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Cultural and Pedagogical Dimensions of Technical Competence Formation in Engineering Students through Professionally Directed Physics Education

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ABSTRACT

This study examines the socio-cultural transformation of engineering education through the integration of professional contexts into university physics instruction. The research conceptualizes technical competence (TC) not only as a set of applied skills, but also as a culturally mediated form of professional identity shaped by educational environments. A pedagogical model was designed and validated to align academic physics education with the evolving cultural and industrial demands of the engineering profession. Grounded in personality-activity and competency-based approaches, the model defines the structure, components, and socio-educational mechanisms of TC formation within professionally directed physics courses. The accompanying pedagogical technology promotes students' motivation, cognitive engagement, and creative problem-solving through contextualized learning rooted in authentic professional practices. Empirical testing (N = 283; 103 in the experimental group, 180 in the control group) confirmed the model's effectiveness in improving academic outcomes and in fostering culturally grounded professional readiness. The findings demonstrate that integrating real-world professional and cultural contexts into physics education enhances students' technical competence, social responsibility, and adaptability to technological change. The proposed framework contributes to the modernization of engineering education by bridging the gap between disciplinary knowledge, professional culture, and the societal mission of higher technical education.

Keywords: Physics Education; Professional Context Integration; Technical Competencies; Pedagogical Model; Cultural Transformation in Education, Professional Identity of Engineers, Socio-Cultural Dimensions of STEM Education

INTRODUCTION

Research conducted by both domestic and international scholars demonstrates a diversity of perspectives regarding the structure, objectives, and organization of technical training for future professionals. These studies approach the issue through multiple theoretical lenses, including personality-directed, activity-based, and competency-driven frameworks, as well as the socio-psychological dimensions of innovative and technological education [1–5]. Considerable emphasis is placed on identifying the degree to which students acquire and internalize the knowledge, skills, and abilities required for future professional engagement, as well as on determining the composition and dynamics of competencies vital for successful professional performance [6–10]. Numerous works underline the decisive role of technical competencies in ensuring engineers' ability to perform complex professional tasks efficiently and responsibly [11–13].

Existing theoretical models of technical competency formation-such as systemic, activity-based, and competence-directed approaches-provide diverse strategies for integrating professional development within higher education curricula [14–18].

Within the framework of this study, we advocate for an educational model grounded in targeted professional training, in which technical competencies are progressively cultivated through contextual learning and active student participation. The process emphasizes both the structure of educational content and the organization of student activity in accordance with the functional demands of their future professional roles. In this regard, the training model in higher technical education is closely aligned with the evolving characteristics of the learner's professional and personal development. Thus, the object of this research is defined as the professionally directed educational process, while its subject focuses on the mechanisms underpinning the development of students' technical competencies.

Creating pedagogical environments that facilitate the enhancement of technical competencies represents a core challenge of modern higher education. Based on a theoretical review of psychological and pedagogical literature, we have determined that technical competence constitutes an integrated system of professional knowledge, practical skills, and personal qualities that collectively influence an engineer's effectiveness. This effectiveness depends on the capacity to apply scientific and technical knowledge within production contexts aimed at designing, analyzing, and improving engineering systems and technological processes [5].

Moreover, we argue that technical competencies contribute to the ability to set goals, plan, and coordinate collaborative technical and production activities. They ensure responsible engagement with technological systems and resources, adherence to safety standards, effective utilization of tools and materials, and conscientious resource management. Together, these attributes promote safe, sustainable, and ergonomically sound working environments.

The analysis of the educational process and the identification of methodological strategies for the progressive development of technical competencies are intrinsically linked to the evaluation of this phenomenon. This entails determining the structure, levels, and criteria that characterize the formation of TC among undergraduate students. In our research, particular attention is given to natural science disciplines - most notably physics - which serve as an effective foundation for initiating and advancing the process of technical competence formation from the early stages of university training.

Accordingly, the central aim of this study is to identify the structural levels and diagnostic criteria that underpin the formation of technical competencies, establishing them as a pedagogical priority in contemporary higher education [5].

METHODOLOGY

In this research, the conceptual foundation was established upon the principles of personality-directed and activity-based learning theories, which made it possible to formulate an operational understanding of the examined construct-technical competence (TC). Within this context, TC is viewed as an integrative personal attribute that embodies both the potential capacity and the psychological readiness to address professional challenges, while maintaining a value-driven and responsible approach toward occupational tasks [4,5].

When constructing the matrix model of technical competence for university students, the study adopted the principles of the competence-based educational paradigm and the methodology of professionally directed training (PDT) within bachelor's degree programs (see Table 1) [1–2,4-6,9,19–20].

The matrix model provides an integrated perspective on the educational process, where each component of TC corresponds to specific evaluative dimensions that reflect the developmental trajectory of a learner. It captures the qualitative transformation of students' professional growth-from initial motivation and theoretical understanding to the ability to independently apply knowledge in realistic professional contexts. This matrix framework visualizes the interrelation between the structural components of TC and their diagnostic parameters, thereby serving as a tool for assessing and optimizing the educational process in technical universities:

1. Value–Motivational Component

This component represents the **emotional-axiological foundation** of technical competence and determines the student's inner motivation, professional orientation, and personal values in relation to engineering practice.

Criterion: Student Activity and Independence

This criterion assesses the student's **engagement and self-regulation** during professionally directed learning. It reflects their initiative in problem-solving, perseverance in goal achievement, and willingness to assume responsibility for learning outcomes.

Indicators

- ✓ Active participation in laboratory, project, and research activities.
- ✓ Evidence of self-motivated learning and continuous professional interest.
- ✓ Demonstration of autonomy in decision-making within educational projects.
- ✓ Reflection on personal growth and alignment of academic efforts with career goals.

This set of indicators reveals the intensity of professional motivation and the learner's capacity to independently organize and direct their educational trajectory.

2. Cognitive-Substantive Component

The cognitive-substantive dimension characterizes the **depth and integration of professional knowledge**. It reflects how effectively students assimilate scientific principles and relate them to the functional roles of engineers in modern technological systems.

Criterion: Understanding of the Professional Role

This criterion evaluates how well students conceptualize the **purpose and significance** of professional activity within the energy and engineering sectors. It identifies their awareness of how theoretical knowledge underpins technological development and innovation.

Indicators

- ✓ Mastery of theoretical and empirical content in physics and related sciences.
- ✓ Understanding of the principles governing technological systems and energy processes.
- ✓ Recognition of the social and collaborative nature of engineering professions.
- ✓ Use of interdisciplinary connections to interpret and solve technical problems.

The indicators within this criterion illustrate how cognitive depth transitions into professional understanding, bridging scientific abstraction with applied engineering practice.

3. Technological–Operational Component

This component demonstrates the student's capacity to translate theoretical knowledge into action-the ability to perform professional tasks using scientific, analytical, and technological tools. It embodies the practical outcome of competence formation.

Criterion: Professional Self-Perception

This criterion focuses on how students identify themselves with their future professional roles and how they demonstrate readiness for real engineering tasks. It reflects self-efficacy, applied creativity, and an understanding of professional responsibility.

Indicators

- ✓ Independent execution of laboratory and design assignments simulating real-world technical problems.
- ✓ Application of modern instruments, software, and measurement techniques.
- ✓ Awareness of safety, ergonomics, and resource management principles.
- ✓ Self-assessment of readiness for professional integration and lifelong learning.

The operational indicators in this category measure the student's preparedness to transfer academic learning into practical implementation, thus confirming the maturity of technical competence as a personal and professional construct.

The correlation between the components, criteria, and indicators within the matrix model ensures that each dimension of technical competence can be empirically observed and pedagogically developed. The model facilitates both formative assessment (monitoring progress throughout training) and summative evaluation (determining the achieved level of competence).

By combining qualitative descriptors with measurable indicators, the table provides a holistic diagnostic tool for educators and researchers. It highlights not only the functional aspects of knowledge and skill acquisition but also the motivational and self-reflective mechanisms essential for professional identity formation in engineering students.

Table 1. Criteria and Indicators of Technical Competence Development.

Component of Technical Competence	**Criteria**	**Key Indicators of Development**
value–motivational	student activity and independence	- demonstrates initiative and autonomy in laboratory and project work. - shows consistent interest and motivation toward professional learning tasks. - sets personal educational goals aligned with career objectives. - reflects on professional growth and responsibility for learning outcomes.
Cognitive–substantive	understanding of professional role	- applies theoretical and empirical knowledge of physical and engineering principles in coursework. - understands the professional and social roles of engineers in modern energy systems. - recognizes interdisciplinary relationships between physics and applied technologies. - demonstrates analytical thinking and the ability to generalize technical information.
Technological–operational	professional self-perception	- performs applied engineering tasks independently using appropriate instruments and software. - observes safety, ergonomics, and sustainability standards in simulated or real environments. - assesses own readiness for professional activity and continuous learning. - demonstrates responsibility and creativity in solving practical technical problems.

Table 1 systematizes the internal structure of technical competence formation by correlating each component with observable criteria and measurable indicators. The matrix enables a multidimensional evaluation of students' progress, combining motivational, cognitive, and operational evidence. It also functions as a diagnostic framework for instructors, allowing targeted interventions at different stages of professional preparation. The qualitative and quantitative balance within the model ensures reliability in assessing both personal development and readiness for real engineering tasks.

Based on the structural model of students' technical competencies (TC), four progressive levels of development were distinguished: high, sufficient, average, and low. These levels reflect the qualitative dynamics of students' professional growth and the degree of their readiness to apply technical knowledge in real or simulated professional contexts.

- High Level

Students who reach this stage display a stable, purposeful, and positive attitude toward both learning and their chosen profession. They fully recognize the value of mastering knowledge that directly supports their future engineering roles. Such students demonstrate a well-formed professional identity, the ability to collaborate effectively with peers and instructors, and competence in applying theoretical knowledge to complex problem-solving situations. They can critically assess their own capabilities by distinguishing between the ideal and the actual self, which promotes self-reflection and a proactive attitude toward lifelong learning. At this level, professional aspirations are harmoniously integrated with personal goals and ethical values.

- Sufficient Level

Students at this level show consistent cognitive engagement and intellectual curiosity that enable them to form a solid theoretical foundation. They maintain a positive view of their professional future and willingly participate in learning activities, understanding that personal qualities such as adaptability and persistence are essential for future success. Although these learners are able to apply their knowledge to educational tasks, they still require methodological guidance from instructors. They are, however, capable of evaluating their own learning progress and identifying areas for improvement.

- Average Level

This category is characterized by a generally favorable attitude toward education and professional self-development, often motivated by external or social factors. While students at this level exhibit awareness of the importance of professional preparation, their motivation tends to be situational rather than intrinsic. Consequently, their engagement in academic or professional contexts may fluctuate depending on external encouragement or immediate rewards.

- Low Level

Students in this group demonstrate limited motivation for professional learning. They acknowledge, in general terms, the necessity of developing technical abilities but experience significant challenges in doing so. Their decision-making autonomy and reflective self-assessment are minimal, and they frequently rely on external direction to complete learning tasks. As a result, their readiness for independent professional activity remains insufficient.

The criterion-level framework thus not only encompasses the indicators outlined in Table 1 but also provides a hierarchical understanding of students' TC formation. This framework allows educators to trace the developmental trajectory of competencies and to design differentiated pedagogical strategies suited to each level.

The proposed model of technical competence development for students in technical universities reveals the internal mechanisms governing this phenomenon. Understanding these mechanisms enables the identification of pedagogical tools, methods, and gradual learning formats that effectively nurture TC within the academic environment. Consequently, this contributes to enhancing the overall quality of engineering education and the professional preparedness of future specialists.

The empirical phase of the study was carried out over seven years (2018–2025) and consisted of several stages. The main objective of the experimental investigation was to determine the pedagogical conditions, methods, and strategies that most effectively foster the development of technical competencies among students of electrical engineering. To support this goal, a scientific-methodological seminar was organized for university instructors engaged in the training of electrical engineers. The initiative was implemented at both national and international levels.

During the study, we conducted a detailed review of state educational standards, standard curricula, and scientific literature related to the pedagogy of electrical engineering and the modeling of learning processes. This integrative approach led to the development of a conceptual activity model for specialists, illustrating how technical competencies can be formed within the bachelor's program in *Electrical Power Engineering* in alignment with labor-market expectations and the current demands of professional engineering education (see Figure 1).

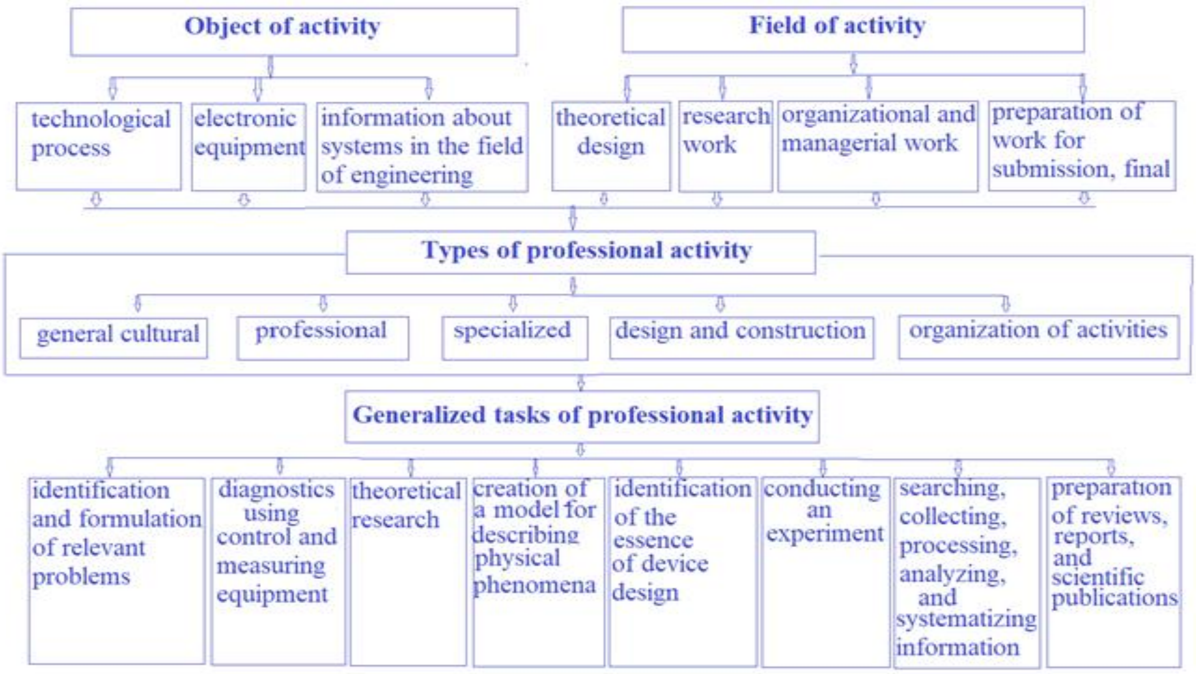

Figure 1. Conceptual Model of Technical Competence Formation in Electrical Power Engineering Students.

Figure 1 illustrates the conceptual model of professional activity underlying the development of students' technical competencies (TC) in higher technical education. The diagram integrates three interconnected dimensions: the object of activity, the field of activity, and the types and tasks of professional activity. This structure demonstrates how educational and professional experiences are aligned with real engineering practice, thereby fostering a coherent process of TC formation.

The object of activity encompasses the technological and informational domains in which future engineers operate - including technological processes, electronic equipment, theoretical and system-based knowledge of engineering mechanisms. The field of activity represents the main functional areas of engineering practice: theoretical design, research, organizational and managerial work, and the preparation of professional and scientific outputs.

The second tier of the model - **types of professional activity** - includes five interrelated categories:

1. *General cultural* (formation of scientific worldview and communication culture);
2. *Professional* (application of fundamental and specialized engineering principles);
3. *Specialized* (deep professional and technical problem-solving);
4. *Design and construction* (innovation and creative engineering design);
5. *Organization of activities* (coordination, planning, and quality management in technical environments).

At the third level, the model identifies generalized professional tasks that link educational goals to professional outcomes. These include the identification and formulation of engineering problems; diagnostics using control and measurement tools; theoretical modeling of physical phenomena; the design and optimization of devices; conducting experiments; data processing and analysis; and the preparation of technical reports and scientific publications.

This hierarchical representation demonstrates the continuity between theoretical learning and professional application, emphasizing the integration of scientific, technological, and communicative competencies. The model reinforces the notion that technical competence is formed not as a discrete skill set, but as a systemic quality of personality, manifested through professional thinking, self-organization, and active engagement in research and engineering design.

Consequently, Figure 1 visualizes the pedagogical mechanism by which professionally directed physics education contributes to the development of holistic engineering competence. It aligns the educational content, types of activity, and expected professional outcomes, providing a theoretical foundation for designing curricula that bridge university training with the realities of the engineering labor market.

METHODOLOGY OF EXPERIMENTAL RESEARCH

At Gumarbek Daukeyev AUPET, an initial diagnostic experiment was conducted at the outset. The primary objective of the confirming experiment was to assess the levels of technical competencies among bachelor's students and to evaluate the applicability of the indicators outlined in our model along with the corresponding diagnostic tools. A comprehensive methodology was utilized during the experiment, incorporating surveys, observations, tests, interviews, task performance, and other methods [22-23].

The findings from the confirming experiment supported our hypothesis that the absence of specially organized, professionally directed training in the early years affects the development of students' technical competencies. A total of 283 students participated in the study, which we divided into two groups: 103 in the experimental group and 180 in the control group. Specifically, 58.2% of students in the experimental group and 61% in the control group exhibited a low level of technical competencies, while the average levels were 31.1% and 48.8%, respectively. This data led us to conclude that targeted efforts are necessary within the university to enhance technical competencies. To address this, we selected the specialty «Electrical Power Engineering».

We are convinced that developing competencies in the context of a bachelor's degree in electrical power engineering can be effectively achieved by aligning the educational process with the model of the specialist's activities (Figure 1).

In this case, to conduct the next formative experiment, we developed a professionally directed educational and methodological complex for the discipline «Physics» for future electrical power engineers. For students enrolled in the educational program (EP) in «Electrical Power Engineering», 135 hours are allocated for physics, of which 15 hours are for lectures, 15 hours for practical classes, and 15 hours for laboratory sessions. The remaining 15 hours are for independent work of a student under the guidance of a teacher (IWST), and 75 hours are for independent work of the student (IWS).

Table 2 shows an example of the components of a traditional and professionally directed physics course for students of the EP «Electrical Power Engineering» on the topic «Molecular Physics and Thermodynamics».

Table 2. Example of the components of a traditional and professionally directed physics course for students of the educational program «Electrical Power Engineering» on the topic «Molecular Physics and Thermodynamics».

Type of Class	Traditional Objectives	Professionally Directed Objectives
Topic: *Molecular Physics*		
Lecture	Study of the basic principles of molecular-kinetic theory, laws of molecular velocity and energy distribution, and the concepts of pressure and temperature.	Formation of technical competencies through the analysis of heat transfer processes and the properties of gases, liquids, and solids, applicable to energy systems, refrigeration units, heat engines, and ventilation systems.
Practical Class	Solving problems involving the use of the ideal gas law, determining	Development of engineering thinking through solving problems related to the efficiency of heat engines, turbine

	internal energy, and calculating gas work in various processes.	performance, selection of working substances, and optimization of thermodynamic cycles.
Laboratory Work	Experimental determination of the expansion coefficients of gases and liquids, measurement of saturated vapor pressure, and study of thermal conductivity.	Performing laboratory work that reflects real engineering tasks: determining heat losses in pipelines, studying the properties of coolants, assessing the efficiency of insulating materials, and diagnosing thermal processes in equipment.
Topic: *Thermodynamics*		
Type of Class	**Traditional Objectives**	**Professionally Directed Objectives**
Lecture	Study of the main laws of thermodynamics, the concepts of internal energy, work, heat, entropy, and Carnot cycles.	Formation of technical competencies through the analysis of energy processes in heat engines, turbines, and compressors; understanding the operating principles of heating and refrigeration systems used in industry and energy sectors.
Practical Class	Solving problems involving the application of the first and second laws of thermodynamics, calculating the efficiency of ideal and real cycles, and determining gas and steam parameters.	Development of engineering skills through solving problems related to the optimization of thermodynamic cycles, improving the efficiency of turbines, boilers, and heating systems; assessing energy losses and environmental performance of installations.
Laboratory Work	Studying isoprocesses and measuring their parameters; determining specific heat capacities of substances; experimental verification of equations of state.	Conducting experiments that model real industrial processes: studying the heat balance of a steam boiler, analyzing the efficiency of compressor and refrigeration systems, calculating energy losses, and identifying ways to reduce them.

The integration of professionally directed tasks into the *Molecular Physics* section enables students not only to master fundamental physical laws but also to understand their practical significance in engineering systems - from thermal installations to energy networks. This approach increases motivation, develops analytical and project-based thinking, and contributes to the formation of sustainable technical competencies.

Professionally directed tasks within the *Thermodynamics* topic aim to form students' engineering vision of thermal and energy processes. Studying the fundamental laws of thermodynamics in the context of practical applications - from designing heat engines to improving system energy efficiency - fosters the development of analytical and environmentally responsible approaches to engineering activity.

This balanced allocation ensured that students not only mastered theoretical knowledge but also engaged in practical, research-directed, and self-directed activities conducive to the development of professional competencies. The methodological structure of the experiment was designed to assess the effectiveness of this integrated approach in enhancing the technical competency levels of future electrical power engineers.

Development and Integration Stages of the Experimental Study

At the first (orientation) stage, the focus was on introducing students of the *Electrical Power Engineering* specialization to the objectives, structure, and significance of technically oriented physics education. This phase aimed to raise students' awareness of the role of physics in solving professional engineering problems, to motivate them toward the practical application of physical knowledge, and to establish a cognitive foundation for the development of technical competence. Introductory lectures, diagnostic assessments, and discussions on real engineering cases were used to form a professional mindset and to identify students' initial level of readiness.

At the second (formation) stage, the emphasis shifted toward the development of students' basic technical skills through guided learning activities. This included targeted exercises that integrated physics principles with engineering practice—such as problem-solving sessions, laboratory work, and project-based assignments. The purpose of this stage was to form essential components of technical competence, including analytical thinking, understanding of technical processes, and the ability to apply theoretical knowledge to standard engineering situations.

At the third stage - the development phase, the pedagogical focus shifted toward the enhancement of students' practical abilities and technological skills. This phase emphasized the technological component of technical competence (TC) through the systematic completion of progressively more complex learning tasks. Students were encouraged to apply their theoretical knowledge in practical settings, solving context-based engineering problems and demonstrating the ability to select and justify appropriate technological methods.

To strengthen the value–motivational component (as defined in Table 1), the research team designed detailed methodological guidelines for students' independent and project-based learning. The guidelines aimed to cultivate self-directed inquiry and professional interest in the discipline. Student motivation was sustained through interactive consultations, mentoring sessions, and supervised independent study. Instructors provided continuous feedback and addressed individual questions that arose during the study of physics, ensuring that self-learning remained purposeful and structured.

During this stage, additional independent and creative assignments were introduced to stimulate learners' engagement and sense of responsibility for their educational progress. The motivational growth of students was facilitated by cultivating their interest in professional achievement and by forming a holistic understanding of physical knowledge at an abstract, conceptual level. Analytical and reflective approaches to problem-solving were also reinforced, promoting the ability to generalize principles and apply them to new engineering contexts.

The development of the cognitive–substantive component was achieved through the consistent use of technically directed problem sets and specialized laboratory exercises aligned with real-world engineering tasks. Students were guided to connect theoretical knowledge with experimental observation and data interpretation.

To further enhance the technological–operational component, the educational process incorporated multi-level, structured tasks and student-led research projects. These activities allowed learners to acquire procedural and experimental competencies, perform diagnostics, and test hypotheses relevant to electrical power systems. The complexity of assignments increased gradually, fostering autonomy, precision, and analytical rigor.

At the fourth stage - the integration phase, attention was directed toward consolidating the acquired competencies and evaluating their practical transferability. A set of diagnostic procedures was applied, including active surveys, standardized tests, direct and indirect pedagogical observations, and expert evaluations. The purpose of these methods was to assess the stability of the formed competencies and to identify the dynamics of their development within the experimental and control groups.

Through these comprehensive assessment techniques, the study ensured the reliability and validity of the results while providing empirical evidence of the effectiveness of the professionally directed approach to physics education. The integration stage thus completed the experimental cycle, confirming that the developed pedagogical model fosters measurable and sustainable improvements in students' technical competencies.

RESULTS AND DISCUSSION

Empirical data for this phase of the study were collected through a structured survey instrument designed to assess students' professional readiness and perceptions of key activities within the *Electrical Power Engineering* field. The data analysis followed a multi-stage procedure that included descriptive statistical processing, qualitative interpretation, and comparative evaluation of outcomes between the experimental and control groups. This methodological sequence ensured both the reliability and the interpretive depth of the results obtained from the pedagogical experiment.

The experimental findings revealed a consistent trend across both groups: during the progressive stages of technical competence (TC) development, positive transformations in students' professional and personal characteristics were recorded. However, the magnitude and nature of these changes differed significantly between the experimental and control cohorts, confirming the effectiveness of the professionally directed educational intervention.

As shown in Table 2, the proportion of students demonstrating a *low level* of technical competence in the experimental group declined sharply from 58.2% (60 students) to 14.5% (15 students), which corresponds to a reduction of 43.7% (45 students). In the control group, the decrease was notably smaller-from 61% to 40% (a reduction of 21%, equivalent to 38 students).

A similar pattern was observed for the *average level* of TC formation. Among the experimental group participants, the share of students with average competence increased from 31.11% (32 students) to 38.9% (40 students)-a gain of 7.79% (8 students). In contrast, the control group exhibited a smaller and less stable improvement, with an increase of 18.3% (from 48.8% to 30.5%, corresponding to 33 students).

The most substantial progress occurred at the *sufficient level* of technical competence. The proportion of students in this category within the experimental group rose dramatically from 10.69% (11 students) to 41.79% (43 students), indicating a 31.1% increase (32 students). Meanwhile, the control group recorded only a marginal 2.5% improvement (from 11% to 8.5%, or approximately 5 students).

It is also worth noting that the number of students achieving a high level of technical competence was significantly greater in the experimental group compared to the control group, underscoring the positive influence of the professionally directed pedagogical approach in physics instruction.

Overall, the comparative analysis confirmed a sustained upward trend in the development of students' technical competencies within the experimental group. These findings demonstrate that contextualized, professionally directed physics education effectively fosters higher levels of professional readiness, self-efficacy, and cognitive engagement among future electrical engineers.

The summarized data, reflecting the quantitative dynamics of competence formation, are presented in Table 3, which outlines the distribution of TC levels among bachelor's students across different stages of the pedagogical experiment conducted on the basis of professionally directed physics training (in %).

Table 3. Levels of Technical Competence Development among Bachelor's Students at Different Stages of the Experimental Work (in %).

Level of Technical Competence	**Before Experiment – *Experimental Group***	**Before Experiment – *Control Group***	**After Experiment – *Experimental Group***	**After Experiment – *Control Group***	**Change (Δ)**
High	0.00	0.00	4.81	1.00	+4.81 / +1.00
Sufficient	10.69	11.00	41.79	13.50	+31.10 / +2.50
Average	31.11	48.80	38.90	30.50	+7.79 / –18.30
Low	58.20	61.00	14.50	40.00	–43.70 / –21.00

The data presented in Table 3 clearly demonstrate that the experimental group exhibited significant improvements in all measured indicators of technical competence. The marked decrease in the proportion of students at the low level and the simultaneous increase at the sufficient and high levels confirm that the professionally directed physics model exerts a measurable and positive pedagogical effect.

The **dynamic progression** of students' technical competence (TC) levels throughout the experimental work is visually depicted in **Figure 2**. The graph provides a comparative illustration of the quantitative changes that occurred between the experimental and control groups during the pedagogical intervention.

On the **x-axis**, the **zero point** represents the *initial diagnostic stage*-the baseline measurement of students' technical competencies prior to the implementation of the formative experiment. Subsequent points on the axis correspond to the intermediate and final stages of the experimental cycle, reflecting the gradual enhancement of TC levels achieved through professionally directed physics instruction.

The **y-axis** displays the **percentage distribution of students** across the identified levels of technical competence (low, average, sufficient, and high). This visualization highlights the marked upward trend within the experimental group, confirming a steady transition of students from lower to higher levels of competence development.

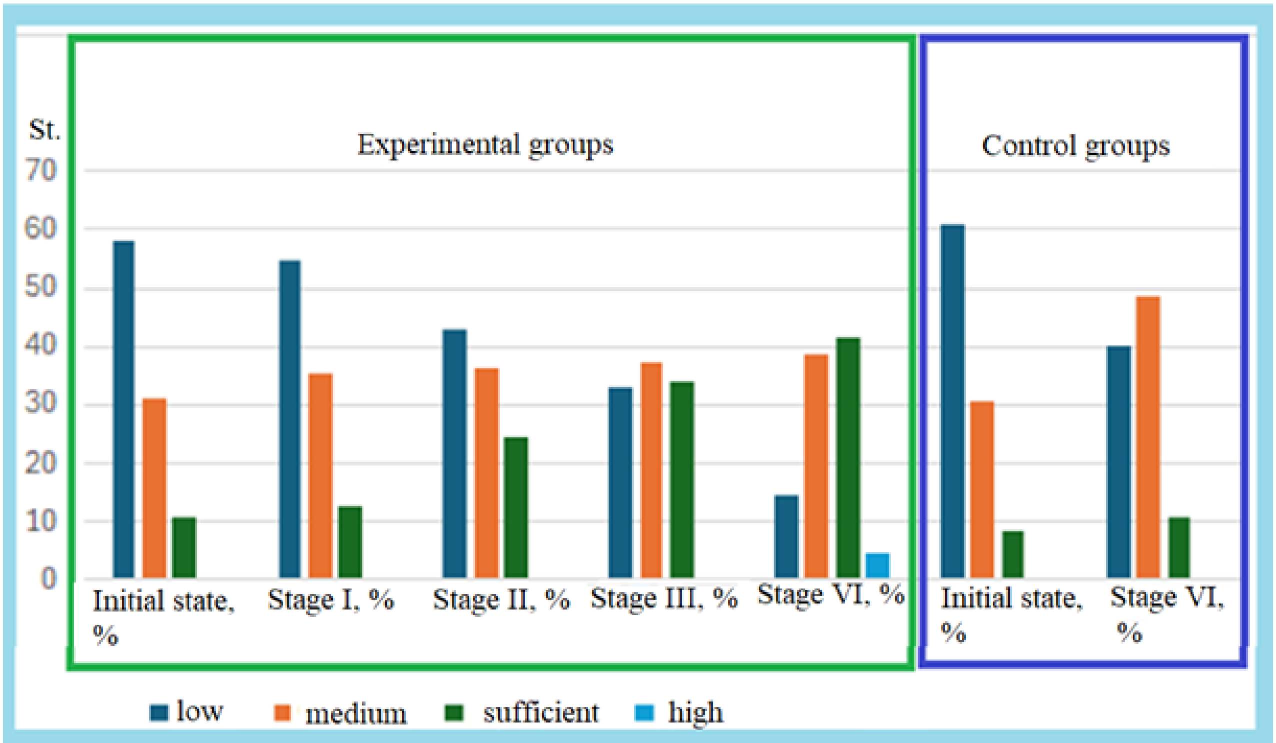

Figure 2. Dynamics of changes in students' TC levels.

CONCLUSION

The results of the conducted research confirm that the effective development of technical competencies (TC) among bachelor's students in Electrical Power Engineering is achieved when the educational process is deliberately structured in accordance with a professional activity model (see Figure 1). This model ensures that academic content, pedagogical strategies, and practical tasks are harmoniously aligned with the functional requirements of future engineering professions. The integration of such a framework facilitates the transfer of theoretical knowledge into practice and promotes the systematic growth of professional readiness throughout the learning process.

The professionally directed educational and methodological complex developed for the discipline Physics proved to be an essential pedagogical tool for this alignment. It serves as a cognitive and methodological foundation for mastering subsequent specialized subjects, enabling students to assimilate interdisciplinary knowledge and to contextualize abstract physical principles within their professional domain. In this way, fundamental training in physics not only supports students' understanding of modern technological processes but also accelerates their adaptation to emerging innovations and complex engineering tasks. Professionally contextualized instruction thus becomes a catalyst for cultivating analytical thinking, creative problem-solving, and sustained motivation-qualities indispensable for future engineers.

The experimental validation of this methodology, conducted over the period from 2018 to 2025, demonstrated its pedagogical efficacy and practical applicability. The approach can be effectively implemented in universities, technical institutes, and colleges offering bachelor's programs in engineering and related disciplines. Its adoption contributes to raising the overall quality of professional training, ensuring that graduates possess the competencies demanded by the contemporary labor market. Moreover, it establishes a replicable educational model that supports the continuous improvement of teaching practices and the sustainable development of technical and professional skills in engineering education.

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Transparency: The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

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