frontiers | Frontiers in Education

TYPE Original Research
PUBLISHED 12 December 2025
DOI 10.3389/feduc.2025.1661526

A structural approach to the assessment and development of engineering students' professional skills

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RECEIVED 07 July 2025
REVISED 15 November 2025
ACCEPTED 24 November 2025
PUBLISHED 12 December 2025

CITATION
Karstina S, Tussupbekova A and Mussenova E (2025) A structural approach to the assessment and development of engineering students' professional skills. *Front. Educ.* 10:1661526.
doi: 10.3389/feduc.2025.1661526

On-the-job training plays a key role in developing the professional skills and practical experience of students in engineering education programs. In this regard, the aim of this study was to create a toolkit for analyzing the factors that influence the development of these skills and the integration of students into the professional environment. The methodology included surveying three target groups—students, teachers, and employees of companies involved in the implementation of practice-oriented training at universities—as well as testing three updated training modules integrated with practical training. Based on the collected data, regression models were constructed reflecting the influence of four blocks of factors (organization of practice, digital and production resources, educational support, project activity) on the development of skills in the application of engineering equipment and technologies. The most significant predictor was the block of digital and production resources (standardized regression coefficient $\beta = 1.666$, $p < 0.001$, $R^2 = 0.684$ for the experimental group of students), which emphasizes the importance of the technological content of the learning environment. As a result of training using the updated modules, an increase in the level of proficiency in the application of engineering tools and technologies was recorded. The average score for this criterion was 4.52 in the control group and 4.74 in the experimental group. Progress was also noted in key skills such as basic economic and legal knowledge (F6), self-analysis (F9), and planning (F7). This confirms the effectiveness of a structured approach to combining theoretical and practical training. The proposed structured toolkit for analyzing influencing factors, tested through a multilateral survey and pilot implementation, is a key innovation of the study and can be used by universities and companies to modernize workplace training programs.

KEYWORDS

engineering education, educational program, workplace learning, skills, learning outcomes, forms of communication, feedback

1 Introduction

Contemporary research in the field of engineering education emphasizes the need to strengthen ties between universities and industrial partners, which contributes to the development of practice-oriented training for students and the acquisition of real work experience (Rampasso et al., 2020; Marcos et al., 2020; Karstina, 2025). This is especially relevant given the shortage of specialists with practical skills and employers' dissatisfaction with the quality of training provided to engineering program graduates (Ortiz-Marcos et al., 2020; Karstina S., 2022; Karstina S. G., 2022; Pacher et al., 2023). To overcome these challenges, universities need to adapt the educational process to the dynamics of industry development and digital transformation (Pacher and Woschank, 2020; Lerman et al., 2024). An important condition is the early involvement of students in professional activities, ensuring access to modern equipment, technologies, and production sites (Goggins and Hajdukiewicz, 2022; Karstina S., 2022; Karstina S. G., 2022; Zhang and Chen, 2023). Digital production environments, specialized software, and engineering platforms play a significant role in this process, strengthening the practical focus of training and increasing student motivation. In addition to technical resources, modern teaching methods, the creation of a comfortable educational environment, and an assessment system that takes into account both academic achievements and the opinions of employers remain important (López-Pérez et al., 2025; Rowe and Zegwaard, 2020; Poveda et al., 2021; Ferns and Rowe, 2021; Soliman et al., 2021). Involving students in solving professionally oriented tasks, participating in projects, developing innovative solutions in collaboration with companies, and interacting with the professional community (Félix-Herrán et al., 2022; Zaher et al., 2023; Karstina and Tussupbekova, 2025; Senthil, 2020; Hernández-de-Menéndez et al., 2019; Khuzwayo and Vahed, 2021; Kay et al., 2023) ensures faster adaptation of graduates to the professional environment and stimulates their sustained motivation for self-realization and professional growth (Yusuf et al., 2024; Khampirat, 2021; Aris et al., 2024; Karstina, 2023; Karstina et al., 2024; Almetov et al., 2020; Khodadad, 2023). Summarizing the results of the literature review, we can identify the key factors that influence the quality of engineering education: systematic work by the university to interact with industrial partners (Caeiro-Rodríguez et al., 2021), access to modern digital and production resources, early integration of students into professional activities, mentoring, creation of a functional educational environment, and regular adjustment of educational strategies based on feedback (Jiang et al., 2020; Succi and Canovi, 2020; Hasslöf et al., 2022; Lee and Fang, 2020; Álvarez-Risco et al., 2023; Mourtos, 2020; Müller et al., 2022; Bohle Carbonell et al., 2020).

However, in Kazakhstan, these tasks are complicated by a number of specific problems: limited access of universities to modern production sites, insufficient involvement of enterprises in the educational process, and weak integration of digital production tools into curricula. In these conditions, there is a particular need for tools that allow analyzing the impact of various factors on the development of students' professional skills and their successful integration into the professional environment. The development and testing of such tools is the goal of this study.

To achieve this goal, the following tasks were formulated:

1) to identify and analyze the factors influencing the development of students' professional skills and their acquisition of practical experience (based on surveys of students, teachers, and company employees);
2) to develop regression models based on the survey data obtained and to conduct a comparative analysis of the assessments of various target groups;
3) formulate key recommendations for the development of students' professional skills and integrate them into training modules that combine theoretical training at the university and practical training at the company;
4) test the updated modules and analyze changes in the development of students' professional skills.

2 Methods

Global and local challenges are transforming the requirements for engineering training, contributing to the creation of new jobs and the renewal of existing ones. In these conditions, the structure of professional skills required for specialists to work effectively, master modern technologies, advance their careers, and adapt to changes in the labor market is changing.

In order to identify the factors influencing the development of students' professional skills in the context of workplace learning, a survey was conducted among three target groups directly involved in the implementation of engineering and natural science educational programs at universities in Kazakhstan:

1) students—921 people studying in their 3rd-4th years. All respondents had completed part of their core disciplines and undergone professional internships at partner companies, which ensured their ability to make an informed assessment of the indicators under study;
2) teachers—144 people with experience in teaching engineering and natural science disciplines, as well as participating in the practical training of students;
3) company employees—110 representatives of engineering, production, and administrative departments of partner companies, including student mentors. The companies operate in the fields of telecommunications, information technology, and digital systems, and also apply optical spectroscopy methods in industrial control, analytical measurements, and the development of high-tech solutions.

This approach to sampling ensured that data was obtained from participants with practical and methodological experience in implementing training programs in the workplace. This made it possible to consider their opinions as expert opinions from different perspectives of the educational process.

The questionnaires were developed taking into account the current challenges in engineering education and are based on a preliminary analysis of scientific literature, regulatory documents, international practices in the field of engineering education, as well as the results of pilot studies and expert interviews. The questionnaire questions were grouped into thematic blocks reflecting the key conditions for workplace training and the development of students' professional skills. Respondents evaluated the analyzed factors on a five-point Likert scale, which ensured the comparability and statistical validity of the data.

The results of the survey revealed the difficulties students face in workplace learning and identified key factors that contribute to or hinder the development of professional skills. In doing so, not only the skills formed by students in the process of training and practical activities were analyzed, but also the conditions of the educational environment that contribute to their development.

To systematize the analysis, a logical model was constructed that reflects the relationship between external conditions (organization of practice, digital resources, educational support, project activity) and the skills developed by students. The factors were grouped into four semantic blocks, each of which reflects key aspects of workplace learning:

Block 1—Organization of practice, mentoring, equipment (availability of equipment, interaction with mentors, level of involvement):

- F1: Safe working practices and professional ethics;
- F2: Professional interaction skills in the workplace;
- F7: Work planning skills;

Block 2—Digital and production resources (digital resources and tools available to students as part of educational and production activities):

- F4: Skills in working with instructions and reports;
- F5: Skills in analyzing the impact of engineering solutions;
- F8: Skills in analyzing and explaining work results;

Block 3—Educational support and management (educational support, motivation, feedback, managerial and organizational aspects):

- F3: Self-learning and self-development skills;
- F6: Basics of economic and legal knowledge;
- F9: Self-analysis skills;

Block 4—Student engagement, project activity (personal student engagement, presence of project and research assignments in the course program, interdisciplinary interaction, interaction with the professional environment):

- F2: Professional interaction skills in the workplace;
- F3: Self-learning and self-development skills;
- F5, F8, F9: in-depth mastery and reflection on the results of project activities.

Block 1 combines factors related to the organization of practical training and the conditions of industrial training. It includes skills for safe and ethical work, professional interaction, and planning of tasks (F1, F2, F7). These components characterize the student's basic readiness for professional activity and adaptation in a real engineering environment. Block 2 focuses on the use of digital and production resources. It covers skills in working with instructions, analyzing engineering solutions, and interpreting results (F4, F5, F8), forming the basis of technical literacy and analytical thinking when performing project and practice-oriented tasks. Block 3 reflects the components of educational support and management aspects. The factors in this block (F3, F6, F9) are related to self-learning, knowledge of the legal and economic foundations of engineering, and reflective skills. This ensures the sustainable professional development of students and shapes their responsibility for their personal growth trajectory. Block 4 is integrative in nature and includes factors that characterize the student's personal involvement in professional activities, ability to learn independently, reflect, and participate in project work (F2, F3, F5, F8, F9). It reflects the degree of student activity in an interdisciplinary and practice-oriented learning environment that is close to the real professional environment. In the proposed structural model, individual factors may be included in several blocks due to their multidimensional nature and complex influence. Thus, F2 (professional interaction skills in the workplace) reflects both the organization of practice (Block 1) and student participation in the project environment (Block 4), which makes it significant for both components. F3 (self-learning and self-development skills) is related to educational support (Block 3), but at the same time determines the success of project tasks. Factors F5, F8, and F9 ensure in-depth mastery of content and reflection on the results of project activities, contributing to the integration of academic and practical components of learning. Thus, it is within the framework of project work that these factors are most fully manifested, and their distribution across four blocks allows for a more accurate assessment of their multidimensional impact on the development of students' professional skills. The resulting model is presented in Figure 1 and demonstrates that the formation of students' key professional skills occurs as a result of the interaction of their personal motivation and activity with the organizational, technological, and educational infrastructure created by universities and partner companies in the process of workplace learning.

The model presented in Figure 1 reflects the universal components of engineering education, including design activity, working with equipment, using digital resources, educational support, and professional interaction. These elements are characteristic of a wide range of engineering disciplines. Thanks to this structure, the model can be adapted to different educational contexts. At the same time, in each educational program, individual blocks may play a more or less significant role depending on its specifics. This makes it applicable in an interdisciplinary and cross-sectoral perspective.

Cronbach's alpha coefficient (α) was used to assess the internal consistency of each subsystem of factors. The coefficient was calculated using a standard formula based on the variances and covariances of the scale items. The calculated Cronbach's alpha values reflect the extent to which the same constructs are measured consistently by different items.

The calculated Cronbach's alpha values in each target group of respondents for the factor blocks identified in the questionnaires are presented in Table 1.

The obtained values showed a high level of reliability across all blocks among students (α ranges from 0.863 to 0.922), as well as among teachers and company employees in general (α ranges from 0.700 to 0.867). These results confirm the admissibility of using the selected groups of factors as a reasonable tool for analyzing the formation of students' professional skills.

At the next stage, a correlation and regression analysis was carried out to determine the relationships between the factors of the educational environment and the skills formed in students. Correlation analysis made it possible to determine the nature of the relationship between respondents' answers, including its type, direction, and strength. The regression analysis made it possible to propose a mathematical dependence of the estimates of the influence of various factors on the development of students' professional skills and practical experience in workplace training. To assess the significance of the regression coefficients, p-values were used at significance levels of $\alpha = 0.01$ and $\alpha = 0.05$. The reliability of the models was confirmed using t- and F-tests.

At the final stage of the study, recommendations and methods for their implementation were formulated for the development of students' professional skills and practical experience, which formed

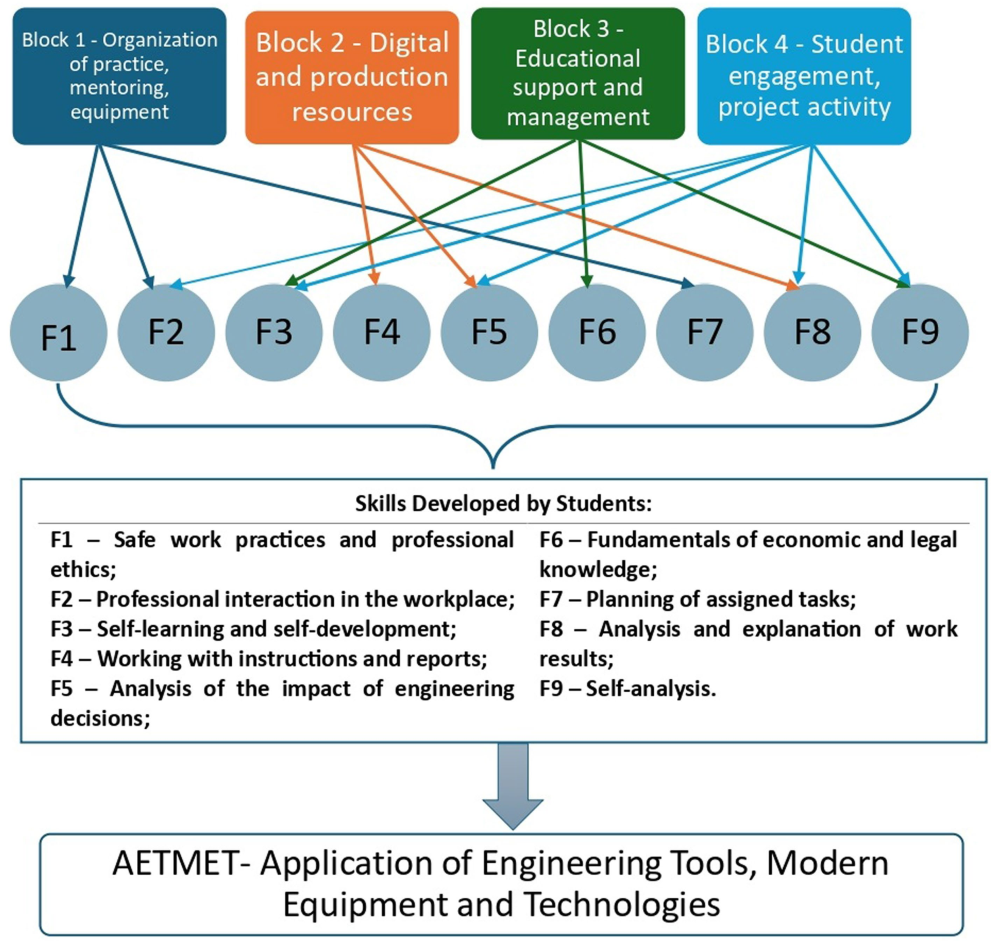

FIGURE 1
Structural model for developing students' professional skills through workplace learning involving universities and partner companies.

TABLE 1 Table of Cronbach's alpha values and the degree of consistency of factor subsystems for three target groups.

Target group	Block 1 (F1, F2, F7)	Block 2 (F4, F5, F8)	Block 3 (F3, F6, F9)	Block 4 (F2, F3, F5, F8, F9)
Students	0.884 (high)	0.863 (high)	0.880 (high)	0.922 (high)
Employees of companies	0.777 (medium)	0.867 (high)	0.716 (medium)	0.865 (high)
Educators	0.805 (high)	0.791 (medium)	0.700 (medium)	0.837 (high)

the basis of the updated training modules integrating workplace training: "Fundamentals of Radio Engineering and Telecommunications," "Design of Radio Electronics Devices on Printed Circuit Boards Using CAD," "Optical Spectroscopy Instruments and Methods." Each module corresponded to 5 ECTS.

From the available sample of respondents, 72 students and 54 teachers of the "Physics" and "Radio Engineering, Electronics, and Telecommunications" educational programs from two universities in Kazakhstan, as well as 30 employees of partner companies, were selected to participate in the testing of the training modules. The updated training modules were tested in three experimental groups over a period of 15 weeks. The classes included lectures and practical components, laboratory work using modern equipment and digital simulators, as well as project assignments completed by students in small groups. Regular consultations with mentors from companies were a mandatory element of the program. The results of the testing were compared with data from three control groups of students studying using the non-updated training modules. There were 12 students in each experimental and control group. They were distributed using a stratified selection method, taking into account academic performance (grade point average/GPA) and expert assessment of the level of preparedness by mentor teachers. This approach made it possible to balance the composition of the groups and ensure the comparability of learning conditions, which strengthened the validity of the causal conclusions. Teachers were selected based on their direct participation in the implementation of practice-oriented modules and their mentoring experience. Company employees were selected from among specialists involved in organizing student internships and interacting with universities. After testing the updated modules, a final survey was conducted among students, teachers, and mentors, which made it possible to take into account both the students' subjective perception of their own skills and the objective results of their practical activities. The assessment was carried out using rating scales, as well as categorical scales (often/sometimes/never) to analyze the frequency of interaction, feedback, and project activity. The analysis of the survey results included both quantitative methods (weighted average scores, correlation coefficients, regression analysis) and qualitative methods (thematic coding of open-ended responses, grouping of typical judgments, identification of barriers, and suggestions for improving learning conditions). Standard statistical concepts were used to interpret the results: Pearson's correlation coefficient (r) to assess linear relationships, the coefficient of determination R^2 to assess the proportion of explained variance, and p-values to test the significance of regression coefficients. This comprehensive approach made it possible to formulate well-founded recommendations for improving the effectiveness of student learning in the workplace.

3 Results

Based on the results of the survey of respondents from three target groups, Pearson's correlation coefficients (r) were calculated between the target variable—"Skills in the use of engineering tools, modern equipment, and modern technologies" (AETMET, Application of Engineering Tools, Modern Equipment and Technologies)—and the average values of four blocks of factors: Block 1—Organization of practice, mentoring, equipment, Block 2—Digital and production resources, Block 3—Educational support and management, Block 4—Student involvement, project activity. AETMET is an integral indicator that reflects the totality of students' practical skills. The results showed positive and statistically significant correlations in all target groups: students, teachers, and company employees. The highest correlation of the target variable was observed with the factors of block 2 (digital and production resources), which indicates the key role of this component in the formation of students' practice-oriented skills. At the same time, block 4 (involvement, project activity) demonstrated a positive but less pronounced correlation, which may be related to individual characteristics of students' perception and participation in project activities. The results of the correlation analysis are presented in Table 2. For all values in Table 2, $p < 0.001$, which confirms the statistical significance of the identified dependencies.

To study in more detail the influence of the factors under consideration on the development of students' skills in the use of engineering tools, modern equipment, and modern technologies, a multiple linear regression model was constructed. The dependent variable in the regression model was the skills in using engineering tools and technologies. The independent variables in the model were the average values for the factor blocks. The calculated regression coefficients (β) and the level of significance for all three target groups are presented in Table 3.

TABLE 2 Correlation coefficients between factor blocks and skills in the use of engineering tools, modern equipment, and modern technologies.

Target group	Block 1	Block 2	Block 3	Block 4
Students	0.752	0.779	0.723	0.732
Employees of companies	0.584	0.620	0.631	0.606
Educators	0.592	0.649	0.505	0.591

TABLE 3 Regression coefficient values (β) and significance level (ns — insignificant values at $p > 0.05$).

Target group	R^2	Block 1	Block 2	Block 3	Block 4
Students	0.653	0.443 ($p < 0.001$)	0.795 ($p < 0.001$)	0.511 ($p < 0.001$)	−0.875 ($p < 0.001$)
Employees of companies	0.452	0.251 (ns)	0.504 ($p = 0.005$)	0.587 ($p = 0.005$)	−0.545 (ns)
Educators	0.427	0.171 (ns)	0.570 ($p < 0.001$)	−0.020 (ns)	−0.076 (ns)

As can be seen from Table 3, the highest coefficient of determination ($R^2 = 0.653$) was obtained for the group of students, which indicates the good quality of the model. In the groups of teachers and company employees, the explanatory power of the models ranged from 42 to 45%. In all models, block 2 had a positive and significant contribution, confirming its key role. At the same time, Block 4 showed a significant negative effect only in the model for students, which requires further analysis (e.g., analysis of the variability of student engagement, difficulties in adapting to project tasks). In other groups, the coefficients of Block 4 were negative but statistically insignificant.

Summarizing the results of the correlation and regression analysis in terms of target groups, the following can be noted:

1) for the group of students in all four blocks of factors, there is a strong positive correlation with the indicator "Skills in the use of engineering tools, modern equipment, and technologies." The highest correlation coefficient ($r = 0.779$) was found for block 2, which includes digital and production resources. This confirms the importance of students' access to modern technical means in the educational and practical environment. The results of the regression analysis ($R^2 = 0.653$) also demonstrate the high explanatory power of the model. Blocks 1 ($\beta = 0.443$), 2 ($\beta = 0.795$), and 3 ($\beta = 0.511$) were significant predictors. At the same time, block 4 (involvement and project activity) showed a negative effect ($\beta = -0.875$, $p < 0.001$), which may be due to the fact that students perceive and implement project work differently and do not always associate it with professional competence and practical experience;
2) Among company employees, the highest correlation of skills in the use of engineering tools, modern equipment, and technologies was recorded with block 2 ($r = 0.620$), which is consistent with employers' views on the importance of modern resources. Moderate correlation values were also obtained for blocks 3 ($r = 0.631$) and 4 ($r = 0.606$). The results of the regression analysis showed a moderate strength of the model ($R^2 = 0.452$). Blocks 2 ($\beta = 0.504$, $p = 0.005$) and 3 ($\beta = 0.587$, $p = 0.005$) were statistically significant predictors. Block 4 was not significant, although it showed a negative coefficient ($\beta = -0.545$), which may be related to the difference in expectations between mentors and students in terms of the latter's involvement in practical tasks;

3) in the group of teachers, the correlation with block 2 ($r = 0.649$) was most pronounced, while block 1 showed a similar value ($r = 0.592$), which indicates the importance of both resource provision and organizational conditions for practical training. The regression model has a coefficient of determination $R^2 = 0.427$. Only block 2 was statistically significant ($\beta = 0.570$, $p < 0.001$), while the other blocks did not demonstrate a significant contribution to the model. This may indicate that teachers focus more on technical and organizational aspects, while project involvement and self-development of students remain secondary in their perception.

The results confirm the hypothesis about the multi-component nature of the development of students' professional skills and practical experience in the context of workplace learning. The availability of digital and production resources, the organization of practical training, and the level of student involvement play a special role in this process. Regression models have demonstrated high predictive power and can be used to build effective strategies for individualization and optimization of the learning process.

A comparison of results between target groups shows the consistent role of block 2 (digital and production resources) in all models. It is this block that demonstrated the highest correlation coefficients and a significant contribution to the regression models. This indicates that in order to effectively prepare students in engineering and natural science educational programs, it is important to create an educational environment rich in digital and production resources, including company resources. At the same time, block 4 (engagement and project activity), despite a positive correlation for the group of students, showed a significant negative impact. This may be due to the high workload on students when performing project work, insufficient adaptation of project tasks, or weak feedback from mentors. For example, students noted the following about the content of the assignments: "The project contained too many assignments and required a large amount of independent work, while the assessment criteria remained unclear"; "The project assignments were too difficult for our level of preparation, and this caused a lot of stress." Other respondents also pointed out: "The mentor only provided feedback after the project was completed, so we were unable to correct mistakes in time"; "The mentor only commented on the final version of the project, and this was not enough for real learning." These comments show that students faced difficulties due to the excessive volume and insufficient structure of the project tasks, as well as untimely and limited feedback, which reduced the value of the experience of participating in project activities. Teachers were most focused on the technical part of training, while company employees emphasized the importance of self-learning and practical adaptation. Thus, the results of the study revealed differences in the perception of key factors that shape students' professional skills and practical experience, which highlights the need for a balanced and coordinated approach to the development of workplace training programs.

Taking into account the results of the correlation and regression analysis, the paper makes recommendations for strengthening the influence of each block of factors in the proposed structural model, the implementation of which should increase the effectiveness of the formation of students' professional skills in the process of workplace training with the participation of universities and partner companies. Methods for implementing each recommendation were identified (Table 4).

Based on the recommendations made and the proposed methods for their implementation, the following training modules were updated: "Fundamentals of Radio Engineering and

TABLE 4 Recommendations for improving the effectiveness of students' professional skills development and practical experience in the process of their workplace training and methods for their implementation.

Factor block	Recommendations	Ways of implementation
Block 1- Organization of practice, mentoring, equipment	Strengthening the institution of mentoring, formalization of briefings and induction sessions	1) Conduct regular individual and group consultations of students with mentors at the workplace, focused not only on solving production tasks, but also on discussing professional ethics and safety standards; 2) Include elements of trainings on effective communication in engineering teams, business ethics, microgroup management and production tasks in the training modules; 3) Systematically develop students' skills of safe and responsible professional activity in real production conditions
Block 2- Digital and production resources	Strengthening of the resource component, clarification of assessment criteria for the practical part of the training module	1) Integrate more practical exercises into the modules using modern equipment, software and simulators; 2) Include case studies that simulate real professional tasks; 3) Provide for mandatory interaction with companies' digital platforms; 4) Develop an evaluation system in which one of the key indicators will be the level of confident application of professional tools and technological solutions
Block 3- Educational support and management	Formation of motivation and need for self-development	1) Include reflective assignments (mini-essays, self-assessment of skills, etc.) in training modules; 2) Activate the use of feedback from teachers and mentors; 3) Use reward systems for initiative and autonomy in learning; 4) Conduct group discussions on the results of professional practices and project work
Block 4- Student involvement, project activity	Ensuring a balanced project load	1) Clarify the scope and complexity of project assignments; 2) Introduce step-by-step structures for project implementation with regular student support; 3) Strengthen the role of mentors at the stage of project planning and analysis

TABLE 5 Comparison of correlation analysis data before and after testing the updated training modules in the experimental groups.

Factor block	Correlation coefficients with AETMET (before approbation)	Correlation coefficients with AETMET (after validation)	Conclusion
Block 1- Internship organization, mentoring, equipment (F1, F2, F7)	0.518	0.632	Perception of organizational conditions of on-the-job training improved
Block 2- Digital and Production Resources (F4, F5, F8)	0.582	0.669	Understanding of the technical context improved
Block 3- Educational Support and Management (F3, F6, F9)	0.495	0.615	Self-work and reflective skills improved
Block 4- Student engagement, project activity (F2, F3, F5, F8, F9)	0.604	0.701	There was an increase in involvement and professional activity

Telecommunications," "Designing Radio Electronics Devices on Printed Circuit Boards Using CAD Tools" and "Optical Spectroscopy Instruments and Methods."

The updated training modules were tested with 36 students from three experimental groups. To assess effectiveness, indicators for nine factors (F1–F9) were used, as well as an integral indicator of AETMET skills. The values obtained were compared with similar assessments of students in the control groups, which made it possible to identify differences in the level of skill formation between the groups. A comparative analysis showed that in the experimental groups, the average values exceeded those of the control groups for most factors. Thus, for factor F6, the average score was 4.57 versus 4.30 in the control group, for factor F7—4.66 versus 4.52, and for factor F9—4.68 versus 4.52. The advantage was particularly noticeable in the AETMET indicator, where the average score reached 4.74, exceeding 4.52 in the control group. These results confirm the positive impact of the updated modules on the development of students' practical skills.

The results of the correlation analysis showed that after testing, the students in the experimental groups showed a stronger correlation between the characteristics of the blocks and the key indicator of skills (AETMET) for all four blocks. This indicates a stronger link between learning conditions and skill development after the introduction of the updated training modules. The results of the comparison of correlation analysis data before and after the testing of the updated training modules in the experimental groups are presented in Table 5.

The results of the regression analysis showed that after testing the updated modules, the regression model became more predictable and stable. After testing the new training modules, the influence of organizational conditions (Block 1) on the development of skills in working with engineering equipment and technologies increased. The coefficient in the regression model increased from 0.443 to 0.646. The most significant change was the increased influence of digital and production resources (Block 2) on the development of skills in working with engineering equipment and technologies. This is confirmed by the increase in regression coefficients from 0.795 to 1.666 and the increase in the explanatory power of the regression model ($R^2 = 0.684$). The assessment of company employees also confirmed an improvement after the testing of the updated training modules: the R^2 value increased to 0.603, and the positive influence of Block 4 (engagement, project activity) became particularly pronounced. These results demonstrate that the updated workplace training modules contribute to more effective development of practical engineering skills among students and are perceived as more effective by key stakeholders.

Thus, a comparative analysis between students before and after testing the updated training modules showed an improvement in the development of professional skills, in particular the skills of using engineering tools, modern equipment, and technologies. This is confirmed by an increase in correlation coefficients in all factor blocks, as well as a particularly pronounced influence of organizational conditions (Block 1) and digital and production resources (Block 2), which became the most significant predictors of the development of practical engineering skills. The regression model explained a significant part of the variation in students' skills ($R^2 = 0.684$), confirming its stability. These results demonstrate the effectiveness of the updated modules in providing practice-oriented training for students. At the same time, the continuing negative influence of Block 4 in the regression model indicates the need for earlier and more systematic involvement of students in project activities and their support. A comparative analysis of regression models and average scores by factors for the experimental and control groups showed that students who studied the updated modules improved their skills in applying engineering tools and technologies. The average score was 4.74 compared to 4.52 in the control group. Despite the small difference (0.22 points), it was statistically significant due to the stability of the scores within the groups. The increase is primarily associated with improvements in key skills such as planning (F7), basic economic and legal knowledge (F6), and self-analysis (F9), which directly reflects the content of the updated modules, which included interdisciplinary tasks, practical cases, and elements of reflection. At the same time, the negative impact of student involvement in project activities (Block 4) persisted, but it became less pronounced in the experimental group, indicating better adaptation to new formats of project work and interaction with the professional environment. Overall, the results confirm the effectiveness of the updated modules and the need for their further scaling.

4 Discussion

The existing gap between the skills of graduates of engineering education programs and the requirements of the industry determined the research focus on approaching the learning outcomes of training modules to the expectations of students and the industrial sector. To this end, the paper built regression models based on surveys of students, teachers and company employees, and tested updated training modules integrated with workplace learning.

Comparative analysis of the regression models demonstrated differences in the perception and importance of factors influencing the development of students' professional skills and practical experience. The most stable factor in all target groups was Block 2—digital and production resources, which emphasizes the key role of technological infrastructure in engineering education. The significant influence of block 1 (internship organization, mentoring, equipment) was especially evident in the experimental group of students, which confirms the importance of the quality of the production environment and mentor support. Block 3 (educational support and management) showed a moderate but stable positive influence, especially in the assessments of students and company employees. This emphasizes the importance of feedback, support and motivation, as well as the need to integrate reflective and mentoring practices into the training modules. After the implementation of the updated programs, the importance of this block increased, which additionally confirmed the importance of educational support in the process of practice-oriented learning. Block 4 (student involvement, project activity) deserves special attention, which showed a negative influence in the regression model of students, despite the positive correlation. This may indicate students' difficulties in adapting to project activities, insufficient support or weak integration of project assignments into the general learning process. In the experimental group, the influence of block 4 decreased, which probably reflects the effectiveness of structured support in project implementation. This effect is consistent with the recommendations implemented, as presented in Table 5: clarifying the scope and complexity of project tasks (recommendation 4.1) and introducing phased implementation structures with regular support (recommendation 4.2) alleviated students' feelings of overload and increased the manageability of project activities, as confirmed by an increase in correlation and a decrease in the negative β coefficient. Similar phenomena have been noted in international studies (Succi and Canovi, 2020; Hasslöf et al., 2022; Lee and Fang, 2020), which emphasize the importance of pedagogical support when introducing project formats. At the same time, despite the positive changes, the effect of project activities remains moderate, which may be due to the limited scale and short-term nature of the pilot study. Longitudinal studies and cross-cultural validation are needed to obtain more reliable conclusions, allowing for the diversity of educational practices and contexts to be taken into account.

Comparison of the views of different target groups revealed a difference in emphasis: company employees highly value the importance of independent learning and adaptation of students in the professional environment, teachers—organizational and resource conditions, and students—the quality of the educational environment and practice. Differences in the perception of the importance of project activity are particularly noticeable: students tend to overestimate their own participation, while teachers and mentors emphasize the importance of organized support. These differences indicate the need to harmonize the expectations of all participants of the educational process and to strengthen coordination between universities and industrial partners.

The obtained results confirm the importance of a structured and multicomponent approach to the formation of students' professional skills. Our study is consistent with a number of international works emphasizing the importance of practice-oriented learning and close integration of students into the industrial environment (Poveda et al., 2021; Ferns and Rowe, 2021). For example, in Lerman et al. (2024) and Álvarez-Risco et al. (2023) it is noted that access to modern digital and technical resources is one of the determining factors in the development of applied engineering skills. At the same time, numerous studies emphasize that students' participation in project activities becomes truly effective only in the presence of systemic support, clearly structured assignments and regular feedback from teachers and mentors (Karstina, 2023; Lee and Fang, 2020; Mourtos, 2020; Müller et al., 2022). In particular, Hasslöf et al. (2022) emphasize the importance of ongoing pedagogical support, while Mourtos (2020) stresses the need to build a comprehensive system of organizational and methodological support for project work. Our study complements these findings by providing quantitative evidence: although Block 4 correlates with skill development, its regression coefficients indicate a negative impact in conditions of insufficient support. This confirms that Block 4 itself is not a negative factor, but its positive potential is only revealed when combined with resource provision (Block 2), organizational support (Block 1), and educational support (Block 3). Additionally, our study emphasizes the role of educational support not only as a tool of organizational support, but also as an important component contributing to the formation of reflective skills, independent learning and sustainable professional development. These findings are consistent with the results of other studies (Bohle Carbonell et al., 2020), which emphasize the importance of feedback, coaching, and stimulating self-assessment in the context of workplace learning.

Thus, the proposed structural model allows us to take into account the influence of organizational, resource and personal factors on the development of students' professional skills. The coordination of university and company efforts in implementing the format of on-the-job training becomes a key condition for the effectiveness of the educational process and the formation of professional identity of future engineers.

The testing of the updated modules, conducted on the example of three training courses, demonstrated positive changes. The increase in the average score of the key skill (application of engineering tools and technologies) in the experimental group (4.74 points) compared to the control group (4.52 points), as well as the increase in the explanatory power of the regression model ($R^2 = 0.684$) confirm the effectiveness of the changes. The influence of organizational factors (Block 1) and digital resources (Block 2) was particularly strengthened, highlighting the importance of an integrated approach.

The proposed model can be used to design curricula that integrate theoretical and practical learning. The findings emphasize the need for coordinated participation of all stakeholders and further improvement of student support mechanisms, especially in terms of project activity.

A limitation of this study is the use of respondents' self-assessments, which may affect the objectivity of the perception of skill formation. In addition, the study covered a limited number of training modules and partner organizations, which limits the generalizability of the findings. Nevertheless, even with the small sample size of the pilot project, the differences identified were significant: the average difference was 0.22 on a 5-point scale, the coefficient of determination increased to $R^2 = 0.684$, and the statistical significance of the changes was stable ($p < 0.001$). An important confirmation of the rigor of the data obtained is the consistency of these results with a larger-scale survey ($n > 1,000$ respondents), as well as the clear and reproducible structure of the proposed model and the interventions implemented. The prospect for further research is to expand the sample, use methods of external objective assessment of skills, and conduct a longitudinal analysis of the dynamics of the formation of students' professional competencies in the process of workplace training. In this regard, it is advisable to apply a triangulation strategy-comparing survey data with objective indicators of academic performance, including academic achievement, exam results, completion of laboratory and project assignments, as well as expert assessments by teachers and mentors. This will increase the validity and reliability of conclusions and provide a more comprehensive understanding of the process of developing professional competencies.

5 Conclusion

This paper proposes a methodological approach to analyzing the influence of various factors on the development of professional skills, the acquisition of practical experience and the integration of students into the professional environment. The approach is based on the methods of correlation and regression analysis, supplemented by a structural model reflecting the relationship between the external conditions of the educational process and the skills formed in students. The results of the study showed that the formation of students' key professional competencies occurs in the interaction of their personal motivation and activity with the organizational, technological and educational infrastructure created by universities and partner companies as part of workplace training. Among the four identified blocks of factors, Block 2 (digital and productive resources) had the greatest influence in all target groups. This emphasizes the critical importance of providing students with access to state-of-the-art hardware, software and production platforms. The regression models built for students, teachers and company employees revealed the multicomponent nature of the process of professional skills formation and differences in the perception of the importance of individual factors. The regression models built for students, teachers and company employees revealed the multicomponent nature of the process of professional skills formation and differences in the perception of the importance of individual factors. These differences confirm the need for a balanced and coordinated approach in the development of workplace training programs, taking into account the views of all stakeholders. Based on this analysis, practical recommendations were developed to strengthen the influence of each set of factors. These recommendations formed the basis for updating three training modules that combine theoretical training at the university with practical training in companies. Approbation of the updated modules showed positive changes in the level of professional competencies formation, especially in terms of application of engineering tools, modern equipment and technologies.

Following the implementation of the changes to the training modules:

- the influence of Block 1 (internship organization, mentoring, equipment) increased, which confirms the importance of structured support for students in the workplace;
- the contribution of Block 2 (digital and production resources) increased significantly, which is confirmed by the increase in the regression coefficients and explanatory power of the model ($R^2 = 0.684$);
- Block 3 (educational support and management) showed a positive impact on the development of students' professional skills after the implementation of the updated training modules, emphasizing the importance of educational support, motivation and feedback in the workplace learning process;
- although the negative impact of Block 4 (engagement and project activity) remained, its expression decreased, indicating better adaptation of students to the updated formats of project activities and interaction with the professional environment;
- improvement was noted in key skills, including planning of work (F7), basics of economic and legal knowledge (F6), self-analysis skills (F9).

The obtained results confirm the effectiveness of the proposed changes to the training modules and emphasize the expediency of their further scaling. The results showed that digital and production resources (Block 2) are a key factor in the development of students' professional skills, but their effectiveness is most fully realized only when combined with organizational support (Block 1) and educational support (Block 3). In this context, the proposed model facilitates the transition from fragmented forms of internships to integrated practice-oriented formats based on empirical data and agreed upon with participants in the engineering education ecosystem. To scale this approach, universities and companies should adapt the proposed factor blocks to their local conditions, building a system of interaction that takes into account available resources and partnerships. This approach will ensure the gradual transformation of practice-integrated learning in various educational and cultural contexts. The developed structural model and analytical tools can be used in the practice of universities to improve the quality of engineering and science students' training, to strengthen the practice-oriented component of education and to better integrate students into the professional community. Although the pilot project was implemented on the basis of specific modules at two Kazakh universities, the structural model and methodology for its validation (survey design, regression model, intervention mapping) are highly scalable and transferable, making it possible to replicate them in other disciplines and educational institutions. Looking ahead, it is important for universities to strengthen partnerships with industry, develop digital and production infrastructure, and introduce mentoring mechanisms. For companies, participation in the design of training modules is becoming a priority, ensuring that training meets the demands of the labor market. In addition, the proposed model can be adapted to other areas of higher education where a combination of academic and practical components is required, opening up opportunities for further interdisciplinary and international research. At the same time, the study has certain limitations related to the small sample size, the use of student self-assessment data, and the short-term nature of the testing of training modules. In the future, it would be advisable to expand the empirical base by applying objective methods of assessing skill development, as well as conducting longitudinal and cross-cultural studies. This will increase the reliability of conclusions and allow the proposed model to be adapted to different educational contexts.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical approval was not required for the study involving humans in accordance with the local legislation and institutional requirements. Written informed consent to participate in this study was not required from the participants or the participants' legal guardians/next of kin in accordance with the national legislation and the institutional requirements.

Author contributions

SK: Writing – review & editing, Conceptualization, Investigation, Writing – original draft, Supervision, Software, Data curation, Validation, Project administration, Resources, Formal analysis, Methodology, Visualization. AT: Validation, Data curation, Methodology, Writing – review & editing, Writing – original draft, Software, Formal analysis, Visualization. EM: Visualization, Validation, Supervision, Writing – review & editing.

Funding

The author(s) declare that financial support was received for the research and/or publication of this article. This research was funded by the Committee of Science of the Ministry of Science and Higher Education of the Republic of Kazakhstan (grant no. AP19679248 - "Integration of new forms of corporate training in the implementation of dual education programs in engineering and science").

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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