondents equally and allowed them to participate meaningfully. The limitations in the selection of students were related to the inclusion of third-year students, whose training was more focused on specialized subjects (e.g., general pedagogy, educational psychology, physics teaching methods, educational monitoring and assessment of education quality). The sample was selected from among students at Atyrau University named after H. Dosmukhamedov, Caspian University of Technology and Engineering named after Sh. Yesenov, and West Kazakhstan University named after M. Utemisov. The students were selected from these educational institutions after reaching an agreement with the university administration to involve them in the study. Initially, it was planned to involve second-year students as well, but this could have affected the consistency of the results and the equality of learning conditions for all students. To assess the positive and negative aspects of STEAM education, 18 teachers from the selected universities who were directly involved in teaching the students were invited to participate.

3.3 Data analysis

The comparison of students' results before and after the study was carried out using statistical calculations, namely the Student's t-test (Huang and Qiao, 2024). The Student's t-test was used for paired samples, which involved comparing the results of one group of respondents. The calculation of the Student's t-test was focused on determining the effect of learning using STEAM technologies. The calculations were performed at a significance level of $p = 0.05$, which implies the significance of the results before and after training with results equal to 0.05. The use of Student's coefficient required fulfillment of the prerequisites. First of all, the calculation of parameters was based on the normal distribution of data, which provided for the initial construction of a histogram. It was built on the basis of all the students' results, which made it possible to study the symmetry of the results and identify significantly different data. The equality of dispersions between groups and the independence of answers were also determined on the basis of independent observations of students, including an assessment of their theoretical and practical knowledge and the results of their practical activities.

To compare the skills acquired by students with the skills they considered to be most pronounced, a statistical calculation of the McNemar test was performed (Boice et al., 2024). The test is used for categorical paired data, which involves determining the chi-square criterion with 1 degree of freedom. The absence of a connection between the determination of developed skills in students with different approaches can be observed when obtaining calculated values that deviate from the normative level of significance of 0.05.

StatSoft software was used to analyze the numerical results, which allowed statistical calculations of varying degrees of complexity to be performed. The calculation process was automated based on the input data. The software helped to obtain the final results not only in tabular form, but also in graphical form, which facilitated the perception of the data.

4 Results

After completing STEAM training, the performance levels of student teachers were assessed. Performance indicators were presented before and after the study (Table 1).

A comparison of student results showed the positive impact of STEAM technologies on the learning process, which was confirmed by the scores after the study. Practical and theoretical knowledge were developed at almost the same level, which was associated with students' understanding of interdisciplinary connections and the practical justification of theoretical facts and ideas. Students were able to correctly apply theoretical knowledge in practice, focusing on professional opportunities. Integrated learning contributed to the solution of specific technical problems. This allowed students to analyze available information more accurately and use it to develop professional skills.

Students were also able to achieve high results in project activities compared to the results before the start of the study. This is due to the quality of the knowledge gained and the understanding of the principles of its self-application. STEAM technologies have

TABLE 1 Student performance before and after training using STEAM technologies.

Learning outcomes	Before the study			After the study			Student's t-statistic (2.920—value from the table)	p-value
	Average student score	M	SD	Average student score	M	SD		
Theoretical knowledge	4.2	95.2	9.6	4.6	123.2	14.8	2.815	0.05
Practical knowledge	3.8	94.7	9.3	4.8	123.9	15.1	2.985	0.03
Project work	3.5	93.1	9.1	4.8	123.7	15.0	2.991	0.02

influenced the possibility of using non-standard approaches to teaching topics, focusing on the use of interdisciplinary elements and the transfer of new ideas. Students' high results were linked to the provision of structured information that was logically supported. Critical analysis of information influenced the depth of the projects created by students. The use of Student's coefficient showed the relationship between the theoretical knowledge obtained by the students before and after the study, as its calculated value (2.815) does not exceed the tabulated value (2.985) and confirms the preservation of p-value at 0.05 level. However, the practical knowledge gained (2.985) and practical performance (2.991) were higher than the tabulated value, indicating better performance of the students after the training.

After using STEAM technologies in teaching, it was determined which skills the students were able to develop. During the study, the students' opinions were taken into account regarding the expression of their strongest skill and the overall development of various skills, which were assessed by teachers (Table 2).

Among critical thinking skills, students considered observation and attention to detail to be the most developed. Students considered that this skill allowed them to perceive educational information in greater detail and interpret scientific patterns. This skill contributed not only to the study of theoretical materials but also to the development of practical skills for tracking changes and evaluating numerical patterns.

Among creative skills, students identified the ability to use a creative approach to solving complex problems. This was achieved through the use of non-standard methods that facilitated the implementation of learning strategies. The use of creative approaches to solving complex problems was linked to the initial depth of analysis, which allowed for the development of flexible thinking. Thus, students focused on using technical and mathematical knowledge to solve specific problems.

Among the critical thinking skills developed by students were observation skills and the ability to interpret, analyze and compare information. This influenced the use of a meaningful approach to interpreting educational information and the ability to take reasoned approaches to solving set tasks. The critical thinking skills outlined above enabled students to identify the most important information when studying a particular topic and to understand existing patterns, which also influenced the development of their skills in generalization, evaluation and the formation of reasoned conclusions.

Based on a comprehensive study of educational information, students were able to develop skills of intellectual curiosity and

broadening their horizons. With these skills, students analyzed the topics studied in depth and developed professional skills within the framework of their pedagogical specialization. Students also developed logical reasoning and structured thinking skills, which allowed them to consistently perceive information and visualize the problem at hand.

Among the creative skills of students, flexibility in adapting to new ideas and approaches was more pronounced, which allowed them to perceive structured information more deeply. This enabled students to fully comprehend information from various disciplines, which was focused on examining educational issues from different angles. This allowed students to change their strategies for completing educational tasks.

Skills in effectively performing creative tasks and generating unique and innovative ideas were well developed. This was linked to the creation of new combinations of knowledge and the elimination of formulaic thinking. In this way, stable knowledge was formed, which could be applied in original interpretations. Application of the statistical calculation of McNemar's test showed slight disagreement in the respondents' answers with the real results obtained, which is due to the increase in the nominal value of 3.84.

During their studies, it is important for students to develop situational problem-solving skills, which contribute to their understanding of the principles of professional practice. In the study, this was linked to an assessment of the advantages of STEAM technologies for solving situational problems (Figure 2).

It has been established that the greatest advantages of STEAM technologies for solving situational problems are associated with the use of an interdisciplinary approach. This allowed students to find connections between different subjects, which contributed to the expansion of their pedagogical skills. The use of an interdisciplinary approach helped them to focus on information from different sources, perceiving combined knowledge. This allowed for a critical approach to information analysis for non-standard professional solutions. This had a positive impact on the ability to focus on professional knowledge rather than individual subjects.

STEAM technologies in solving situational problems also influenced the use of a flexible approach to information processing, which made it possible to focus on solving complex problems and eliminate formality in the learning process. With the help of a flexible approach, students were not limited to knowledge of a single subject, but could use a comprehensive approach. This also helped to ensure an understanding of the principles of practical orientation, which is linked to an in-depth focus on practical

TABLE 2 Identification of skills developed by students during the learning process.

Developed skills	Students' opinions		Results obtained by students		χ^2 (at $\alpha = 0.05$ $\chi^2 = 3.84$)
	Percentage of responses, %	d	Percentage of responses, %	d	
Critical thinking skills					
Strong observational skills and attention to detail	43	18	25	11	1.69
Ability to interpret, analyze and compare information	11	12	23	9	3.92
Ability to generalize, evaluate and form reasoned conclusions	23	8	21	7	3.96
Developed logical reasoning and structured thinking	16	6	16	7	3.90
Intellectual curiosity and broad outlook	7	5	15	6	3.95
Creative skills					
Flexibility in adapting to new ideas and approaches	22	9	23	10	3.89
High productivity and effective execution of creative tasks	24	12	19	8	3.85
Originality in creating unique and innovative ideas	16	6	20	9	3.84
Use of a creative approach to solving complex professional problems	30	14	21	10	3.75
Use of creative thinking to solve situational tasks	8	4	17	8	3.94

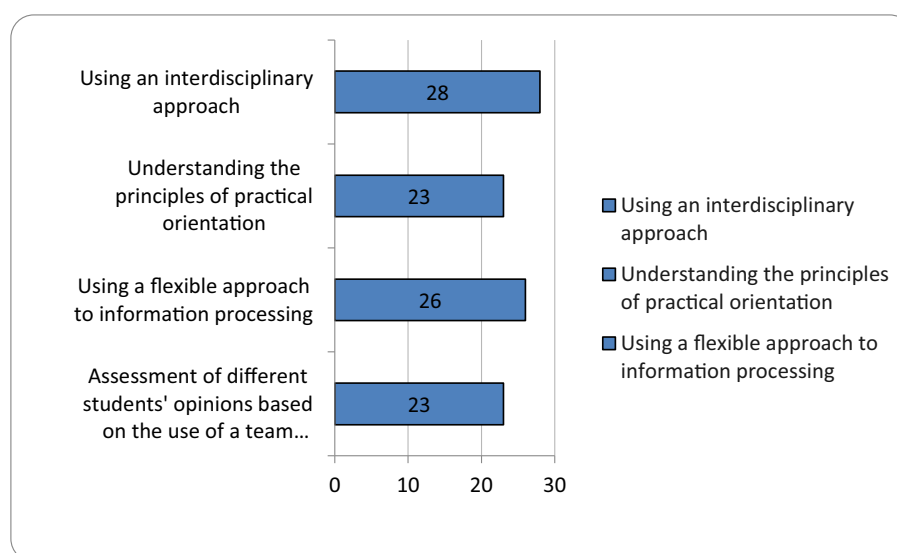


FIGURE 2

The importance of STEAM technologies for solving situational problems.

classes. This is related to the ability to solve situational problems that are close to professional activities.

Assessing the opinions of different students based on the use of a team approach is also an advantage of STEAM technologies for solving situational problems, as it allows one to not be

limited to a single source of information. Discussing information among students allows for filling gaps in knowledge and correcting mistakes. This broadens the experience of pedagogical activity.

A TOWS analysis was used to assess the advantages and disadvantages of STEAM technologies in education. The TOWS

TABLE 3 TOWS analysis for assessing the advantages and disadvantages of STEAM education.

Positive aspects	Negative aspects
Interdisciplinary education focused on studying specific topics rather than individual subjects. Focus on specialized technical and scientific knowledge used in professional activities. Development of critical thinking. Development of confidence in one's own knowledge. Development of independence and active participation in solving professional problems.	Large amount of information, which may increase the workload on students Limited educational resources Lack of necessary training for teachers Lack of sufficient teaching materials
Capabilities	Threats
Developing motivation to learn through an individualized approach Preparing for professional activity Developing a comprehensive understanding of professional activity Ensuring a personalized approach to learning	Additional load on educational programs, which may affect the incomplete implementation of STEAM technologies Lack of correct approaches to student assessment Lack of developed mechanisms for continuous improvement of the educational program

analysis focuses on the impact of external and internal factors (Table 3).

An examination of the TOWS analysis indicators revealed a greater number of positive aspects of STEAM technologies in the educational process. Negative aspects may be associated with a lack of quality organization of the educational process. Training teachers will enable the development of methods for implementing STEAM technologies and the selection of appropriate tools to improve their effectiveness. This will eliminate difficulties in teaching students and developing their motivation. STEAM technologies contribute to the strategic development of professional skills. It also influences the possibility of acquiring interdisciplinary knowledge, developing creative skills.

5 Discussion

The importance of STEAM education is related to the fact that it allows students to develop a certain level of competence necessary for the implementation of work projects. STEAM education aims to help students understand the value of science, technology, engineering, mathematics and art, which affects their perception of professional trends and is reflected in their self-development and motivation (Bahadur et al., 2025). STEAM education helps overcome the gap between traditional and interactive learning. First and foremost, STEAM education contributes to the development of social and emotional skills that influence students' anxiety management. This motivates students to be creative and perceive business knowledge. Social interaction is linked to self-regulation and self-management, which influence academic performance (Li, 2025). The results of published works are related to the development of students' professional potential based on STEAM education. The rationale for these advantages is related to

the complexity of learning and anxiety management based on obtaining sufficient educational information. The results of our study are focused on developing teaching approaches that promote the use of STEAM technology opportunities. This is due to the use of interactive platforms, group work and student modeling of learning topics.

The effectiveness of STEAM education can be achieved through the development of creative skills, student collaboration, critical thinking, and disciplinary learning. However, high results can be achieved through continuous improvement of teaching and the search for new assessment methods. The use of modern teaching approaches influences the development of systematic thinking and creative development for the implementation of project skills (Nguyen, 2025). Creative thinking skills in students contribute to the improvement of professional activity. Students who achieved higher academic results also had higher levels of creative thinking. This affects the visual perception of educational ideas, which is related to solving scientific and technical problems and understanding the connections between different sciences. Students can use their developed creative skills to solve professional problems. This also affects the development of students' motivation for independent learning (Ekayana et al., 2024). STEAM projects in education contribute to the value-based education of students, which influences the development of their psychomotor skills. Education should be based on a deep understanding of potential problems that may conflict with students' interests. Taking these aspects into account will help develop critical thinking, creativity, and problem-solving skills among students (Limbu, 2024). The studies analyzed focus on the development of students' creative skills, which are shaped by STEAM education. However, the approaches that contributed to their development are not discussed in the article. Our article substantiated the acquisition of creative and critical thinking skills, which were divided into additional categories for in-depth analysis.

Professional development can be achieved through educational simulations that promote structured thinking. The GeoGebra programme supports STEAM education, which focuses on the study of mathematical disciplines using dynamic models and 3D graphics. This promotes the perception of abstract concepts and develops research potential. This approach improves technological and pedagogical skills, which is focused on student engagement (Dos Santos et al., 2025). STEAM education has had a positive impact on the development of digital literacy among students with a natural science profile. Digital technologies influence the visual perception of educational materials, which allows for the expansion of professional skills. The approach used allows students to work with software, study scientific materials in greater depth, and develop skills in presenting educational projects. It also affects the opportunity to select educational information that contributes to the professional development of each student (Holm, 2025). The use of additional digital tools in the implementation of STEAM education is discussed in published studies. However, attention is focused on describing the opportunities available to students, but there is no justification for the skills acquired. In our article, we evaluated student performance and the skills acquired, which helped us assess the advantages and disadvantages of this type of education using TOWS analysis.

The use of interdisciplinary approaches influences students' ability to solve complex problems. However, it is necessary to consider appropriate pedagogical strategies, such as project-based learning, which will help students develop confidence in developing specialized skills. This will enable them to form skills that will meet social challenges and the needs of their future professional activities (Wong et al., 2023).

The published articles focus on exploring the benefits of STEAM education for developing professional skills. However, they do not describe specific strategies for incorporating STEAM approaches into the educational process, focusing on a particular specialization of students. Our article proposed specific mechanisms for implementing STEAM technologies in education, which made it possible to compare student performance before and after training and to assess critical thinking and creative skills. The research was also focused on assessing the significance of STEAM technologies for solving situational problems. The problems and advantages of STEAM education were assessed using TOWS analysis.

5.1 Practical significance

The practical significance of the article focuses on the opportunity to improve approaches to studying natural science disciplines based on the application of STEAM technologies in the educational process. Results can be achieved by selecting appropriate teaching approaches that are focused on expanding professional knowledge.

5.2 Theoretical significance

The theoretical significance of the study lies in examining the importance of the professional component for students of natural sciences using STEAM technologies. The study highlights the importance of project-based learning, creative approaches, and an interdisciplinary approach for developing professional skills, including critical thinking and creative skills.

6 Conclusions

The results obtained correspond to the initial research objective, confirming the effectiveness of STEAM technologies in improving the professional competence of students in natural science disciplines.

The introduction of STEAM technologies into teaching was linked to the use of advanced teaching approaches, which involved the use of interactive platforms such as PhET Interactive Simulations and Khan Academy to obtain theoretical and practical knowledge. There was also a focus on developing teamwork skills during group learning and on students modeling learning topics using STEAM opportunities. Based on this approach to teaching, students were able to achieve higher results in the development of theoretical knowledge (4.6 points), practical knowledge (4.8 points), and project activities (4.8 points).

STEAM education contributed to the development of critical thinking skills, among which strong observation skills and attention to detail (25%) and the ability to interpret, analyze and compare information (23%) were most evident. The development of these skills contributed to a clear understanding of scientific principles. The most pronounced creative skills among students were flexibility in adapting to new ideas and approaches (23%) and the use of creative approaches to solving complex professional problems (21%). This allowed them to use flexible approaches to solving situational tasks and to focus on new ideas.

It has been established that the primary significance of STEAM technologies in solving situational problems is associated with the use of an interdisciplinary approach (28%), which contributed to the comprehensive solution of professional problems. The use of a flexible approach to information processing (26%) influenced a better perception of the principles of practical orientation. The results of the TOWS analysis showed that STEAM technologies in education are largely focused on highlighting the positive aspects associated with acquiring professional knowledge and a variety of skills. The negative aspects are not significant and can be eliminated with careful preparation.

The novelty of the research lies in improving approaches to using STEAM technologies in the educational process to implement practical activities with the help of developed critical and creative skills. The prospects of the research will be focused on studying approaches to improving students' professional competence based on the formed motivation for learning with the help of STEAM technologies.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by Atyrau University, Local Ethics Committee. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

GZ: Conceptualization, Writing – original draft, Writing – review & editing. BK: Data curation, Methodology, Writing – original draft. MR: Conceptualization, Project administration, Supervision, Writing – review & editing. GS: Investigation, Resources, Writing – original draft. AK: Validation, Visualization, Writing – original draft. AT: Formal analysis, Software, Writing – original draft.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/feduc.2025.1659717/full#supplementary-material>

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