

BASIC METHODOLOGIES FOR DEVELOPING SCIENTIFIC AND CREATIVE COMPETENCE IN FUTURE ENGINEERS

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Abstract

This article analyzes the main methodologies for developing scientific and creative competence in future engineers. The demands placed on modern engineering education – in the context of Industry 5.0, digital transformation, and complex socio-technical systems – require specialists to possess not only technical knowledge but also creative thinking, problem-solving skills, and innovative approaches. The study examines methodological approaches such as the competency-based approach, problem-based learning, project-based learning (PBL), the TRIZ methodology, design thinking, and educational clusters. Based on the results of experimental work, it has been determined that the proposed methodological system significantly increases the level of scientific and creative competence of future engineers.

Keywords: scientific-creative competence, future engineers, methodology, competency-based approach, problem-based learning, project-based learning, TRIZ, design thinking.

INTRODUCTION

Relevance of the problem. In the context of increasingly complex modern engineering practice, specialists are required not merely to reproduce traditional technical knowledge, but to generate original ideas, adapt technological solutions to changing contexts, integrate knowledge from various disciplines, and transform abstract concepts into practical projects [1]. In engineering education, technological creativity is no longer viewed as an individual personality trait, but as a competence that can be purposefully developed.

The era of Industry 5.0 – which entails human-centric automation, hyper-customization, and sustainable collaboration in production – necessitates a reconfiguration of the engineering education paradigm. International engineering education standards (CDIO Standards 3.0) emphasize not only the fundamentals of science, but also creative thinking, systems thinking, teamwork, and design-implementation experience [2].

The insufficient development of a systematic methodological approach to fostering scientific and creative competence in future engineers at higher technical education institutions in Uzbekistan constitutes the main problem of this research. Many educational programs still place greater emphasis on mastering technical knowledge, while relegating the development of creative and innovative competencies to a secondary concern.

METHODS

Research design

- The research is based on a mixed methodology, incorporating theoretical analysis, pedagogical experimentation, and statistical data processing methods. The experimental work was carried out during the 2024–2025 academic years, with a total of 334 students participating.

Set of methodological approaches

In the experimental group, the following methodological approaches were applied in a comprehensive manner:

1. Problem-Based Learning. Students are presented with real engineering problems and encouraged to find solutions independently. This method serves to develop students' knowledge, skills, and creative thinking abilities through non-standard tasks.

2. Project-Based Learning. Students work on projects in groups, going through the stages of design, prototyping, and presentation. In this methodology, problem-based learning, project-based instruction, and creative work occupy a central place [3].

3. TRIZ methodology (Theory of Inventive Problem Solving). Based on this theory, students develop systematic and creative thinking.

4. Design Thinking. A method that encompasses the stages of empathy, problem definition, ideation, prototyping, and testing.

5. Educational clusters. Organizing the educational process within a network environment that brings together universities, research laboratories, industrial enterprises, and innovation centers.

6. Mediation and digital technologies. Combining theoretical knowledge with practical skills through interactive programs and simulations.

For the purpose of assessing scientific and creative competence, the following criteria were developed in the study:

Table-1. Criteria and indicators of scientific and creative competence

Criteria	Indicators	Assessment Level
Goal-- otivational criterion	Interest in research activities, striving for new knowledge, and a spirit of discovery	Goal-Oriented (Purpose-Directed)
Cognitive criterion	Mastering theoretical knowledge and the	Introductory-Orientational (Acquaintance-Oriented)

Criteria	Indicators	Assessment Level
Goal-- otivational criterion	Interest in research activities, striving for new knowledge, and a spirit of discovery	Goal-Oriented (Purpose-Directed)
	ability to identify problems	
Technical- technological criterion	Designing, prototyping, and implementing solutions	Conceptual-Analytical
Scientific- creative criterion	Creating original ideas and proposing alternative solutions	Productive-Synthetic (Creative)

For assessment, tools developed based on the Engineering Creativity Assessment Tool (ECAT) methodology were used.

Stages of the experiment

The experiment was conducted in three stages:

- ascertaining stage (September–December 2024): the initial level of students' scientific and creative competence was determined;
- formative stage (January–May 2025): the above-mentioned methodological approaches were implemented in the experimental group;
- final (summarizing) stage (June–August 2025): the results were subjected to comparative analysis.

Statistical data processing

For data processing, the SPSS software package was used to calculate the mean, standard deviation, and Student's t-test. Differences were found to be statistically significant at the $p < 0.05$ level.

RESULTS

Initial diagnostic results

At the ascertaining stage, no statistically significant difference was observed between the scientific-creative competence indicators of students in the two groups ($t = 0.42$; $p > 0.05$). The majority of students (67%) were assessed at the

introductory-orientational level, 24% at the conceptual-analytical level, and only 9% at the productive-synthetic (creative) level [4].

Formative stage results

As a result of applying the set of methodological approaches in the experimental group, the following changes were observed:

Table-2. Dynamics of scientific-creative competence indicators

Indicator	Experimental group (mean score)	Control group (mean score)	t-value	p-value
Problem Identification	4,2 → 8,7	4,1 → 5,9	6,34	<0,001
Original Idea Generation (or <i>Ideation</i>)	3,8 → 8,9	3,9 → 5,2	7,12	<0,001
Designing Solutions (or <i>Solution Design</i>)	4,0 → 8,5	4,0 → 6,1	5,89	<0,001
Prototyping and Testing	3,5 → 8,2	3,6 → 5,8	5,43	<0,001
Teamwork (or <i>Collaboration</i>)	4,5 → 8,8	4,4 → 6,5	4,98	<0,001

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Formative stage results

As a result of applying the set of methodological approaches in the experimental group, the following changes were observed:

Dynamics of scientific-creative competence indicators

Note: Scores were assessed on a 10-point scale.

In the experimental group, the proportion of students at the productive-synthetic (creative) level increased from 9% to 41%. In the control group, this indicator changed from 11% to 16%.

Effectiveness rating of methodological approaches

The effectiveness of the methodologies, as assessed by students and instructors, was rated as follows:

1. Project-Based Learning – 9.2 points
2. Design Thinking – 8.8 points
3. Problem-Based Learning – 8.5 points
4. TRIZ methodology – 8.3 points

5. Educational clusters – 7.9 points
6. Mediation and digital technologies – 7.6 points

Additional results

During the experiment, the following skills of students significantly improved:

- the ability to analyze complex problems and break them down into components [5];
- proficiency in using digital fabrication tools [6];
- the ability to integrate interdisciplinary knowledge;
- the integration of ethical and human competencies into the design process.

DISCUSSION

Theoretical aspects

The research results show that developing scientific-creative competence in future engineers requires a comprehensive methodological approach.

As Rajabov G.B. (2026) emphasizes, technological creativity in engineering education is not a spontaneous individual trait, but a competence that can be purposefully developed through a properly designed pedagogical environment, integrated curricula, interdisciplinary collaboration, and authentic problem-solving [7].

The methodological approaches applied in this study are aligned with the revised version of Bloom's taxonomy, covering the higher levels of cognitive development (analysis, synthesis, evaluation, and creation). This serves to develop students' abilities not only to acquire knowledge but also to apply it creatively [8].

Interrelation of methodologies

The study demonstrated that the combined application of methodological approaches yields higher effectiveness compared to applying each one individually. In particular:

- when Project-Based Learning was combined with Design Thinking, students' prototyping skills improved by 2.3 times;
- when Problem-Based Learning was combined with TRIZ, the number of original ideas increased by 3.1 times;
- when educational clusters were combined with mediation technologies, the level of interdisciplinary integration was 2.7 times higher.

These findings confirm the conclusions of the CEDE project: the systematic integration of creativity-related competencies into engineering education is possible through participatory and interdisciplinary approaches [4].

Advantages of methodological approaches

Problem-Based Learning actively engages students in the learning process, developing independent thinking and problem-solving skills. As Baratov (2025) notes, the application of non-standard tasks based on an integrative approach allows for the development of students' knowledge, skills, and creative thinking abilities [9].

Design Thinking fosters empathy, deep understanding of problems, and an iterative approach in students. This method is associated with students' cognitive

openness and supports the development of sustainable solutions within the scope of professional activity.

The TRIZ methodology provides systematic methods for solving inventive problems, harmonizing algorithmic and creative thinking in students. This methodology is particularly effective in solving complex technical problems.

Educational clusters ensure cooperation between universities, industry, and research institutions, bringing students closer to a real engineering environment. This approach plays a crucial role in bridging theoretical knowledge with practice.

Limitations and challenges

The following limitations were identified during the study:

1. Time constraints. One academic year was insufficient to observe the full effect of the methodologies. Long-term monitoring is required.

2. Material and technical resources. Some methodologies (e.g., digital prototyping) require modern equipment, which is not available in all educational institutions.

3. Instructor training. Effective implementation of the methodologies requires professional development for instructors. As Ganihanova (2022) emphasizes, almost everything in the learning process depends on the methodology and the student's engagement in the process [10].

4. Assessment challenges. Assessing creative competencies cannot be limited to traditional tests. It is necessary to widely implement specialized tools such as ECAT.

Comparison and future prospects

The obtained results show similar trends when compared with studies in other countries. Identified issues include the insufficiency of creativity-enhancing methodologies in engineering curricula, limited practical training, and a lack of interdisciplinary education opportunities. The comprehensive approach proposed in this study is aimed at addressing these problems [11].

Future research is planned to continue in the following directions:

- studying the long-term effects of the methodologies (3–5 years of monitoring);
- developing AI-based tools for creativity assessment;
- adapting the methodologies for various engineering specializations;
- examining the effectiveness of the methodologies in online and hybrid education formats.

CONCLUSION

The research findings allow for the identification of the following key methodologies for developing scientific-creative competence in future engineers:

1. Problem-Based Learning: develops independent and critical thinking through solving real engineering problems.

2. Project-Based Learning: develops design, prototyping, and teamwork skills.

3. TRIZ methodology – teaches systematic methods for solving inventive problems.

4. Design Thinking: develops empathy, iterative approaches, and the ability to generate innovative solutions.

5. Educational clusters: create a real engineering environment through cooperation between universities, industry, and research institutions.

6. Mediation and digital technologies: integrate theoretical knowledge with practical skills through interactive tools.

The experimental results confirmed the effectiveness of the proposed methodological system: in the experimental group, the proportion of students at the creative level increased from 9% to 41%, and statistically significant differences were recorded across all indicators ($p < 0.001$).

The combined application of methodological approaches yields higher effectiveness compared to applying each one individually. At the same time, special attention should be paid to issues of material and technical resources, instructor qualifications, and assessment tools when implementing these methodologies [12].

This study provides a theoretical and practical foundation for further improvement of the methodology for developing scientific-creative competence in future engineers. Future research is planned to explore the long-term effects of the methodologies, the use of artificial intelligence tools, and the adaptation of methods for various engineering specializations.

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