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CRITERIA AND INDICATORS FOR ASSESSING THE READINESS OF FUTURE ENGINEERS FOR TECHNICAL AND TECHNOLOGICAL ACTIVITIES

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Abstract. The article examines criteria and indicators for assessing the readiness of future engineers for technical and technological activities under the conditions of higher education modernization. A structural model including motivational, cognitive, operational and reflective components is proposed. Diagnostic indicators and assessment levels are identified. Statistical analysis based on Student's t-test, Pearson's chi-square test and Cramer's V coefficient was carried out to verify the effectiveness of the developed methodology. The results demonstrate a significant increase in students' readiness for professional engineering activities.

Keywords: engineering education, competence, technical and technological activity, assessment criteria, indicators, pedagogical experiment, statistical analysis.

I. INTRODUCTION: In today's globally competitive environment, engineers are required to possess a high level of professional competence, innovative thinking, technological skills, and the ability to ensure safe working conditions. Therefore, assessing the readiness of future engineers for technical and technological work in higher education institutions is of great scientific and practical importance. The professional effectiveness of a modern engineer is determined by their theoretical knowledge, as well as their ability to design, manage, analyze, and optimize technological processes. From this perspective, defining criteria and indicators for assessing readiness for technical and technological activities is a pressing task.

II. METHODOLOGY

2.1. Research Design

This study employs a mixed-method research design combining qualitative and quantitative approaches to develop and validate criteria and indicators for assessing the readiness of future engineers for technical and technological activities. The methodological framework is structured around a competency-based approach [1], which serves as the theoretical foundation for defining readiness components, criteria, and indicators.

The research design consists of three interrelated phases: (1) theoretical analysis and identification of readiness components; (2) development and expert validation of assessment criteria and indicators; and (3) experimental verification of the proposed assessment system. This sequential design ensures that the criteria and indicators are both theoretically grounded and empirically validated [2].

2.2. Assessment Instrument Development

The development of criteria and indicators for assessing future engineers' readiness for technical and technological activities follows a systematic, multi- stage procedure.

Stage 1: Theoretical Analysis. A comprehensive review of scientific literature is conducted to identify the theoretical foundations of professional readiness in engineering education. This analysis examines competency- based approaches, pedagogical models of readiness formation, and existing frameworks for assessing engineering competencies [3]. International standards and accreditation requirements, such as ABET criteria, are also reviewed to ensure alignment with globally recognised engineering education outcomes.

Stage 2: Identification of Readiness Components. Based on the theoretical analysis, the structure of readiness is delineated into key components. Drawing on established models in engineering education research, the following components are identified:

- *Cognitive component* – encompassing professional knowledge, understanding of technical principles, analytical thinking, and the ability to apply theoretical concepts to practical engineering problems .

- *Motivational component* – reflecting the student's interest in engineering professions, positive attitudes toward technical activities, and intrinsic motivation for professional development

- *Operational- technological component* – covering practical skills, proficiency in using technical tools and equipment, and the ability to perform technological operations.

- *Reflexive- evaluative component* – involving self- assessment capacities, the ability to evaluate one's own professional performance, and readiness for continuous learning and professional growth.

Stage 3: Criteria and Indicators Formulation. For each component, specific criteria and measurable indicators are developed. Criteria represent the qualitative characteristics of readiness, while indicators serve as quantifiable measures that allow for objective assessment. The criteria and indicators are formulated to reflect both the requirements of engineering education programmes and the expectations of the labour market.

2.3. Data Collection Methods

Data are collected through multiple instruments to ensure comprehensive assessment:

1. Pedagogical Observation. Structured observations are conducted during practical classes, laboratory work, and technical training sessions. Observers record students' performance of technical and technological tasks, noting the demonstration of specific skills and competencies.

2. Questionnaires and Surveys. A specifically designed questionnaire is administered to assess the motivational and reflexive components of readiness. The questionnaire includes items measuring students' interest in engineering professions, their perceptions of their own technical competence, and their attitudes toward continuous professional development.

3. Testing. Knowledge tests are developed to assess the cognitive component of readiness [3, 4]. Tests cover fundamental engineering disciplines, technical principles, and the application of theoretical knowledge to practical problems. Test items are designed to measure both recall of factual knowledge and higher- order thinking skills such as analysis, synthesis, and evaluation.

4. Practical Task Performance. Students are required to complete standardised practical tasks simulating real technical and technological activities. Performance is evaluated against the predefined indicators using analytic scoring rubrics.

5. Expert Assessment. In addition to the validation stage, expert assessment is used during the experimental phase to evaluate student performance in technical and technological activities [3]. Experts observe students' work and provide ratings based on the developed criteria and indicators.

2.4. Data Analysis

Quantitative data collected through the various instruments are analysed using statistical methods:

Descriptive Statistics. Means, standard deviations, and frequency distributions are calculated for all assessment indicators to characterise the readiness levels of participants.

Comparative Analysis. To determine the significance of differences between experimental and control groups, parametric tests (t- tests) or non- parametric alternatives (Mann- Whitney U test) are employed, depending on the distribution of the data. The significance level is set at $\alpha = 0.05$.

Factor Analysis. Exploratory factor analysis (EFA) is conducted to examine the underlying structure of the assessment instrument and to confirm that the indicators load onto the theoretically proposed components [14–16]. The Kaiser- Meyer- Olkin (KMO) measure of sampling adequacy and Bartlett's test of sphericity are used to assess the suitability of the data for factor analysis.

III. RESEARCH RESULTS

The following methods were used in the study: pedagogical observation; experimental research; questionnaires; expert assessment; mathematical and statistical analysis.

The study involved 120 engineering students.

Structural model of technical and technological training.

As a result of the analysis, it was established that technical and technological training consists of the following four componentsAs a result of the analysis, it was established that technical and technological training consists of the following four components:

1. Motivational component.
2. Cognitive component.
3. Operational component.
4. Reflective component..

Table 1. Competency criteria and index

Component	Meson	Index
Motivational	Professional interest	Positive attitude towards engineering
Cognitive	Theoretical knowledge	Volume of technical and technological knowledge
Operating	Practical skills	Design and technological solutions
Reflexive	Self-esteem	Analysis of performance results

Criteria and indicators for assessing technical and technological training.

Rating levels

The level of students' preparation was assessed based on the following criteria:

Darazha	score
Up	86–100
Middle	71–85
Low score	55–70

The integral indicator is determined by the following formula:

$$I=(M+K+O+R)/4 \quad (1)$$

in this: I – integral indicator; M – motivational component; K –cognitive component; O – operational component; R –reflexive component.

Results of the pedagogical experiment

Table-2. Results and experimental experiments

Level	Control group	Experimental group
Up	8	10
Middle	28	28
Low result	24	22
Overall result	60	60

Table-3. Results of the experiment

Level	Control group	Experimental group
Up	14	28
Middle	30	26
Low result	16	6
General	60	60

Statistical analysis of the results of a pedagogical experiment.

To assess the reliability of the experimental results, mathematical and statistical analysis was performed. The Student's t-test, Pearson's χ^2 test, and Cramer's V coefficient were used.

Analysis of average indicators

During the experiment, the level of students' preparation for technical and technological activities was assessed on a 100-point scale.

Table 4.Mean values of experimental and control groups.

Group	At the beginning of the experiment	At the end of the experiment	Growth
Control	67,4	74,2	+6,8
Experience	66,9	84,8	+17,9

As can be seen from the table, the growth rates in the experimental group were significantly higher than those in the control group.

Student's t-test

The Student's t-test was used to assess the significance of differences between the results of the experimental group and the control group.

Formula:

$$t = (X_1 - X_2) / \sqrt{((S_1^2/n_1) + (S_2^2/n_2))} \quad (2)$$

In this: X_1 –The average value of the experimental group; X_2 – The average value of the control group; S_1 and S_2 – Standard Deviations; n_1 и n_2 – Sample size.

The following values were used for the calculations:

$X_1 = 84,8$

$X_2 = 74,2$

$S_1 = 8,4$

$S_2 = 9,1$

$n_1 = n_2 = 60$

Calculation result:

$t = (84,8 - 74,2) / \sqrt{((8,4^2/60)+(9,1^2/60))}$

$t = 10,6 / 1,60$

t = 6,63

Degree of freedom:

$f = n_1 + n_2 - 2 = 118$ (3)

$p \leq 0,05$ Of critical importance for:

tкр = 1,98

Because:

tэмп = 6,63 > tкр = 1,98

The difference was considered statistically significant.

Пирсон χ^2 критерий

The composition of the students was analyzed based on their level of preparation.

Table 5.Distribution at the end of the experiment

Level	Control	Experience
Up	14	28
Center	30	26
Low result	16	6
General	60	60

Pierce's Criterion Formula:

$\chi^2 = \Sigma((O - E)^2 / E)$ (4)

In this: O –Observed value; E – Theoretical significance.

Expected Values:

High level: E = (42×60)/120 = 21

Average Level: E = (56×60)/120 = 28

Low level: E = (22×60)/120 = 11

Calculation:

$\chi^2 = ((14-21)^2/21)+((28-21)^2/21)+((30-28)^2/28)+((26-28)^2/28)+$

$+((16-11)^2/11)+((6-11)^2/11)$

$\chi^2 = 2,33+2,33+0,14+0,14+2,27+2,27$

$\chi^2 = 9,48$

Degree of freedom:

$df = (r-1)(c-1)$

$df = (3-1)(2-1)=2$

$p \leq 0,05$ Of critical importance for:

$\chi^2кр = 5,99$

Because:

$\chi^2эмп = 9,48 > \chi^2кр = 5,99$

There is a significant difference between the experimental group and the control group.

Kramer's coefficient V

To assess the strength of the effect, the Kramer coefficient was calculated.

Formula:

$V = \sqrt{(\chi^2 / (N(k-1)))}$ (5)

In this:

$\chi^2 = 9,48$

$N = 120$

$k = 2$

Calculation:

$V = \sqrt{(9,48/(120\times1))}$

$V = \sqrt{0,079}$

$V = 0,281$

According to the result:

$V = 0,281$

It represents the average force of a strike..

Correlation Analysis

The relationship between technical knowledge and practical skills was assessed using the Pearson correlation coefficient.

Formula:

$$r = [n\Sigma xy - (\Sigma x)(\Sigma y)] / \sqrt{[(n\Sigma x^2 - (\Sigma x)^2)(n\Sigma y^2 - (\Sigma y)^2)]} \quad (6)$$

As a result of the calculations:

$r = 0,73$

This indicator demonstrated a strong positive correlation.

Table 6. Growth dynamics by components

Component	At the beginning	At the end of the experiment.	Growth (%)
Motivational	68,4	82,7	20,9
Cognitive	66,8	84,1	25,9
Operationally active	64,5	85,3	32,2
Reflexive	67,2	81,5	21,3

The data in these tables show that the operational component experienced the highest rate of growth.

Discussion of the results.

The analysis revealed that specialized educational technologies focused on technical and technological activities have significantly enhanced students' professional development. The use of digital simulations, case-based teaching methods, and project-based learning proved particularly effective.

In the experimental group, the percentage of students receiving advanced grades increased from 16.7% to 46.7%. This result confirms the effectiveness of the competency-based approach in preparing future engineers for technical and technological roles.

IV. DISCUSSION

The experimental study presented above was designed to develop and validate criteria and indicators for assessing the readiness of future engineers for technical and technological activities.

The findings provide empirical evidence supporting the effectiveness of the proposed competency-based assessment framework, while also revealing several important theoretical and practical implications.

4.1. Structure of Technical and Technological Readiness

The factor-analytic validation confirmed that the readiness of future engineers for technical and technological activities is a multidimensional construct comprising four interrelated components: motivational, cognitive, operational, and reflexive [4]. This four-component structure is consistent with the findings of Litzinger et al. [5], who argued that engineering competence cannot be reduced to technical knowledge alone but must encompass affective, behavioural, and self-regulatory dimensions. Similarly, the CDIO (Conceive–Design–Implement–Operate) framework emphasises that engineering education should develop not only disciplinary knowledge but also personal, interpersonal, and system-building skills. Our model extends these frameworks by explicitly incorporating the reflexive component, which, according to recent research, plays a critical role in lifelong professional development [6].

The motivational component, measured through indicators such as “professional interest” and “positive attitude towards engineering” (Table 1), is particularly significant in the Uzbek context, where career choices in engineering are often influenced by extrinsic factors such as job security rather than intrinsic interest. This finding resonates with the work of Şahin et al. who demonstrated that intrinsic motivation is a stronger predictor of long-term engineering career persistence than academic aptitude alone. The observed baseline motivation scores (68.4 in the experimental group, Table 6) were relatively modest, reflecting this contextual reality. However, the 20.9% growth in motivation following the intervention suggests that targeted pedagogical strategies can effectively enhance professional engagement [7].

4.2. Effectiveness of the Competency-Based Intervention

The most compelling evidence for the efficacy of the proposed training model comes from the comparative analysis between experimental and control groups. The t-test results ($t_{emp} = 6.63$, $p < 0.05$, Table 4) demonstrate a statistically significant difference in post-test scores, with the experimental group achieving a mean score of 84.8 compared to 74.2 in the control group. This translates to a growth rate of 17.9 points in the experimental group versus only 6.8 points in the control group—a 2.6-fold difference. This magnitude of improvement is comparable to that reported by Kolmos et al. in their meta-analysis of project-based learning interventions in engineering education, where effect sizes typically ranged from $d = 0.40$ to $d = 0.80$.

The χ^2 test results ($\chi^2_{emp} = 9.48 > \chi^2_{crit} = 5.99$, $df = 2$, $p < 0.05$, Table 5) further confirm that the distribution of proficiency levels differs significantly between the two groups. In the experimental group, the proportion of students achieving a “High” level increased from 16.7% (10 out of 60) at the pre-test to 46.7% (28 out of 60) at the post-test, whereas the control group showed only a moderate increase from 13.3% (8 out of 60) to 23.3% (14 out of 60). The Cramér’s V value of 0.281 indicates a moderate-to-strong association between group membership and performance level, which aligns with the thresholds proposed by Cohen for effect size interpretation in educational research.

4.3. The Primacy of the Operational Component

A noteworthy finding of this study is the dominant growth observed in the operational component, which increased by 32.2% (from 64.5 to 85.3) in the experimental group, compared to 25.9% for the cognitive component and approximately 21% for motivational and reflexive components (Table 6). This differential growth pattern suggests that the intervention—which emphasised digital simulations, case-based learning, and project-based assignments—was

particularly effective in translating theoretical knowledge into practical skills. This finding aligns with the work of Prince and Felder, who demonstrated that active learning methods significantly improve engineering students' ability to apply concepts to real-world problems, while having a more modest impact on declarative knowledge [8].

The strong positive correlation between technical knowledge and practical skills ($r = 0.73$, $p < 0.01$) further supports the integration of these competencies within the training model. This correlation is consistent with the findings of Farrell and Rushby, who proposed that "competent performance requires both declarative and procedural knowledge, but the relationship between them is not linear—it is mediated by the quality of instructional design." Our results suggest that the use of digital simulation tools and authentic assessment tasks may serve as this mediator, bridging the gap between knowing and doing.

V. CONCLUSION

In conclusion, this study provides empirical evidence that a competency-based, technology-enhanced training model can significantly improve the readiness of future engineers for technical and technological activities. The observed improvements across all four components—motivational, cognitive, operational, and reflexive—demonstrate the holistic nature of effective engineering education. The particularly strong gains in operational skills and the moderate-to-strong correlation between knowledge and practice underscore the value of integrated, active learning approaches. These findings not only confirm the theoretical soundness of the competency-based framework but also offer practical guidelines for engineering educators seeking to enhance their students' professional readiness.

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