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Formation of technical competencies of university students based on professionally oriented physics education

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Abstract

The article is dedicated to the study of technical competencies (TC) of university students and their development through professionally oriented physics education. The aim of this research is to provide a theoretical justification and practical basis for developing content and methods aimed at enhancing the TC of university students through professionally oriented education in physics. The work is based on fundamental principles of personality and activity theory. The structure, content, levels, components, criteria, and indicators of TC are defined. A model of the future bachelor's activity is presented using the example of the «Electrical Power Engineering» specialty to determine educational goals related to professional tasks in the industry. A technology for effectively developing TC in first-year students of technical universities based on professionally oriented education has been developed, linking all components of training with the competencies necessary for professional activity. The pedagogical study involved 283 students, including 103 from the experimental group and 180 from the control group. Theoretical methods, numerical calculations, and experimental data were used to compare the research results. Pedagogical conditions for developing technical competencies in students during professionally oriented physics education have been identified. According to pedagogical research data, it has been proven that the formation of TC in university students within the framework of bachelor's training in «Electrical Power Engineering» can be effectively implemented by orienting the educational process towards a specialist's activity model. A connection has been established between the levels of technical competency formation and the academic success of students in university.

Keywords: Physics, Professionally-oriented training, Student, Technical competencies, University.

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1. Introduction

The research conducted by both local and international scholars and educators showcases a variety of perspectives on the content and organization of technical training for professionals. These ideas are explored from the standpoint of theories on personality development, including personality-oriented, personality-activity, and competency-based approaches, as well as the social aspects of innovative activity and the dynamic characteristics of educational technologies [1-5]. Attention is paid to the level of formation of knowledge, skills and abilities necessary for future professional activity, the formation of specialist competencies that are considered necessary for successful professional activity [6-10]. The crucial role of technical competencies in enabling engineers to effectively fulfill their professional responsibilities is also highlighted [11-13].

Existing approaches to the formation and development of technical competencies as systemic, personal-activity, and competence-based models consider various frameworks for implementation within university education [14-18].

In our research, we promote the implementation of targeted professional training, where TCs are cultivated through educational experience, emphasizing the educational content and the organization of student activities in relation to their future professional responsibilities. In this framework, the training model for students in higher technical education will align with the characteristics of the personality traits being examined. Thus, our study focuses on the professionally oriented educational process as the object, while the subject pertains to the development of students' TC.

Creating an environment within the educational framework that allows students to enhance their TC is a key priority in higher education. Through a theoretical review of psychological and pedagogical literature, we have previously concluded that TC encompasses a combination of knowledge, skills, and personal attributes that influence the effectiveness of engineering tasks. This effectiveness relies on the application of scientific and technical knowledge in production, aimed at researching and refining engineering entities, such as technical systems and technological processes [5].

Furthermore, we assert that TC aids in goal setting and the organization of collaborative production and technical efforts focused on developing and sustaining systems that fulfill socio-technical requirements. This encompasses appropriate attitudes towards technology, proper use of machinery, tools, and materials; adherence to safety protocols; maintaining a tidy workspace; and a responsible approach to resource management, all of which contribute to creating safe and comfortable working conditions. The university of the educational process and the identification of methods for the gradual enhancement of TC in university education are fundamentally linked to the assessment of the phenomenon being studied.

This includes identifying the structure and levels at which university students form TC in undergraduate education. In our case, we focus on natural science disciplines, such as physics, which allow for the initiation of the TC formation process in early coursework.

The aim of this research is to identify the levels and criteria essential for developing TC, positioning them as a fundamental priority in higher education for students [5].

2. Methodology

In our research, we based our work on the core principles of personality and activity theory, which enabled us to formulate a working definition of the quality being examined - TC. This quality is defined as a characteristic of an individual that includes both the potential ability and the readiness to tackle professional challenges encountered in the workplace, thereby fostering a value-driven approach to these tasks [4, 5].

When developing the matrix model of TC for university students, we based our approach on the competence-based theory and professionally oriented training (POT) for bachelor's programs [1, 2, 4, 6, 9, 19, 20]. Accordingly, we identified three key components of TC: value-motivational, substantive, and technological.

Value-motivational component: This component reflects an individual's professional orientation, showcasing their value systems and motivation to engage with educational and professional tasks pertinent to their selected field.

Substantive component: this includes both theoretical and empirical knowledge, comprising scientific theories, principles, laws, and facts related to natural processes and their characteristics, as well as an understanding of the profession and the roles of specialists involved in the development and maintenance of energy systems.

Technological component: This component highlights the capability to apply acquired knowledge in practical and operational ways that are suited to specific contexts, relevant to both educational and cognitive activities during training and in future professional pursuits.

Based on our analysis of existing studies on the formation of technical competencies and in line with our definition of their essence, we identified specific criteria and indicators [21].

In line with our methodological framework, technical competencies as a trait of personality are cultivated through a cohesive process of student development, taking place within the comprehensive educational environment of a technical university. Consequently, the criteria we have set forth represent the skills that students need to acquire to successfully tackle professional challenges in the future.

We propose the following criteria for evaluating TC:

- Student activity and independence: This criterion assesses the students' engagement and autonomy in all forms of POT and their motivation to achieve personal goals. The indicators encompass their perspectives on the learning experience and their future career endeavors, along with their comprehension of the personal qualities demanded by the profession.
- Understanding of professional role: This criterion assesses the student's grasp of the roles and importance of specialists in the energy sector within the framework of contemporary collaboration, as well as their proficiency in self-oriented learning techniques. Indicators for this criterion include the level of awareness regarding the need to acquire a comprehensive knowledge base for successful future careers and an emphasis on teamwork within student groups.
- Self-perception as a future professional: This criterion explores how students perceive themselves in relation to their prospective professional roles. Through targeted training, students acquire theoretical knowledge in their academic fields and cultivate a value-driven approach to their future careers. Indicators for this criterion include their ambition for success, understanding of professional expectations, and self-evaluation of their core professional attributes.

Based on these criteria, we established relevant indicators that can be illustrated in a matrix model, capturing both the qualitative elements of the phenomenon being studied and its important quantitative dimensions (see Table 1) [4, 5].

Table 1.
Model of TC in the form of a matrix.

TC: indicators / **TC: Criteria in the formation**	**Components**		
	motivational value	**substantive**	**technological**
Engagement and autonomy in POT, along with the aspiration to reach objectives	Readiness to learn, recognizing the importance of willpower and personal growth.	The possession of knowledge and skills in specific fields.	Capability to apply subject knowledge to practical tasks with an emphasis on future specialization
Understanding the role, function, and importance of a specialist in the energy sector in today's world, along with the ability to engage in self-oriented learning.	A proactive and engaged attitude towards the future professional field, as well as a commitment to acquiring a contemporary technical education.	Acquiring a comprehensive understanding of natural science concepts in POT to ensure effective training in a chosen specialty.	The capacity to organize and categorize knowledge acquired through information research for self-oriented learning.
Perception of oneself as a participant in future professional endeavours.	The ambition and determination to succeed, along with an awareness of one's personal abilities in relation to their educational level.	Acquiring techniques for gaining knowledge during POT and utilizing them in a future career in line with industry standards.	The ability to assess and evaluate the outcomes of educational and cognitive activities, make adjustments as needed, and maintain self-esteem.

In accordance with this structure of students' technical competencies, we have identified high, sufficient, average, and low levels of technical competencies:

- High: Students who have achieved a high level of TC exhibit a consistent and positive attitude towards their academic pursuits and future careers. They acknowledge the importance of acquiring knowledge that is professionally relevant to their field of study. At this stage, students not only grasp the significance of collaboration and professional communication for their future roles but also possess the skills to engage effectively in teamwork with peers and instructors. They are adept at applying their knowledge to tackle complex educational and cognitive challenges. Furthermore, their ability to differentiate between their ideal self and their actual self enables them to assess their skills realistically, promoting a proactive and intentional approach to self-education. At this TC level, students harmonize their professional goals with their personal aspirations.
- Sufficient: This level is marked by a consistently high level of cognitive engagement, which aids in the acquisition of a standard knowledge base. With a positive outlook towards their future careers and a readiness to learn, students recognize the importance of their chosen profession. They understand that their personal characteristics affect their

capacity to address future challenges and adapt to various situations. While they can effectively utilize their knowledge to solve educational and cognitive problems within their discipline, they still require guidance from their instructors. They are also capable of assessing the outcomes of their efforts.

- Average: at this stage, students generally maintain a positive attitude towards their education and future careers, driven by the aspiration to achieve a certain social status. However, their motivation to engage in professional activities tends to fluctuate based on circumstances.
- Low: Students in this category display a vague positive inclination towards learning. They may recognize the importance of developing technical skills but face considerable challenges in doing so. As a result, their initiative in decision-making or self-evaluation is infrequently demonstrated.

In summary, the criterion-level framework for assessing students' TC not only identifies the indicators of their development, as outlined in Table 1, but also categorizes the levels of TC.

The TC model we created for students in technical universities allows us to explore the underlying mechanisms of this phenomenon. Gaining insight into these mechanisms helps us pinpoint methods, tools, and formats for the gradual development of TC within the educational framework of the university, ultimately improving the quality of training for specialists in the technical education sector.

Our research spanned seven years, from 2018 to 2025, and was conducted in phases. The objective of the subsequent experimental study was to investigate and identify effective methods, strategies, and conditions that facilitate the development of technical competencies in aspiring electrical engineers. To this end, a scientific and methodological seminar was organized for university educators involved in training electrical engineers, with efforts taking place at both national and international levels. We reviewed state educational standards and standard curricula, as well as analyzed scientific literature related to research in electrical engineering and the modeling of pedagogical processes. This comprehensive approach enabled us to create a model for the activities of specialists in developing technical competencies for a bachelor's degree in electrical power engineering, aligned with labor market demands for the professional training of engineers Figure 1.

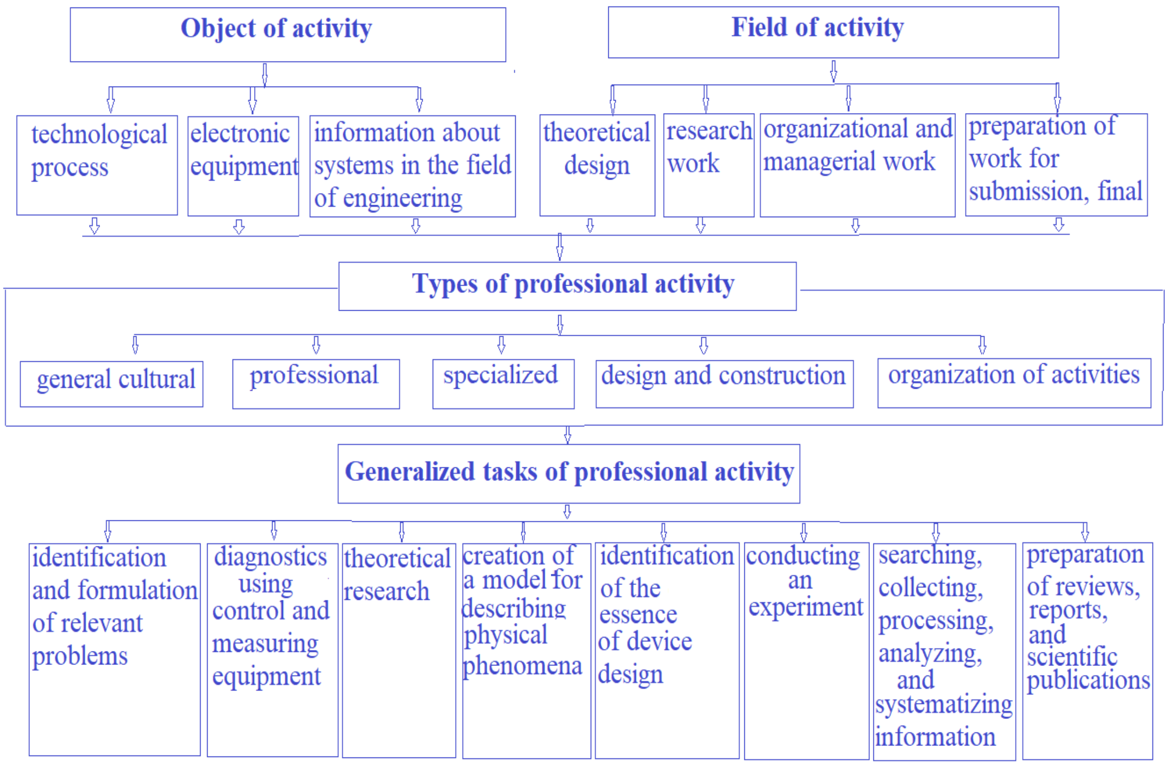

Figure 1.
Model of specialists' activities for developing technical competencies for a bachelor's degree in electrical power engineering.

The objects of study for a bachelor's degree in electrical power engineering can be identified as follows: a) the technological processes involved in the production, transmission, reception, processing, and storage of information within electrical networks; b) the electronic and electrical equipment associated with these systems; c) various types of information regarding these systems and their operational modes.

The areas of activity are characterized by the shared production functions of the aggregate bachelor in this field, which define the theoretical preparedness and organizational role of the engineer within the production process. These areas form a functional component of the model that encompasses the theoretical, research, and organizational-management functions of the engineer. By jointly examining the subject and functional structures of activity, we can identify the primary types of professional activities for this bachelor's profile, and, through them, outline generalized professional tasks.

The main types of activities for an electrical power engineer include [4, 5]:

2.1. General Cultural

- The ability to enhance one’s general cultural and professional level and independently acquire new research methods;
- The capacity to act as a communicator who can facilitate administrative and business communication to activate the human factor;
- The ability to adapt to one’s professional focus;
- The skill for self-assessment and the ability to draw conclusions;
- The capability to make organizational and managerial decisions and evaluate their outcomes;

2.2. Professional

2.2.1. Organizational Management

- The ability to manage projects and networks;
- The capacity to formulate corporate strategies;
- The skill to apply modern methods for addressing strategic challenges;
- The ability to create programs for organizational development and change and ensure their execution.

2.3. Analytical

- The capability to employ both quantitative and qualitative methods for carrying out scientific and applied research;
- Proficiency in strategic analysis methods;
- The capability to create analytical documents for evaluating their effectiveness.

2.4. Research

- The skill to synthesize and critically assess findings from both domestic and international researchers;
- The skill to recognize and articulate pertinent scientific issues;
- The skill to carry out independent research based on a formulated plan;
- The skill to present research outcomes in the format of a scientific report, article, presentation, or analytical note.

2.5. Specialized

- The ability to conduct qualitative and quantitative analysis in the field of the country's electrical power engineering;
- The capability to evaluate contemporary information technologies;
- The capability to assess current theoretical and methodological approaches to investigating scientific issues.

The analysis of information enabled us to identify several generalized tasks related to professional activities in the field of electrical power engineering, which can be applied in physics education.

The developed model comprises four components that represent the object, areas, types, and generalized tasks of professional activity.

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 oriented 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 oriented 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 oriented physics course for students of the EP «Electrical Power Engineering» on the topic «Dynamics».

Table 2.
Example of the components of a traditional and professionally oriented physics course for students of the EP «Electrical Power Engineering» on the topic «Dynamics».

Topic	**Dynamics**	
Lesson type	**Lecture**	
Type of training	**Traditional**	**Professionally oriented**
Used methods	Traditional, modular-heuristic, interactive, problem-based, project-based, case method, remote, electronic, experiential learning, flipped classroom, gamification, differentiated.	
Goals of the lecture	- Development of students' understanding of fundamental concepts and principles of mechanics; - Examination of the laws of dynamics and their characteristics.	- Development of students' understanding of fundamental concepts and principles of mechanics; - Examination of the laws of dynamics and their characteristics. - *Formation of students' technical competencies through the elucidation of the meaning of physical phenomena and the laws of dynamics related to their future professional activities.*
Lecture Contents	Dynamic characteristics of motion, equation of dynamics for a material point. Dynamics of rigid bodies. Work and power. Moment of impulse. Moment of force. Moment of inertia of a rigid body. Steiner's theorem. Equation of dynamics of rotational motion of a rigid body relative to a fixed axis. The analogy between the descriptions of rotational and translational motion [24].	+ *Application of the laws of dynamics in electrical circuits and systems. Free axes. Gyroscope. The principle of wind energy conversion: wind generator (familiarization with the basics of wind energy). Energy-saving opportunities in a frequency-controlled drive: Mechanical characteristics of a pumping unit.*
Lesson type	Practical	
Goals of the practical lesson	- Deepening of theoretical knowledge presented in lectures; - Application of theoretical knowledge to solve practical problems.	+ - Formation of technical competencies in students through the application of materials with technical content.
Lesson type	Laboratory	
	List of proposed works: 1. Investigation of the laws of kinematics and dynamics through the use of Atwood's machine. 2. Determination of the coefficient of rolling friction using the inclined pendulum method. 3. Calculation of the moment of inertia for Maxwell's pendulum. 4. Measurement of the moment of inertia of solid objects through torsional oscillationsDetermination of the projectile's velocity on a ballistic torsional pendulum. 5. Study of the gyroscopic effect.	+ For each subgroup of students, tasks numbered 1, 3, 4, and 6 from this list of assignments are mandatory to complete. These tasks help to understand the importance of calculating the moment of inertia for the development and optimization of machines such as generators, turbines, and electric motors, as it affects their dynamic characteristics, including acceleration and stability (the works in question have been virtualized by us, and there are author certificates) [25].
Type of control		
	Control task, test	A system of practical and technical problems. Physical problems provide insights into the operational principles of mechanisms and machines, as well as the transmission and transformation of energy, among other aspects.
	Calculation and graphic work	lems demonstrated the application of physical laws in electrical energy and everyday human life
	IWS, IWST, SRP (Student research paper) [26]	1. Prospects for the use of wind turbines in Kazakhstan and the world. 2. Anemometers: types, principles of operation, and application in the electric power industry. 3. Methodology for Highly Efficient Pump System Management [27].

At the third stage – development - the emphasis was on improving the skills and abilities related to the technological component through the completion of progressively more complex tasks.

To develop the value-motivational component (Table 1), methodological guidelines for independent work and research projects were created. Interest in the discipline was maintained through consultations during independent work and self-study under the guidance of an instructor. Students received interactive consultations on questions arising during the study of physics. Throughout the educational process, students were assigned additional independent tasks. The level of this component was also enhanced by increasing interest in professional activities to achieve high results in the learning process, which contributes to the formation of physical knowledge in a generalized and abstract manner, as well as to the analytical processing of educational assignments.

The development of the content component among students was linked to solving technically oriented problems and completing selected laboratory work.

Structured and multi-level assignments, along with student research, were used to enhance the technological component of technical competencies in the educational process.

At the fourth stage – integration - active surveys, testing, and both direct and indirect observations were conducted, aimed at analyzing expert assessments and other methods.

3. Results and Discussion

The data was obtained through a survey that included questions related to the professional activities of future power engineers. The processing of data from the pedagogical experiment, obtained through a survey, included several stages. After conducting descriptive statistics, qualitative analysis, and comparative analysis, the results were obtained.

The findings of the experiment indicated that both the experimental and control groups exhibited a common trend: during the phased development of technical competencies, certain personal qualities are observed to develop. However, the nature of these changes differs between the two groups. The data shown in Table 2 reveal that the proportion of students with a low level of developed technical competencies in the experimental groups dropped significantly from 58.2% (60 students) to 14.5% (15 students), which corresponds to a reduction of 43.7% (45 students). In the control groups, this indicator decreased only by 21% (from 61% to 40%, which corresponds to 38 students).

Furthermore, the number of students with an average level of developed technical competencies in the experimental groups increased from 31.11% (32 students) to 38.9% (40 students), reflecting a growth of 7.79% (8 students). In the control groups, this growth was 18.3% (from 48.8% to 30.5%, corresponding to 33 students).

The proportion of students demonstrating a sufficient level of developed technical competencies in the experimental groups rose from 10.69% (11 students) to 41.79% (43 students), reflecting an increase of 31.1% (32 students). In contrast, the control groups experienced only a 2.5% increase (from 11% to 8.5%, equivalent to 5 students).

It is important to highlight that the experimental groups had a greater number of students achieving a high level of technical competencies development compared to the control groups.

The analysis data confirms the positive dynamics of TC development, which is also presented in Table 3.

Table 3.
Levels of developed technical competencies among bachelor's students at different stages of the experimental pedagogical work conducted based on professionally oriented physics training (in %).

Levels of development of students' TC	**Experimental groups**					**Control groups**	
	Phase. %						
	Initial	**I**	**II**	**III**	**IV**	**Initial**	**IV**
Low	58.2 (60st)	52	43	31.9	14.5 (15st)	61	40
Average	31.11	35.5	36	34.8	38.9	30.5	48.8
Sufficient	10.69	12.5	22	33.3	41.79	8.5	11.2
High	-	-	-	-	4.81	-	-

The graphical representation of the changes in students' levels of technical competencies throughout the experimental pedagogical work is shown in Figure 2. The zero point on the x-axis indicates the initial state of students' technical competencies prior to the commencement of the formative experiment.

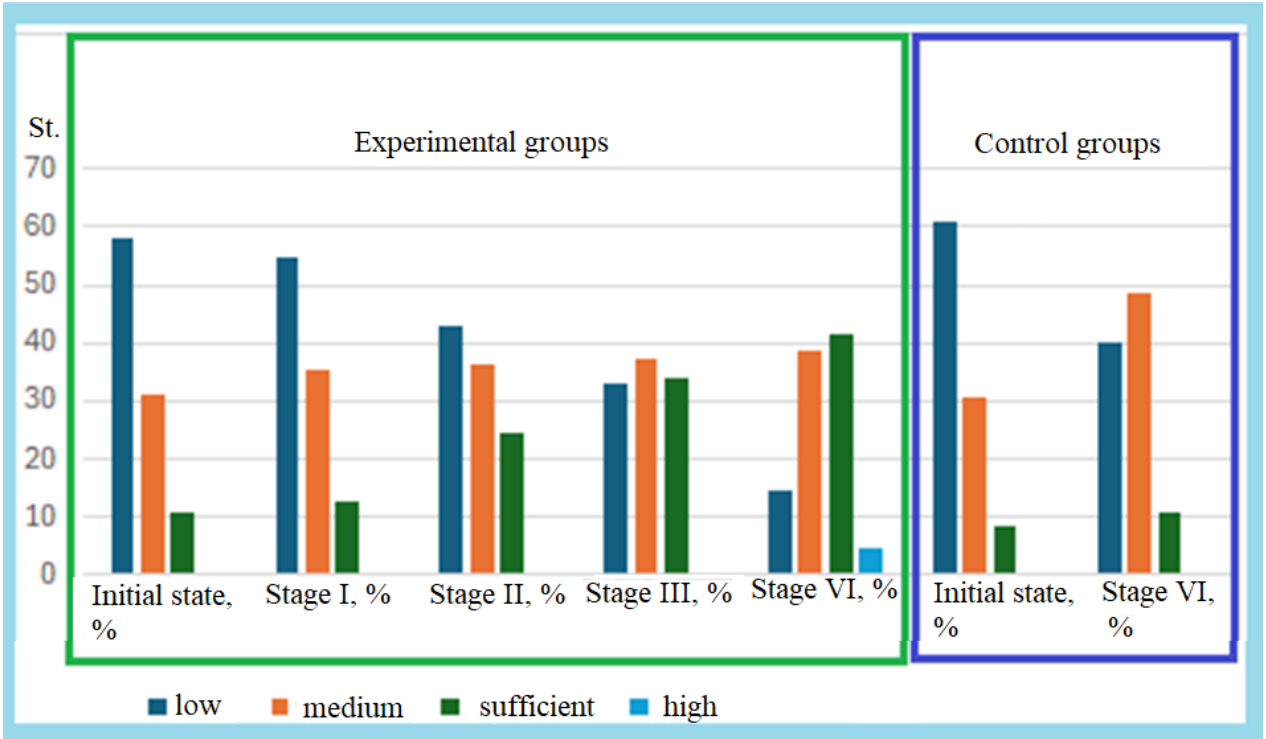

Figure 2.
Dynamics of changes in students' TC levels.

4. Conclusions

Successful development of technical competencies in bachelor's degree students studying electrical engineering can be achieved if the educational process is aligned with the model of professional activities aimed at cultivating these competencies (Figure 1). A professionally oriented educational and methodological complex of the discipline serves as a foundation for studying more complex subjects (prerequisites) and helps students assimilate and integrate information from additional courses. Fundamental knowledge of physics facilitates specialists' adaptation to the demands associated with the development of cutting-edge technologies in the field of electrical engineering, while professionally oriented physics education accelerates the acquisition of new professional tasks, which is important for a successful career.

The experimentally confirmed effectiveness of the methodology for forming students' TC, applied during the academic years from 2018 to 2025, can be successfully implemented in universities and institutions that offer bachelor's degree programs, as well as in technical colleges. The implementation of this methodology will enhance the quality of training specialists who meet the modern labor market requirements and contribute to the effective acquisition of necessary technical skills and competencies by students.

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