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APPLICATION OF PRACTICE-ORIENTED EDUCATION TECHNOLOGIES IN TRAINING STUDENTS IN ENGINEERING AND SCIENCE SPECIALTIES

Abstract: Modern social, economic, technical transformations make adjustments in the organization and training of personnel in engineering and natural science specialties, in the basic elements of the structure and content of educational programs. Adjustment of educational programs taking into account modern trends allows providing graduates with competitive advantages in the labor market. At the same time, the problems related to the imbalance of theoretical and practical training, the gap between the skills and competencies formed in students and the needs of the industrial sector, non-adaptation of technologies and teaching methods to the specifics of academic disciplines and expected learning outcomes are still relevant in engineering and science education. Accordingly, the aim of the work was to analyze the peculiarities of application of practice-oriented learning technologies in engineering and science training. In this work the most important learning outcomes for students and employers were determined, the main deficiencies in the skills and competencies of graduates were identified, students' satisfaction with the quality of organization and conduct of practical classes and professional practices was assessed, practice-oriented educational technologies used in teaching professional disciplines were ranked by the degree of importance. Based on the obtained results, a significant correlation between the responses of students and employees of companies/enterprises has been established, the effectiveness of the application of practice-oriented educational technologies to increase students' motivation for learning and responsibility for learning outcomes has been shown, it has been established that employees of companies/enterprises attach greater importance to learning outcomes related to the development of students' personal, social and technical skills and competencies.

Keywords: practice-oriented educational technologies, experiential learning, case-based learning, project-based learning, workplace learning, engineering education, science education

Introduction. Application of practice-oriented education technologies in training students in engineering and science specialties

The 21st century is characterized by rapid and profound changes in society, science, technology and economy. New, diverse professions related to engineering and natural sciences have appeared on the labor market. The ongoing changes have made adjustments in the organization and training of personnel, in the applied technologies and teaching methods, forms of content delivery, influenced the development of e-learning and digital tools, which provided greater flexibility of the whole learning process, its individualization, expanded learning resources, increased the role of blended and integrated learning (Basavaiah et al., 2021;

Karstina, 2021; Karstina, 2022a). The current trends in engineering and science education are product orientation, commercial potential, and integration with technology. Environmental, social and industrial aspects are gradually becoming the basic elements in the structure and content of engineering and natural science educational programs, which allow introducing students to 1) scientific, technological and mathematical principles of case studies or projects being implemented, including workplaces created in partner companies and enterprises, 2) principles of environmental safety, 3) principles of social interaction through role-playing games, group project work, joint research of real situations and others, 4) principles of social responsibility for proposed technological and innovative solutions (Gutierrez-Bucheli et al., 2022; Udeozor et al., 2022). Educational institutions that have adjusted their educational programs to modern trends provide their graduates with competitive advantages in the labor market, mastering not only professional competencies, analytical skills, but also information technologies in the professional sphere, developing contextual understanding of the needs for technological and sustainable solutions, practical ingenuity, effective adaptation to technological innovations, the ability to integrate knowledge and methods from different fields of knowledge, acting in complex and non-standard situations, career planning (Basavaiah et al., 2021; Karstina, 2022a,2022b; Karstina, 2021; Zaher et al., 2023; Anwar et al., 2022). At the same time, in engineering and science education there are still urgent problems, the solution of which should ensure 1) bridging the gap between the university educational program and skills required for industry, 2) balance between theoretical and practical training of students, 3) increasing motivation and responsibility of students in achieving learning outcomes, 4) interactivity, flexibility and comfort of the learning process, 5) adaptation of teaching methods and their combinations to the specifics of the disciplines taught, students' needs, goals and expected learning outcomes, 6) orientation of the learning process to a specific result. In solving these problems, an important role is played by the application of practice-oriented educational technologies, including project-based learning, workplace learning, experience-based learning, contextual learning, case technologies, "flipped classroom", simulation-based learning, intellectual learning in the laboratory, game-based learning and others.

Purpose and Tasks of the Present Study

The purpose of this paper was to analyze the peculiarities of application of practice-oriented learning technologies in the training of engineering and science personnel in universities and colleges. In order to achieve the purpose, the following tasks were set in the work: 1) determination of the most significant for students and employers learning outcomes of engineering and natural science profile educational programs; 2) identification of the main shortcomings in skills and competencies of engineering and natural science graduates; 3) assessment of students' satisfaction with the quality of organization and conduct of practical classes and professional practices by universities and colleges, the degree of competencies, knowledge, skills necessary for employment in the specialty; 4) ranking the importance of practice-oriented educational technologies used in teaching professional disciplines in engineering and natural science educational programs; 5) development of recommendations on organization of training sessions with application of practice-oriented learning technologies and analysis of their effectiveness.

Method

The success of the implementation of the educational program and the achievement by students of the planned learning outcomes depends on many factors. For example, when developing educational programs, first of all, it is necessary to find out the priorities in training for the student, the needs and expectations of key stakeholders, and then to determine the specific goals and learning outcomes, content, teaching/learning methods, teaching and

assessment strategies, types and forms of academic quality control, to develop the necessary educational material and instructions for students, organize the learning process itself (Basavaiah et al., 2021; Karstina, 2022b), integrate various forms of cooperation with organizations and enterprises into the learning process, align the content of professional disciplines with the production tasks and innovations of specific enterprises and industries (Karstina, 2022b).

In accordance with this, in this paper a survey and interviewing of engineering and natural science students and teachers of professional disciplines in universities and colleges, employees of Kazakhstani companies and enterprises were conducted. Within the framework of the conducted surveys the task was to find out what basic skills and competencies should be developed in students during the process of studying at the university/college, to determine the most significant learning outcomes for students and employers, to identify the main shortcomings in skills and competencies of engineering and natural science graduates, to assess the degree of students' satisfaction with the quality of organization and conduct of practical classes and professional practices by universities and colleges, the formation of competencies, knowledge, skills necessary for employment in the specialty, to find out the priorities of teachers in the application of various practice-oriented educational technologies in the learning process.

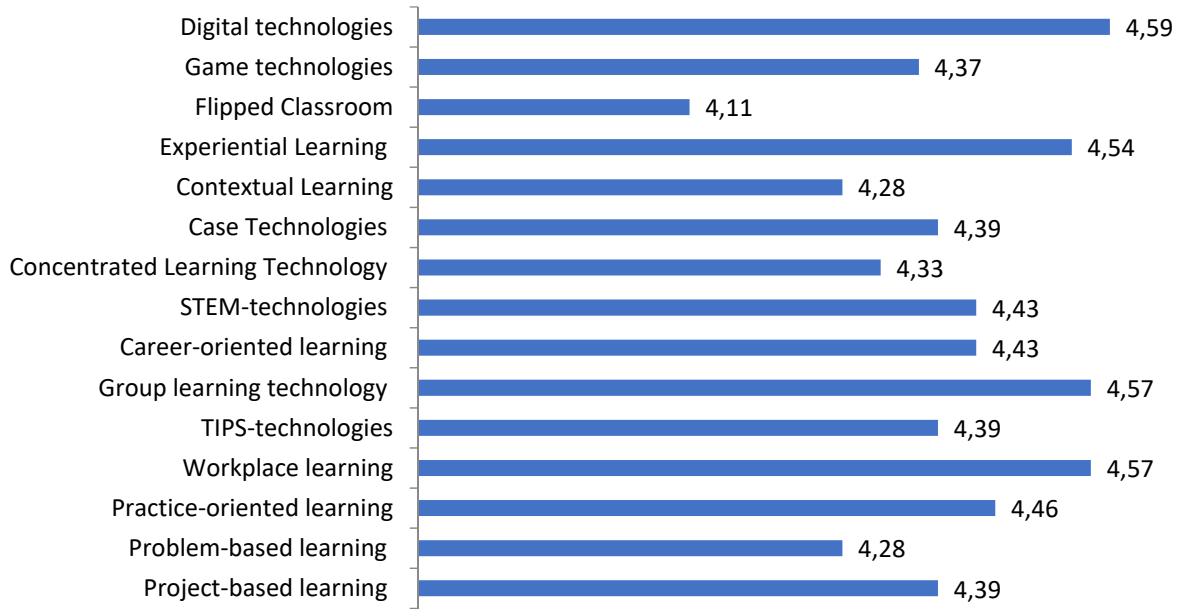
The survey involved 1163 students and 143 teachers from 15 universities and 4 colleges, 109 employees from 46 companies/enterprises located in different regions of Kazakhstan (Astana, Shymkent, Karaganda, Semey, Pavlodar, etc.). Of the surveyed students, 71.9% are enrolled in bachelor's degree programs, 6.7% - in master's degree programs, 21.4% - in technical and vocational education programs in colleges.

Open-ended and closed-ended questions were used to conduct the questionnaire. Response categories in the questionnaires were set by rating scales, allowing respondents to give an assessment in terms of the level of agreement or disagreement, the degree of importance of the analyzed indicator (very important, important, not significant, not important), to apply point evaluation. The proposed options for answering the questionnaires allowed respondents to make single or multiple choices. When analyzing the results of the questionnaire survey, we used the methods of quantitative and qualitative assessment, evaluation of weighted averages and correlation coefficients, ranking of assessed indicators.

To rank the importance of practice-oriented educational technologies used in teaching professional disciplines in engineering and science educational programs, 42 students of professional development courses on the programs "Design of dual educational programs" (10 teachers of universities and colleges with up to five years of teaching experience) and "Modern educational technologies in dual education" (32 teachers of universities and colleges with up to five years of teaching experience) were interviewed. The ranking was based on the students' evaluation of each of the 14 proposed practice-oriented learning technologies on a five-point scale (1 - least important, 5 - most important). According to the ranking results (Figure 1), the most important learning technologies for engineering and science education include: digital technologies, group learning technologies, workplace learning, experience-based learning, STEM-technologies, career-oriented learning, case technologies, TIPS (Theory of Inventive Problem Solving)-technologies, project-based learning, game technologies. Accordingly, the above technologies were considered in this paper in more detail in order to develop recommendations for organizing training sessions with their application.

Figure 1

Assessment of the importance of applying practice-oriented educational technologies for teaching professional disciplines in educational programs of engineering and science profiles



Assessment of students' satisfaction with the competencies, knowledge, skills necessary for employment in the specialty, quality of practical training and professional practice in the university/college was carried out on the basis of comparison of students' survey results in 2021, before the implementation of practice-oriented educational technologies in the educational programs of engineering and science profiles (590 surveyed students), and in 2023, after the implementation (89 surveyed students).

Results and Discussion

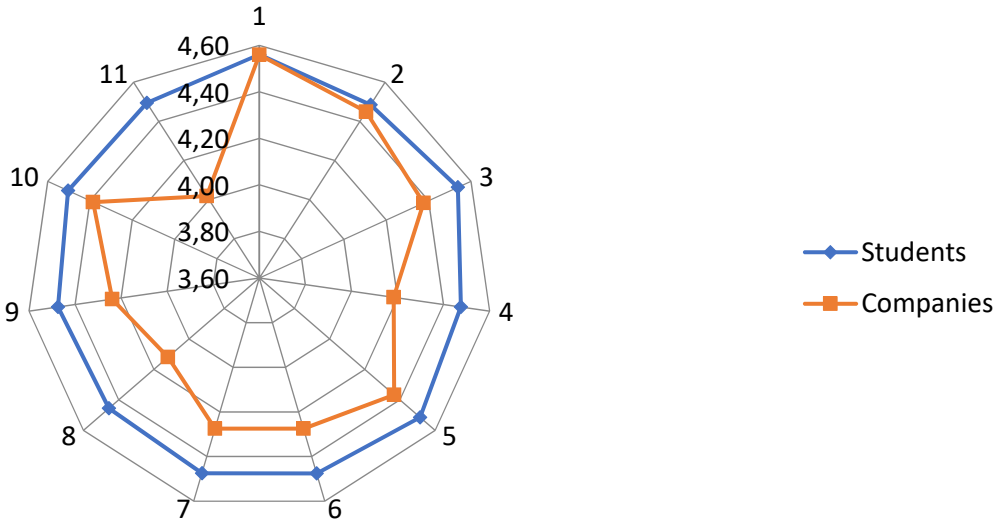
In order to actively involve students in the learning process at both individual and collective levels, it is important to determine the format of training, distribute the time of classes and preparation for classes, and provide access to learning resources, develop learning situations, problem and contextual tasks that require students to make compromise decisions in complex situations, develop various thematic test tasks related to students' independent work and theoretical concepts, define contextualized approaches to teaching and learning (Zaher et al., 2023). At the same time, the teacher needs to choose effective tools to increase students' motivation for learning and responsibility for learning outcomes, feedback tools to guide and control student's mastering of learning material, to define stages and tools for evaluating individual student progress, forms of rewarding students for achieved results and acquired competencies throughout the course (Lin, 2021), to integrate the values of everyday life into the training, to set students up for benevolent business communication and interaction, etc.

When organizing practical training it is important to expand the use of virtual and remote laboratories, technologically advanced means of experimental learning, which will allow students to perform design and research tasks anywhere and at any time, using real equipment or virtual simulators, combining technological attributes and situational learning. To improve the efficiency of students' work when performing practical tasks, various forms of student support should be developed at each stage of work from the preparatory to the final stage, guidelines, instructions, methodological recommendations for performing tasks, setting up and using laboratory equipment and/or software, planning and structuring laboratory activities (Van den Beemt et al., 2023; Karstina, 2024).

In order to increase student satisfaction with the competencies, knowledge, skills required for employment, it is important to find out the priorities in training for the student, needs and expectations of other key stakeholders. For this purpose, according to the results of questionnaire survey of students and employees of companies/enterprises in the work we have calculated average assessments of 11 learning outcomes, which should be achieved by the student during training: 1. Possess the technologies of self-learning, self-development, self-regulation and self-support; 2. Be able to systematize and analyze approaches to study the development of engineering and natural sciences fields; 3. Be able to classify and combine theoretical and practical knowledge; 4. Be able to apply the methods of experiment setting to solve complex problems of engineering, natural sciences, plan and conduct scientific and technological experiments; 5. Demonstrate skills of logical and analytical thinking; 6. Be able to document the results of professional activity; 7. Organize and conduct operation of technological lines, participate in the development and modernization of technological production schemes; 8. Apply innovative methods in professional activity; 9. Assess resources and propose technological/practical solutions; 10. Use modern information and communication technologies; 11. Know the basics of management. The assessment was conducted on a five-point scale (1 being the least important learning outcome, 5 being the most important learning outcome). The results of the evaluation are presented in Figure 2.

Figure 2

Weighted average assessment by trainees and employees of companies/enterprises of the results to be achieved by the student during training



Analyzing Figure 2 it can be noted that weighted average scores of trainees and employees of companies/enterprises of such learning outcomes as 1 - To possess technologies of self-learning, self-development, self-regulation and self-support, 2 - To be able to systematize and analyze approaches to the study of development of engineering and natural sciences, 3 - To be able to classify and combine theoretical and practical knowledge, 5 - To demonstrate skills of logical and analytical thinking, 10 - To use modern information and communication technologies have insignificant differences (from 0 to 0.16 points). Significant difference in the weighted average assessment by trainees and employees of companies/enterprises is observed for learning outcome 11 - To know the basics of management. Based on the analysis of weighted average assessments, it can be noted that employees of companies/enterprises attach greater importance to learning outcomes related to

the development of students' personal, social and technical skills and competencies, and less importance to learning outcomes related to the development of organizational and administrative skills and competencies. At the same time, based on the calculation of the correlation coefficient (***r***=0.67), it can be noted that the relationship between the responses of trainees and employees of companies/enterprises is significant (average correlation).

The paper also analyzes the results of students' assessment of the main skills and competencies to be developed in the process of higher education/college education and the assessment by the employees of companies/enterprises of the main deficiencies in skills and competencies of engineering and natural science graduates of higher education institutions/colleges. For assessment, respondents were offered a list of 20 basic skills and competencies to be possessed by graduates of engineering and natural science specialties of universities/colleges: 1) communication skills, 2) practical skills, 3) managerial and organizational skills, 4) skills of working with professional and technical documentation, 5) problem solving and analysis skills, 6) skills of operating modern technological equipment, 7) language competencies, 8) digital and IT competencies, 9) career development skills, 10) skills in applying innovative technologies, innovative methods, 11) skills in solving complex problems, situational problems, 12) creativity, 13) ability to work with scientific and professional databases, 14) system approach in solving professional problems, 15) skills of self-learning and self-development, 16) knowledge of modern theoretical, methodological and technological achievements of science and practice, 17) ability to apply modern methods of data processing and interpretation, including the use of computer technologies, 18) ability to critically analyze, evaluate and synthesize new and complex ideas, 19) skills of teamwork, successful interaction with people, 20) skills of project work. Trainees rated the importance of skills and competencies on a five-point scale (1 being least important, 5 being most important). Employees of companies and enterprises also used a five-point scale to assess the main deficiencies in skills and competencies of engineering and natural science graduates of universities/colleges (1 - the least deficiency, 5 - the greatest deficiency). All assessed skills and competencies acquired in the course of study were recognized as important by 56.18% to 64.6% of surveyed students. At the same time, the smallest share of students recognizes the importance of a systematic approach in solving professional problems (56.18%), the largest share of students recognizes the importance of practical skills (64.6% of respondents). The percentage of respondents from among the employees of companies/enterprises who rated as the main shortcoming in the skills and competencies of graduates in terms of the proposed list ranged from 20.18% to 46.79% (20.18% of surveyed respondents believe that the lack of career development skills is the most important shortcoming, 46.79% of surveyed respondents believe that the most important shortcoming of graduates is the lack of self-learning and self-development skills). In addition, lack of practical skills (noted by 41.28% of respondents), lack of problem-solving and analytical skills (noted by 34.86%) were among the most important shortcomings of graduates as assessed by company/enterprise employees. All other shortcomings were noted as the most important by a smaller proportion of respondents. The correlation coefficient (***r***) between the evaluation of trainees and employees of companies/enterprises amounted to 0.615, which corresponds to a significant relationship (average correlation).

To overcome the identified deficiencies in skills and competencies of engineering and natural science graduates of universities/colleges, practice-oriented learning technologies play an important role. Let us consider some peculiarities of application of practice-oriented educational technologies highlighted by the surveyed teachers of professional disciplines as the most important in training specialists of engineering and natural sciences. In the context of engineering and science education, digital technologies, educational games and simulations are increasingly used to simulate complex physical or technological processes, solve situational

problems, allowing to imitate real-world scenarios, better understand conceptual differences, to apply various built-in tools for searching the necessary information, to create a dynamic, learner-centered positive environment, to stimulate collaborative work, to create a variety of content and complexity of tasks, the solution of which is aimed at the development of certain skills and competencies (Drakatos et al., 2023). Digital technologies facilitate and improve assessment procedures, enable students to use various mobile devices and ICT applications, artificial intelligence, STEM and robotics.

When using project-based learning, it is important to ensure that students are involved in solving meaningful problems that will be of interest to students and provide opportunities for experiential learning. When organizing students' project work, the following format can be used: before carrying out a project, students should obtain the necessary fundamental and professional knowledge, have an idea of practical approaches to problem solving. For this purpose, lecture classes are held before the start of project implementation. During the seminars, the teacher should present students with examples of problem solving, organize the solution of various research tasks related to the subject of the projects, discuss with students the goals and objectives of the projects being carried out from different points of view, which will contribute to the expansion of students' horizons, depth of knowledge and openness of project work materials (Marhadi et al., 2023), explain the assessment tools. During the mentoring sessions, the course instructor in each project group should consult on technical aspects, time management and ways of interaction within the group, discuss with students the results obtained, evaluate students' progress, answer their questions, encourage students to be creative, critically analyze (Jia et al., 2023), apply interdisciplinary knowledge, iterative cycles that can help students learn from their own mistakes and make progress. For project work, students are usually divided into balanced groups based on predetermined criteria. In the course of project work, each group prepares interim reports in which students describe the tasks performed, the methods used to solve them, and the main results of the project work. The requirements for the reports are defined by the teacher in the relevant recommendations before the start of work on the project. In the final presentation students should present the results of the project, demonstrate the skills and competencies acquired during the project (Anwar et al., 2022; Karstina,2023), the ability to apply knowledge and skills in real life. When assessing students' work on the project, it is recommended to apply various tools of level assessment, which will allow to evaluate the content of the project and the process of project implementation, the results of the work of each group member, his individual contribution to the fulfillment of the project task, to ensure compliance with the principles of objectivity, independence, continuity, flexibility, openness in assessment. At the same time, a set of tools, methods, criteria, indicators and assessment plan should be developed in accordance with the type of project, learning objectives and evidence necessary to confirm the achievement of student learning outcomes (Karstina,2024).

Work-based learning should be applied to enable students to accumulate subjective experience in different contexts, obtain objective results, utilize the advice and opinions of industry experts, acquire and master new skills, which generally improves the quality of their learning. When organizing work-based learning, the learning environment and job requirements should be carefully designed to allow the student to relate theory to practice, workplace experience to theoretical knowledge, and ensure students' adaptation to work situations (Gope & Gope, 2022). For example, when approving the technology of on-the-job training in this work, students were tasked to develop a general structural diagram and circuit diagram of the control and access control device. As a result of solving the problem, students had to create a prototype of a reader (card reader) based on NFC (Near Field Communication) technology. The solution of the task involves the fulfillment of several stages: 1) creation of the structural scheme of the developed device, including several blocks: power supply circuit

block, display switching circuit block, USB interface switching circuit block, external real time source (RTC) block, external memory (EEPROM) block, direct NFC reader switching block; 2) development of independent circuits for each individual block, which were then combined into a general electrical circuit of the device; 3) preparation of a library of components and their arrangement on the printed circuit board, tracing of electrical connections between components; 4) connection of the board to the computer, using utilities for working with STM32 microcontrollers; 5) development of the program part of the device control in the ***C*** programming language. When performing the tasks, students had to pay special attention to the sequence of mounting and soldering of electrical assemblies, identify problems that can affect the start-up of microcontrollers and eliminate them, apply knowledge of the basics of architecture and structure of the microcontroller used, skills of software initialization of microcontroller parameters.

Contextual learning encourages students to make connections between their existing knowledge and its application in everyday life, to see similarities and differences, to systematize ideas. New information is presented to students "in context", i.e. from the position of how theoretical knowledge is applied outside the classroom (Wulandari, 2023; Sue et al., 2022).

To solve situational tasks students should give a brief description of the sequence of actions, analyze examples of possible non-standard situations in solving the problem. At practical classes situational cases can be used, aimed at finding out and analyzing the errors made by the user of a particular application, selection and justification of methods to prevent user errors, analysis of the relevance of the problem, preparation of proposals for the application of the method of solving the problem in the working conditions of a real company/enterprise, preparation of proposals to prevent problem situations and failures in the operation of equipment. Thus, for example, the classes with the use of digital technologies in combination with game and case technologies in the discipline "Fundamentals of radio technology and telecommunications", conducted within the framework of this study, allowed to successfully develop students' skills in the use of modern information technologies, applied software in solving problems oriented to future professional activity, skills of working with network equipment, to form students' skills of teamwork and work for the common result, to develop interest in understanding the work of wireless communication lines and devices, to establish interdisciplinary links, to familiarize with the main functional responsibilities. By performing case assignments students also had to understand the essence and importance of information in the development of modern society, to realize the dangers and threats arising in this process, to learn to comply with the basic requirements of information security, to apply the basic methods, ways and means of obtaining, storing, processing information. The following format was used during the lessons: random division of students into groups of 3-4 people, distribution of roles performed by members of each group. For example, when simulating the work of the Department of Information and Communication Technologies of the Radio-Television Transmission Center, students performed such roles as engineer, chief specialist, specialist, manager. Case assignments for each group included selection of new equipment or modernization of existing equipment for the internal device of the computer network. The case studies used by students contained a task and order form, technical documentation of the devices, details of the enterprise and the customer, job descriptions of an engineer, chief specialist, specialist and manager, and variants of test tasks.

The work performed on the case study included three phases:

Stage 1 - introductory discussion on discussing tasks and case materials, job descriptions in accordance with the role performed in the group. The teacher, playing the role of a facillitator, helps students to assess the situation, leads students to discuss various options for solving the task;

Stage 2 - practical work of students to fulfill the case assignment and search for suitable options for the customer;

Stage 3 - general discussion: presentation of work results and prepared packages of documents, discussion and evaluation of problem solving options. At the end of the lesson, the teacher organizes a discussion of functional responsibilities in accordance with the assigned roles, types of activities and skills and competencies required for each profession.

Figure 3

Results of evaluation by students of the competencies, knowledge, skills required for employment in the specialty formed in the process of training

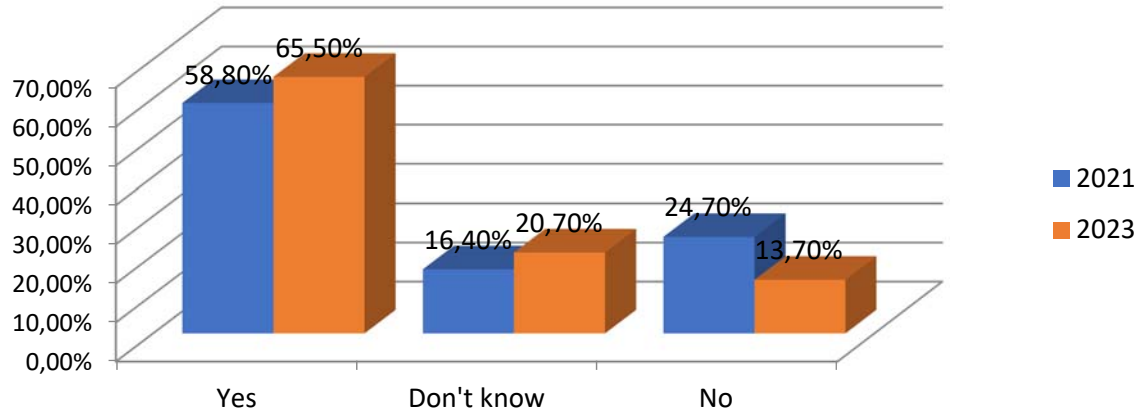
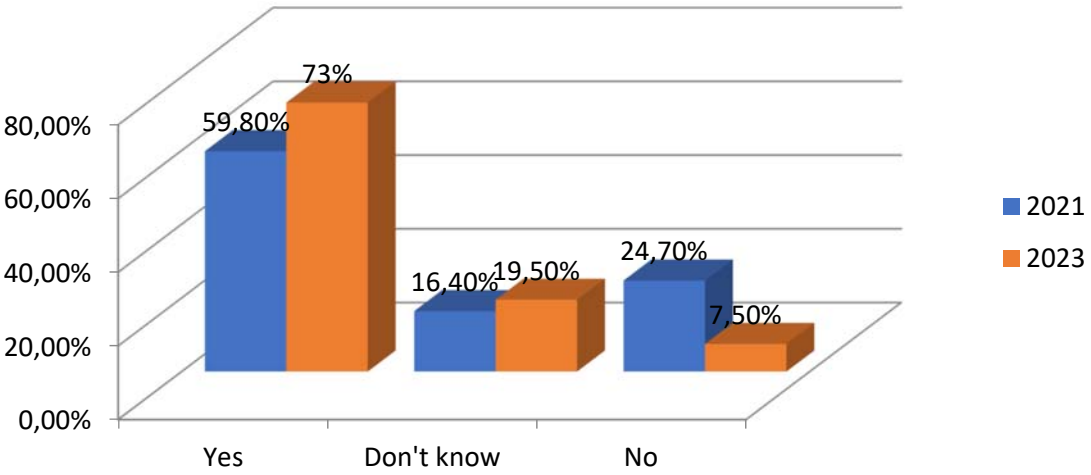


Figure 4

Results of evaluation of students' satisfaction with the quality of practical classes and professional practices in the university/college



The described approaches to the application of practice-oriented educational technologies in the training of engineering and natural science profiles allowed combining theoretical classes with problem solving, project or research work, which contributed to the development of students' critical and evaluative thinking, analytical and innovative abilities, practical skills and professional competencies, balanced and diverse approaches to identifying and solving a real problem, both independently and in a team, the ability to communicate and cooperate at the scientific and professional levels, independence and initiative. The results of the questionnaire survey conducted with students of engineering and science programs before

the implementation of practice-oriented learning technologies (2021) and after the implementation (2023) confirm the effectiveness of the application of practice-oriented learning technologies (Figures 3, 4). The purpose of the survey was to assess the students' satisfaction with the competencies, knowledge, skills required for employment in the specialty, the quality of practical training and professional practice at the university/college. As can be seen from Figures 3, 4, the degree of students' satisfaction with the competencies, knowledge, skills, necessary for employment in the specialty, formed in the process of training increased by 6.7%, the degree of students' satisfaction with the quality of practical training and professional practice in the university/college increased by 13.2%.

Conclusion

The paper ranks practice-oriented educational technologies by the degree of importance and presents recommendations for organizing training sessions with the use of practice-oriented educational technologies.

The analysis of the main deficiencies in skills and competencies of engineering and science graduates carried out in the paper allowed to establish that employees of companies/enterprises attach more importance to learning outcomes related to the development of students' personal, social and technical skills and competencies, and less importance to learning outcomes related to the development of organizational and administrative skills and competencies.

Based on the obtained values of correlation coefficients between the responses of students and employees of companies/enterprises in assessing the importance of learning outcomes, acquired skills and competencies and the main shortcomings in the training of specialists of engineering and science profiles, it was found that the relationship between the responses of students and employees of companies/enterprises is significant.

The paper shows that practice-oriented educational technologies are an effective tool to increase students' motivation for learning and responsibility for learning outcomes. The application of practice-oriented educational technologies in training specialists of engineering and natural science profiles allowed to increase students' satisfaction with the competencies, knowledge, skills required for employment in the specialty by 6.7%, the degree of students' satisfaction with the quality of practical classes and professional practices in the university/college - by 13.2%.

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Conflict of Interest Statement

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