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PEDAGOGICAL CONDITIONS INFLUENCING THE DEVELOPMENT OF RESEARCH COMPETENCIES IN FUTURE ENGINEERS AT HIGHER TECHNICAL EDUCATION INSTITUTIONS AND MECHANISMS FOR THEIR IMPROVEMENT

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Abstract. This article analyses the pedagogical conditions that influence the development of research competencies in future engineers at higher technical education institutions, as well as mechanisms for improving these conditions. The content of research competence is considered in relation to the ability to identify problems, search for and critically evaluate scientific information, select appropriate methods, conduct experiments, process data, interpret results and communicate scientific findings. Problem-based, project-based and research-based learning, academic supervision, material and technical resources, interdisciplinary integration, academic integrity and criteria-based assessment are substantiated as the principal pedagogical conditions. A staged pedagogical mechanism aimed at improving these conditions is also proposed.

Keywords: higher technical education, future engineer, research competence, pedagogical conditions, problem-based learning, project-based learning.

Introduction.

Modern engineering practice is closely associated with improving technological processes, increasing production efficiency, using resources rationally and finding scientifically grounded solutions to complex technical problems. Therefore, the preparation of specialists at higher technical education institutions should not be limited to teaching theoretical knowledge and practical operations. It should also develop students’ abilities to conduct independent inquiry, make evidence-based decisions and apply new knowledge in practice.

Research competence is an important component of a future engineer’s professional preparation. It combines the ability to approach a technical problem from a scientific perspective, formulate the problem clearly, identify relevant sources, select an appropriate methodological approach, conduct experiments and calculations, analyse results and substantiate conclusions. The ABET Criteria for Accrediting Engineering Programs for 2026–2027 also identify solving complex problems, designing and conducting experiments, analysing and interpreting data, working in teams and acquiring new knowledge independently among the expected student outcomes [1].

International reviews on the development of research activity in higher education indicate that access to a laboratory alone is not sufficient to ensure students’ effective participation in research projects. Regular mentoring, engagement with scholarly literature, discussion, reflection and presentation of results are also necessary components [2]. Research competence, therefore, does not develop spontaneously; it is cultivated through deliberately established pedagogical conditions and consistent educational mechanisms.

The Concept for the Development of the Higher Education System of the Republic of Uzbekistan until 2030, approved by Presidential Decree No. PF-5847 of 8 October 2019, identifies improving the effectiveness of research activities at higher education institutions, engaging young people more broadly in research and strengthening the integration of education, science and innovation as priority areas [6]. These objectives provide an organisational and institutional basis for developing research competencies in technical higher education.

The purpose of this article is to identify the principal pedagogical conditions influencing the development of research competencies in future engineers at higher technical education institutions, explain the relationships among these conditions and propose mechanisms for their improvement.

Research Methodology.

The article is theoretical and analytical in nature. The methods used in its preparation include a systematic review of scholarly literature, comparative analysis, classification, synthesis and pedagogical modelling. International engineering education criteria, reviews of undergraduate research experiences, literature on project-based and experiential learning, and regulatory documents concerning the development of higher education in Uzbekistan were analysed. The tables presented in the article were developed by the author through synthesising the content of these sources; they should not be interpreted as the results of a separate experimental study.

Analysis and Results.

The content and components of research competence. The research competence of a future engineer should be viewed as a set of interrelated knowledge, practical activity and personal qualities. The knowledge component includes methods of scientific inquiry, the theoretical foundations of technical disciplines, and the principles of measurement and statistical analysis. The practical activity component comprises formulating problems, developing hypotheses, designing experiments, modelling, processing data and presenting results. The personal and reflective component includes independence, critical thinking, creativity, perseverance, academic integrity and the ability to evaluate one's own work.

In their systematic review of engineering competencies, Passow and Passow synthesised findings from various studies and emphasised the interrelationship among such skills as problem-solving, information seeking, experimental design, accurate measurement and interpretation of data, teamwork and taking responsibility in engineering practice [3]. This indicates that research competence should be developed not within a single subject or one-off project, but as an outcome embedded throughout the entire educational process.

Components of future engineers' research competence and the conditions required for their development

Table 1.

Component	Content	Required pedagogical conditions	Observable outcome
Cognitive	Knowledge of scientific methods, engineering theory, sources and measurement principles	Problem-oriented lectures, work with scholarly sources and methodology seminars	Ability to explain a problem on a scientific basis
Operational and practical	Hypothesis formulation, experimentation, modelling, calculation and data analysis	Laboratory work, projects, practical assignments and engineering simulation	Ability to conduct experiments and draw evidence-based conclusions
Communicative	Written and oral presentation of results and teamwork	Scientific discussions, conferences, project presentations and group analysis	Clear presentation of research findings

Reflective and ethical	Self-assessment, recognition of errors and academic integrity	Reflective journals, correct citation of sources and plagiarism prevention	Independent and responsible research activity

As the table shows, each component of competence should be supported by specific pedagogical conditions. For example, if theoretical knowledge is not reinforced through laboratory and project work, students may experience difficulties applying scientific methods to real engineering situations. Similarly, obtaining experimental results alone is not sufficient: students must also explain them, identify their limitations and defend them in scientific discussion.

The principal pedagogical conditions for developing research competencies. The first condition is the creation of a research-oriented learning environment. In such an environment, learning activities are directed not merely towards reproducing information but towards formulating problem-based questions, comparing alternative solutions and making evidence-based decisions. For example, in a topic on “Energy Efficiency”, students should not simply memorise a ready-made solution. Instead, they may be asked to measure the energy consumption of a particular device, identify the factors affecting consumption and develop proposals for improving efficiency.

The second condition is the consistent use of problem-based, project-based and research-based learning methods. A review of project-based learning in engineering education published in 2024 highlights the importance of connecting projects with real professional contexts, interdisciplinary content, advanced technologies, simulation and industry collaboration [4]. During a project, students should identify a problem, define technical requirements, develop alternative solutions, create a prototype or model, test it and present their results.

The third condition is the establishment of an academic supervision and mentoring system. It is not enough simply to assign a topic to a student. A supervisor should provide regular guidance on narrowing the problem, selecting scholarly sources, justifying the method, ensuring experimental safety and interpreting results. A review by Ahmad and Al-Thani, which compared 67 undergraduate research experience models published between 2011 and 2021, noted that research experiences integrated into coursework can reach a broader range of students, while also emphasising the importance of effective mentoring and a clearly structured educational model [2].

The fourth condition is the provision of modern material, technical and information resources. Students in technical disciplines should have purposeful access to measuring instruments, laboratory equipment, software, electronic libraries, scholarly databases and simulation tools. In addition to the availability of equipment, institutions should provide instructions for its use, ensure compliance with safety requirements, arrange technical maintenance and offer instructor support. The ABET criteria specifically emphasise that laboratories, modern tools, computing resources and library and information infrastructure should support the achievement of student outcomes [1].

The fifth condition is interdisciplinary integration and cooperation with industry. Engineering problems generally require the combined application of knowledge from mathematics, physics, computer science, materials science, economics and environmental studies. Accordingly, research and practical projects should integrate the content of several disciplines and address real problems encountered by enterprises or other organisations. A review of experiential learning by Tembrevilla and co-authors, which synthesised 220 studies, identified stakeholder collaboration, active student participation, staged support, assessment, reflection and educator support as important elements of successful implementation [5].

The sixth condition is the development of a culture of academic integrity and research ethics. Students should follow the principles of citing sources correctly, avoiding the appropriation of others’

ideas, not falsifying measurement results, not concealing errors and openly acknowledging the limitations of experiments. These requirements should not be confined to a separate lecture; they should be incorporated into the assessment criteria for laboratory reports, course projects and graduation theses.

The seventh condition is the organisation of diagnostics, criteria-based assessment and feedback. Research competence cannot be adequately measured solely by the grade awarded for a final article or project. During the process, the clarity of the problem, the quality of sources, the justification for method selection, the experimental protocol, the reliability of data, the depth of analysis, the consistency of conclusions with the evidence and the quality of scientific presentation should be assessed separately. A study on the use of active learning strategies in engineering education indicates that research-based learning and the "think-pair-share" method can help develop critical thinking and written communication skills [4].

A mechanism for improving pedagogical conditions. When the conditions discussed above are implemented separately, the expected outcome may not be fully achieved. It is therefore proposed that they be integrated into a single, staged mechanism. The mechanism begins with diagnosis and goal-setting, proceeds to the organisation of research and practical activities, mentoring and assessment of outcomes, and concludes with improvement. Each stage generates the information and conditions required for the next stage.

A mechanism for improving the conditions for developing research competencies

Table 2.

Stage	Main pedagogical actions	Responsible participants	Expected outcome
1. Diagnosis	Identifying prior knowledge, research interests, methodological and digital skills	Subject instructor, tutor, department	The student's needs and areas for development are identified
2. Design	Defining individual or group research objectives, problem, plan and assessment criteria	Student, academic supervisor, employer	A clear objective and feasible research plan are established
3. Organisation of activities	Problem-based assignments, projects, laboratory work, simulation and work with sources	Instructor, laboratory specialist, industry partner	Experimental and analytical skills are developed
4. Mentoring and monitoring	Regular consultations, discussion of interim results and analysis of errors	Academic supervisor, project team	Independent work and scientific thinking are supported
5. Assessment and reflection	Rubrics, portfolios, project presentations, peer assessment and reflection	Assessment committee, instructor, student	Competence level and development needs are identified
6. Improvement	Updating curricula, assignments,	Department, faculty, industry partner	Continuous improvement of the

	resources and mentoring based on assessment results		educational process is ensured

To implement this mechanism, departments may establish an annual bank of research and practical project topics, compile a list of technical problems in cooperation with enterprises, assign students to small research groups and appoint a mentor for each project. At the end of each semester, students' development can be analysed on the basis of their portfolios, laboratory reports, project outcomes and presentations. In this process, assessment should cover not only the final product but also the entire sequence from problem formulation to the development of conclusions.

An important feature of the proposed approach is that research activity should not be limited to gifted students or those who attend research clubs. It can be organised progressively for all students through small research assignments adapted to the curriculum. For example, students in the early years may focus on searching for sources and conducting simple measurements; those in the middle years may plan experiments and analyse data; and senior students may undertake complex projects, develop prototypes and publicly present research findings.

The Concept for the Development of the Higher Education System of Uzbekistan until 2030 identifies strengthening the integration of education, science and innovation and engaging young people in research as priority objectives [6]. The "Digital Uzbekistan – 2030" Strategy provides a broader policy framework for developing digital infrastructure and information technologies [7]. Within this framework, it is advisable to expand the use of electronic laboratory logbooks, digital portfolios, remote mentoring, scholarly databases and digital archiving of project results at technical higher education institutions.

Conclusions and Recommendations.

The analysis shows that developing research competencies in future engineers at higher technical education institutions is a multifactorial pedagogical process. Its effectiveness depends on the integration of a research-oriented learning environment, problem-based and project-based methods, academic supervision, modern laboratory and digital resources, interdisciplinary integration, cooperation with industry, academic integrity and criteria-based assessment.

Based on these conclusions, the following recommendations are proposed:

1. Systematically incorporate small research assignments appropriate to each year of study into the curricula of every technical specialisation.
2. Establish, at department level, a bank of real engineering problems developed in cooperation with enterprises.
3. Engage students in a system of regular consultations with an academic supervisor or mentor and discussion of interim results.
4. Shift laboratory classes from merely following predetermined instructions towards formulating problems, planning experiments and independently interpreting results.
5. Develop assessment rubrics for research competence that include problem formulation, method selection, data quality, analysis, conclusions and scientific communication.
6. Apply the requirements of academic integrity, source referencing and research ethics to all project and laboratory work.
7. Compile students' research and practical achievements in electronic portfolios and monitor their development across semesters.
8. Regularly evaluate the effectiveness of pedagogical conditions and improve curricula, laboratory facilities and mentoring mechanisms in accordance with the results.

Thus, the development of research competence should be organised not as a task confined to a single subject or final graduation project, but as a continuous pedagogical process embedded in all stages of higher technical education. Such an approach will help prepare specialists who think independently, solve engineering problems on the basis of evidence and are ready to develop new technological solutions.

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