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Teaching physics to future engineers: Approaches, challenges, and prospects

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Abstract

This article explores the significance of physics as the foundation of engineering education and a key instrument in developing engineering thinking among students of technical specialties. The study analyzes current challenges in physics education, including the abstract nature of content, the lack of practical orientation, and the disconnect between academic curricula and industry needs. It also highlights the insufficient student motivation to study the subject, which stems from the gap between theoretical knowledge and real-world engineering experience. The authors propose modern approaches to teaching physics, such as competency-based and project-oriented methodologies, the use of digital technologies, virtual laboratories, simulations of physical processes, and the establishment of interdisciplinary connections with engineering and IT disciplines. Special emphasis is placed on the development of soft skills, including critical thinking, communication, teamwork, and the cultivation of an engineering mindset through experimental, research, and project-based activities. The article also discusses the potential for integrating physics into the context of real engineering problems through the use of industry case studies and collaboration with industrial partners. In conclusion, the authors outline promising directions for the advancement of physics education amid the digital transformation of engineering professions, including adaptive learning, personalized learning trajectories, and the implementation of hybrid educational formats.

Keywords: Engineering education, Engineering thinking, Physics teaching, University, Student.

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1. Introduction

Modern engineering education is evolving within a rapidly changing technological and social environment. Digitalization, the development of artificial intelligence, automation of production processes, globalization of the economy, and environmental challenges require future engineers not only to possess deep professional knowledge but also to demonstrate high adaptability, interdisciplinary thinking, critical analysis, independent decision-making, and innovative capabilities. In this context, physics holds a special and strategically important position as a fundamental science that shapes scientific worldview, logical and systems thinking, and provides a solid foundation for understanding and modeling real engineering processes and technical phenomena [1, 2].

However, despite the recognized importance of physics in engineering training, the teaching of this discipline in most technical universities faces a number of persistent issues. These include the abstract and overloaded nature of the curriculum, a weak connection between theory and real-world practice, a lack of personalized approaches, and a gap between course content and the actual needs of industry. All of this leads to decreased student interest in the subject, superficial knowledge acquisition, and difficulties in applying physical concepts when studying core engineering disciplines or engaging in future professional activities [3].

The relevance of this article lies in the urgent need to modernize the teaching of physics in alignment with contemporary educational and technological demands. Special attention is given to the implementation of competency-based, project-based, and interdisciplinary approaches, the use of digital tools, the visualization of complex concepts, virtual laboratories, and interactive learning formats. In addition, the article emphasizes the importance of soft skills and engineering thinking as integral components of professional training [4].

This article aims to analyze the key problems and trends in teaching physics at technical universities and to substantiate effective pedagogical strategies that can enhance the quality of engineering education in the context of digital transformation [5-7].

2. Methodology

The methodological foundation of this study is based on an interdisciplinary approach that combines elements of pedagogy, engineering didactics, cognitive psychology, and digital educational technologies. The main objective is to identify effective methods and tools for teaching physics in a technical university that contribute to the development of engineering thinking, the formation of key competencies, and the enhancement of student motivation. Both theoretical and empirical methods of analysis were employed throughout the research process.

The theoretical framework included the study and synthesis of scientific literature, regulatory documents in the field of higher education, digital transformation strategies, as well as leading international practices in teaching natural sciences. Special attention was given to research in the areas of competency-based learning, project-based education, STEM pedagogy, and methodologies for fostering engineering thinking.

The empirical phase of the research focused on identifying current issues and needs in teaching physics to students of engineering disciplines. This included the analysis of academic curricula, surveys of students and instructors at technical universities, and expert interviews with representatives from the industrial sector. The sample included second- and third-year students from engineering programs (a total of 120 participants) and physics or related subject instructors (15 participants).

Survey and interview methods helped to identify the following key issues: low motivation to study physics, lack of understanding of the subject's practical relevance, difficulties in mastering abstract concepts, insufficient laboratory and project-based work, and limited use of digital tools and simulation platforms. The collected data served as a foundation for justifying the need to update teaching methodologies.

Pedagogical design methods were also applied. Models for integrating physics into the context of engineering tasks were developed, taking into account interdisciplinary connections (e.g., physics + programming, physics + engineering graphics, physics + astronomy). Case-study methods, elements of problem-based learning, and digital simulations implemented through platforms such as PhET, Algodoo, and Virtual Labs were utilized.

The methodology for evaluating teaching effectiveness was based on both qualitative and quantitative analysis: academic performance, student engagement levels, and reflective feedback were compared before and after implementing the updated pedagogical strategies. Additionally, student reflective journals, project deliverables, and laboratory reports were analyzed.

Thus, the chosen methodology not only made it possible to identify the problem areas in current physics teaching practices but also enabled the testing of several innovative approaches aimed at improving the quality of engineering education. Special attention in the research was given to creating conditions for the development of systems thinking, the ability to analyze complex technical processes, and the enhancement of soft skills through collaborative research and project-based activities.

3. Results and Discussion

As a result of the theoretical and empirical research, significant data were obtained that allow for an assessment of the current state of physics education in technical universities and the identification of areas for its improvement in terms of developing engineering thinking among students.

3.1. Analysis of Academic Programs and Educational Environment

The analysis of current physics curricula in three technical universities showed that, overall, course structures remain traditional and are primarily focused on theoretical instruction. In most cases, laboratory work is limited to a standard set of 8–10 tasks, which generally do not have a direct connection to real-world engineering practice. Interdisciplinary components are minimally represented, and students' involvement in project-based and research activities is still underdeveloped.

Moreover, it was noted that digital educational resources, despite the availability of the necessary infrastructure (computer labs, access to LMS platforms, and internet), are not yet widely used in teaching practices. Digital tools are mainly applied to knowledge assessment (e.g., testing and report submission), while their potential to enhance the content and methodology of instruction remains largely underutilized.

3.2. Survey Results Among Students

A total of 120 students from leading universities in Kazakhstan participated in the survey, including:

- Gumarbek Daukeyev, Almaty University of Power Engineering and Telecommunications (60 students),
- Al-Farabi Kazakh National University (30 students),
- Kazakh Leading Academy of Architecture and Civil Engineering (30 students).
- Participants were 1st- and 2nd-year students enrolled in engineering programs such as power engineering, astronomy, radio electronics, and information technologies. The survey revealed the following trends (Figure 1):
- 72% of students believe physics is taught too abstractly and lacks a clear connection to their future profession.
- 65% struggle to understand the material due to insufficient visualization and weak practical focus.
- 58% feel that classes do not support the development of independent thinking and creative approaches.
- Only 22% of students had participated in any physics-related project during their studies.
- Just 18% consider physics to be one of the "useful" subjects in the context of their engineering education.

At the same time, over 80% of students expressed interest in alternative forms of content delivery, such as simulations, virtual labs, engineering case studies, and interdisciplinary projects.

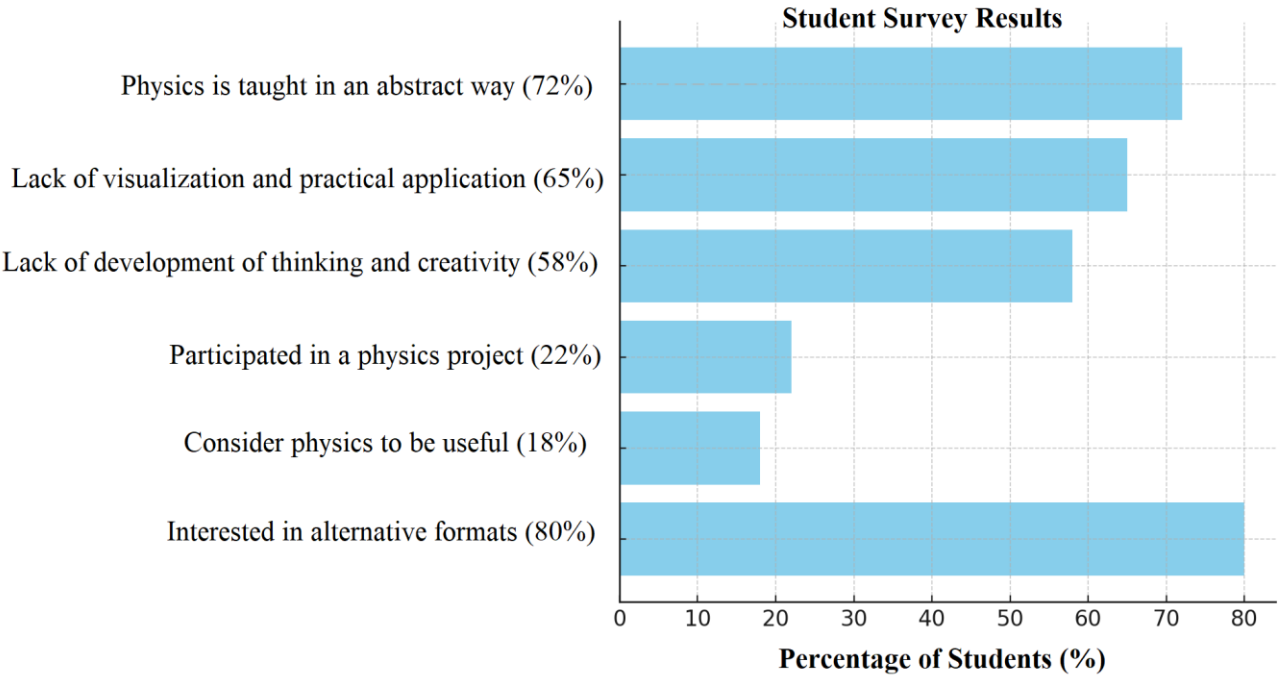

Figure 1.
Results of the student survey.

3.3. Survey of Instructors and Expert Interviews

Out of 15 surveyed instructors, only three reported regular use of digital tools in their classes, although all of them noted a high level of student interest when such tools were applied (Figure 2). The main reasons cited by instructors for not using innovative methods included (Figure 3):

- Lack of methodological support;
- Overloaded curricula;
- Low student motivation;
- Limited preparation time.

Expert interviews were conducted with representatives from industrial partners (four experts from the production sector: JSC «Kazakhtelecom», JSC «Almaty Electric Stations», Tian Shan Astronomical Observatory, and «RAMS Qazaqstan» Construction Company). These interviews revealed that employers expect graduates to possess not only a solid foundation in fundamental knowledge but also the ability to apply it in solving real technical problems. Company representatives noted weak student preparation in logical-mathematical and systems analysis, which could be improved by strengthening the role of physics within the context of engineering design.

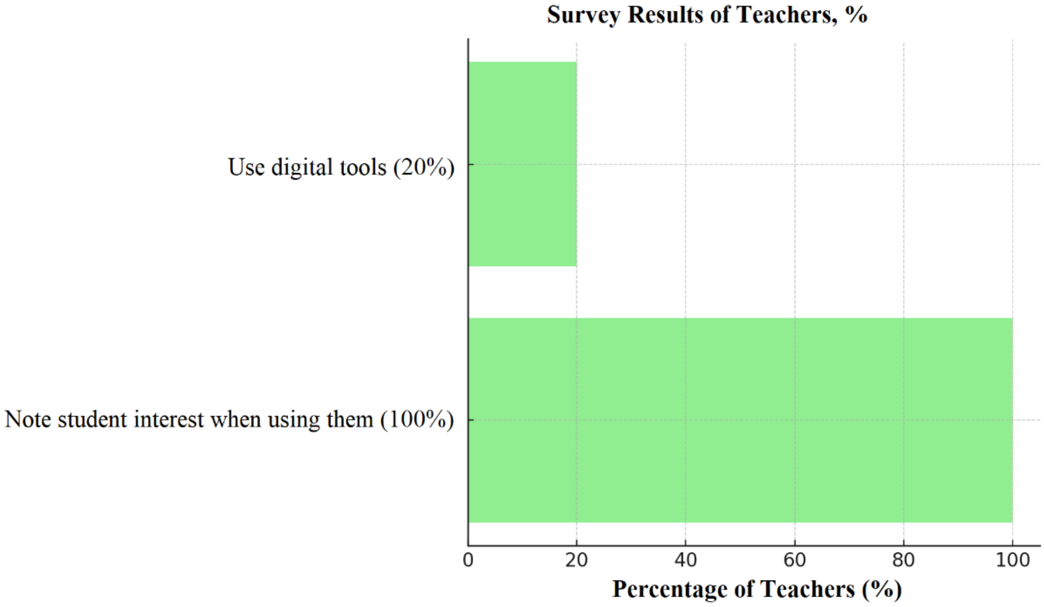

Figure 2.
Survey results of instructors.

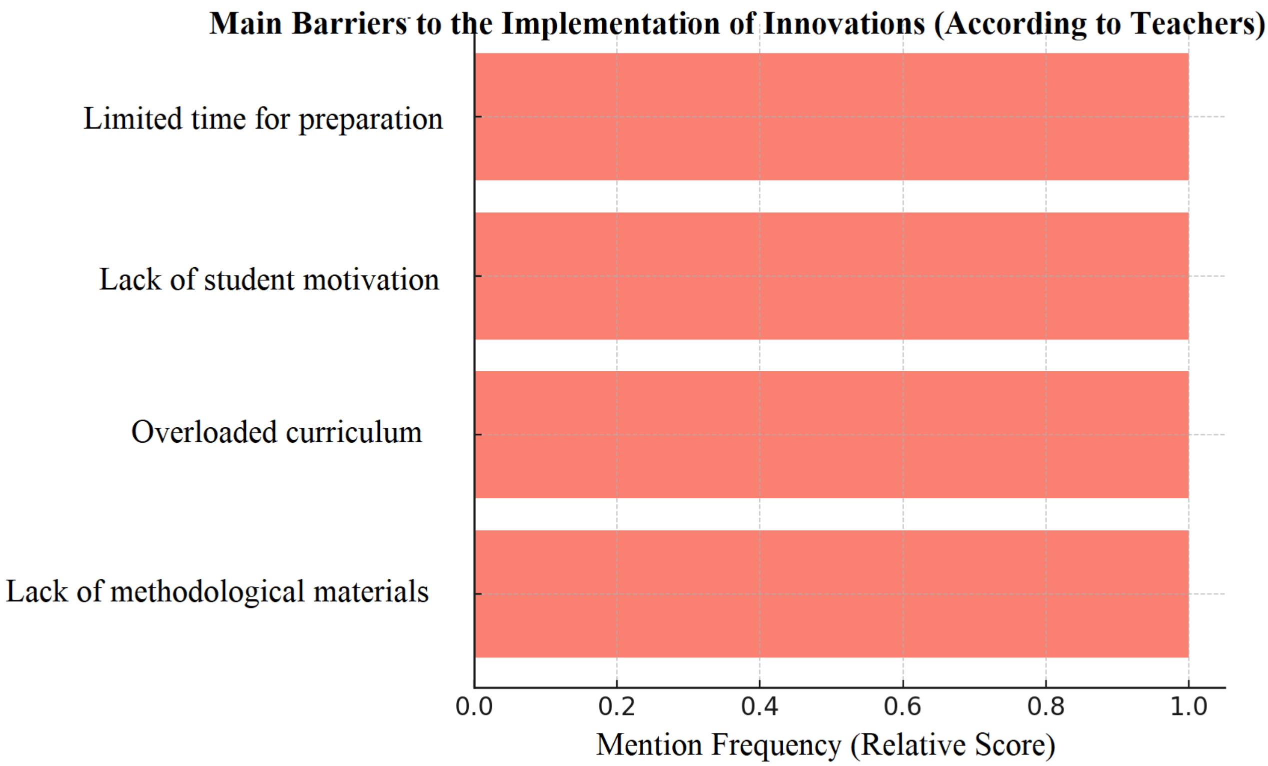

Figure 3.
Barriers to the Implementation of Innovations (According to Teachers).

3.4. Pilot Testing of Updated Teaching Methodologies and Pedagogical Tools

A one-semester pilot implementation of an alternative physics teaching model was carried out across the three participating universities. The model included:

- Application of a competency-based approach,
- Use of simulators (PhET, Algodoo) and virtual laboratories,
- Integration of real industry-based engineering case studies,
- Student participation in mini-projects in team-based formats,
- Interdisciplinary integration of physics with elements of engineering graphics, astronomy, and programming.

The experimental (Table 1) group (three groups, a total of 48 students) demonstrated the following positive outcomes (Figure 4):

- Student engagement levels (based on self-assessment and teacher
- Observations) increased from 35% to 75%;
- The average score on midterm assessments increased by 15% compared to
- The control group;
- 82% of students reported that they began to view physics as a «useful»
- Subject;
- 68% showed improved skills in independent information search and data
- Analysis;
- The majority of students expressed a desire to continue learning in a project-
- And team-based format.

Table 1.
Outcomes of the implemented teaching methodology.

Parameter	**Value (%)**
Engagement level (before)	34.9
Engagement level (after)	75.1
Average score in midterm assessment (increase)	14.8
Perception of physics as a «useful» subject	81.8
Development of independent research skills	68.3

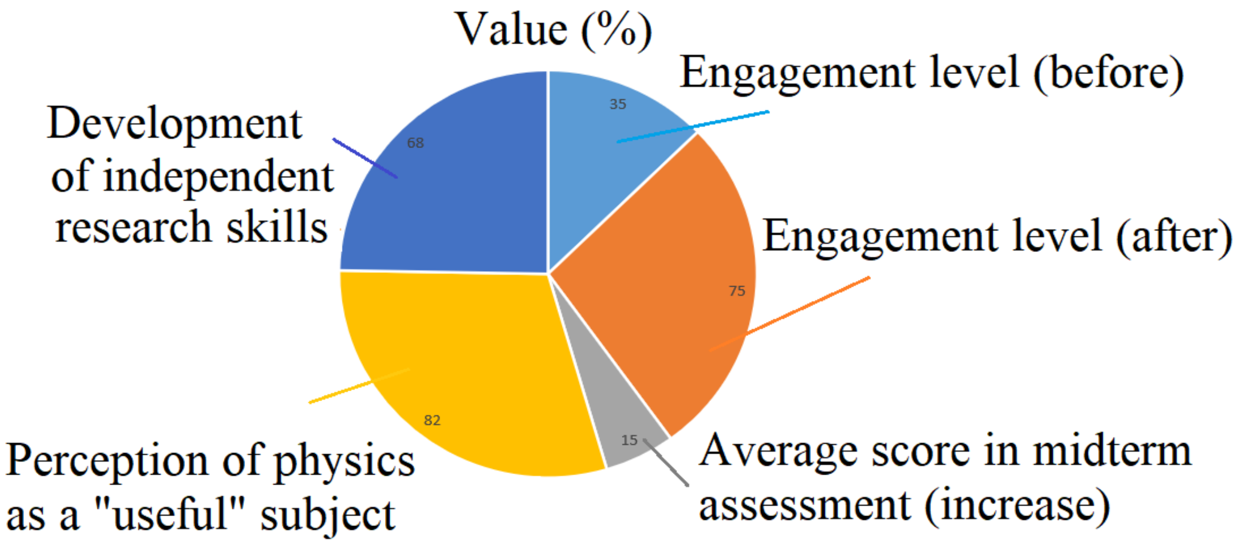

Figure 4.
Dynamics of Positive Changes in the Experimental Group.

4 Discussion of Results

The obtained data suggest that the traditional model of teaching physics in technical universities requires updating in accordance with modern educational demands. The lack of interdisciplinarity, limited practical orientation, and insufficient use of digital technologies contribute to decreased student motivation and do not support the development of engineering thinking.

At the same time, experimental results show that even modest methodological changes such as shifting from lecture-seminar formats to interactive and project-based learning, and integrating visual and digital tools, can significantly enhance students' comprehension of the material and the development of key competencies.

Particularly effective was the use of engineering case studies, where students were not simply reproducing known algorithms but solving open-ended problems: modeling systems, selecting materials, and assessing risks. This approach fosters not only technical abilities but also soft skills such as critical thinking, teamwork, and responsibility for outcomes [8-12].

The importance of interdisciplinary connections must also be emphasized. Integrating physics with engineering disciplines makes the learning process more meaningful and closely aligned with real-world applications. For example, while studying topics such as «Forces and Moments», students solved problems related to structural strength, allowing them to apply knowledge from engineering mechanics and materials science simultaneously.

Furthermore, the use of digital resources—such as virtual laboratories, simulators, and interactive platforms—helped compensate for the lack of physical equipment and created a more flexible learning environment. Students had the opportunity to repeatedly perform experiments, simulate physical processes, and observe the outcomes when system parameters were modified.

5. Conclusions Based on the Results

Thus, the research findings confirm the high effectiveness of applying modern pedagogical approaches in teaching physics to engineering students. In particular:

The integration of project-based and research activities increases student motivation and contributes to the development of engineering thinking.

The use of digital tools makes learning more visual, interactive, and accessible.

Interdisciplinary approaches help students form a holistic understanding of engineering work and promote the practical application of knowledge.

Involving students in solving real technical problems fosters not only professional competencies but also transferable soft skills that are in demand in the labor market [13-18].

The next step should be the systematic adaptation of educational programs in line with these changes, preparing instructors to implement new methodologies, and fostering active collaboration between universities and industry partners to ensure practice-oriented learning.

The conducted study confirmed that physics plays a key role in engineering education as a discipline that forms the foundation for scientific thinking, a systems approach, and the ability to analyze complex technical processes.

However, traditional methods of instruction, primarily based on theoretical lectures and standard laboratory exercises, do not meet the demands of the modern era and fall short in fostering engineering thinking among students in technical fields.

The analysis revealed a significant gap between the content of academic programs and the real needs of industry, a low level of integration between physics and other engineering subjects, as well as insufficient use of digital educational tools. Student surveys indicated a relatively low interest in the subject and a limited understanding of its practical relevance.

At the same time, the pilot implementation of an updated teaching model, including project-based and research activities, digital simulations, engineering case studies, and interdisciplinary connections, demonstrated a positive impact on student motivation, academic performance, and the development of both professional and transferable competencies.

Thus, modernizing the teaching of physics based on competency-based and project-oriented approaches is a necessary step toward improving the quality of engineering education. Digital learning technologies, visualization of physical processes, and contextual links between the discipline and real-world engineering practice are of particular importance. This approach not only enhances students' understanding of the subject but also helps them form a comprehensive vision of their future profession, promotes the development of soft skills, and builds adaptability in the face of a rapidly changing technological landscape.

6. Recommendations

Based on the analysis and synthesis of the collected data, a set of practical recommendations can be formulated to enhance the effectiveness of physics instruction in technical universities and to promote the development of both technical and cross-disciplinary competencies among students.

6.1. Revision of Physics Curricula

Modern requirements for engineering education call for a thorough revision and updating of the content and structure of physics courses. It is recommended to carry out a comprehensive review of current curricula with the aim of integrating project-based and practice-oriented activities. Instruction should move beyond purely theoretical delivery and include tasks aimed at solving applied engineering problems.

This will help students perceive physics not as an abstract subject but as a fundamental foundation of technical training. In addition, it is important to establish strong interdisciplinary links with core engineering courses, fostering systems thinking and a holistic view of the educational process.

6.2. Broad Implementation of Digital Tools

Modern technologies offer extensive opportunities to transform the forms and methods of teaching physics. One of the key priorities is the use of digital tools such as virtual laboratories, interactive simulations, computer models, and educational platforms with visualizations of physical processes. These tools make learning more illustrative, accessible, and interactive. They are especially valuable in situations where access to physical equipment is limited or in remote learning environments. Virtual experiments not only supplement traditional lab work but also expand the possibilities for analyzing complex phenomena that may be difficult or impossible to reproduce in a conventional lab setting.

6.3. Professional Development of Instructors

A crucial element in the successful modernization of physics education is the continuous professional development of instructors. It is recommended to organize regular professional development courses, workshops, training sessions, and methodological internships focused on modern educational technologies, digital tools, and innovative teaching methods. Special attention should be given to pedagogical design, formative assessment, and the implementation of project-based and competency-based approaches. This will ensure a higher quality of teaching and sustained motivation among instructors to engage in self-development and adopt new practices in their teaching.

Strengthening Collaboration with Industrial Partners

Effective physics teaching should be closely connected to the real conditions of students' future professional activities. In this regard, it is recommended to develop cooperation with industrial enterprises, research centers, and engineering companies. This collaboration can enrich the educational process with real-world engineering cases, practical problems, and technology-driven projects [19].

Such partnerships not only support students' professional socialization but also help develop their applied competencies, understanding of industry demands, and engineering mindset. Furthermore, industrial partners can serve as external experts, mentors, and project sponsors, enhancing the relevance and motivation of academic activities.

7. Integration of Soft Skills into the Course Content

Today's engineers must possess not only professional knowledge but also a wide range of universal (soft) skills, such as teamwork, communication, time and project management, critical thinking, and creative problem-solving. Therefore, it is recommended to integrate soft skills development into the structure of the physics course. This can be achieved through team-based projects, group problem-solving tasks, public presentations, analytical and reflective reports, and research assignments. Such an approach not only boosts student motivation but also makes learning more holistic and aligned with real-world work environments [20, 21].

Additional proposals for implementing the recommendations:

Development of methodological guides focused on project-based learning and interdisciplinary integration;

Creation and maintenance of online platforms that connect instructors, students, and industry professionals for experience sharing and collaborative project work;

Introduction of flexible assessment formats aimed at evaluating the development of competencies rather than solely the retention of theoretical knowledge;

Organization of research clubs and student laboratories where physics is studied through practical experimentation;

Implementation of mentoring programs where experienced educators and industry specialists guide students throughout their academic journey.

In conclusion, the implementation of these recommendations will support the modernization of physics teaching in technical universities, making it more contemporary, practice-oriented, and aligned with the professional competency requirements of future engineers.

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