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ENGINEERING EDUCATION AND THE SCIENTIFIC FOUNDATIONS OF DEVELOPING PROFESSIONAL COMPETENCE

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Abstract

Engineering education is undergoing rapid transformation due to the increasing complexity of technological systems, the diversification of industrial requirements, and the shift toward competency-based learning models. Developing professional competence has become a central priority for preparing future engineers capable of solving practical problems, making informed decisions, and adapting to real production environments. This article examines the scientific foundations of shaping professional competence in engineering education, focusing on theoretical, methodological, psychological, and didactic principles that determine the structure, mechanisms, and assessment of competence formation.

Keywords: Professional competence, engineering education, kvalimetry, competency-based learning, assessment, cognitive development, activity theory, engineering thinking.

Introduction

Accelerated technological change and the increasing complexity of production systems require engineers who are not only knowledgeable but also capable of applying knowledge creatively, making rapid decisions, and solving non-standard industrial problems. This has positioned professional competence as the core outcome of engineering education. Competence is no longer viewed merely as the accumulation of knowledge and skills; it represents a holistic, multi-layered integration of cognitive, practical, motivational, communicative, and value-based components.

Engineering education has increasingly shifted toward competency-based learning (CBL), a model that emphasizes measurable learning outcomes, performance indicators, and practice-oriented assessment mechanisms. Within this framework, identifying the scientific foundations of competence formation becomes essential for developing effective pedagogical models, improving curriculum design, and ensuring that teaching methods correspond to the changing demands of modern technology.

Recent research in the field highlights the significance of kvalimetric assessment, multi-stage pedagogical structuring, and diagnostic tools for evaluating engineering students' readiness for professional activity. Findings consistently demonstrate that engineering competence emerges through the dynamic interaction of cognitive processes, practical performance, motivational factors, and reflective judgment [2].

This article examines these components in a systematic manner and presents a scientifically grounded theoretical model for understanding the development of professional competence in engineering education.

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Theoretical Foundations of Professional Competence Formation1. Competence as an Integrated Pedagogical Phenomenon.

Professional competence in engineering is defined as a complex, integrated ability to perform practical tasks effectively, make informed decisions, analyze industrial processes, and engage in continuous learning. The construct includes:

- Cognitive competence: disciplinary knowledge, conceptual understanding, analytical thinking.
- Activity-based competence: practical skills, operational procedures, technological manipulation.
- Creative competence: innovative thinking, problem-solving strategies, flexibility of thought.
- Motivational competence: internal drive, professional interest, value-based orientation.
- Reflexive competence: self-assessment, monitoring of one's decisions, awareness of performance quality.

These components create a unified structure that determines how students acquire and apply engineering knowledge.

2. Epistemological and Cognitive Foundations

Engineering competence emerges from epistemological processes involving perception, logical thinking, abstraction, systematization, and interpretation. Cognitive psychology identifies core mental functions essential to engineering activity [3, 4, 6]:

- Operational memory required to simultaneously process multiple technical parameters;
- Selective attention for focusing on key technological indicators;
- Cognitive flexibility for shifting between conceptual and applied tasks;
- Analytical reasoning for diagnosing technical failures or optimizing engineering systems.

Tests such as *memory span*, *digit-symbol substitution*, *Münsterberg attention test*, and *intellectual flexibility assessments* are useful diagnostic tools to evaluate these processes. Roziyev's research shows that engineering students' cognitive profiles correlate strongly with their academic and practical performance.

3. Activity Theory as the Basis for Engineering Learning

The development of engineering competence is grounded in activity theory, where learning is viewed as purposeful action involving tools, objects, and problem-solving procedures. According to Leontiev's model [7]:

1. Activity represents the student's engagement with professional goals;
2. Actions constitute procedural steps required to achieve these goals;
3. Operations are automatic routines shaped by conditions.

Engineering education must therefore simulate real professional environments, enabling students to perform actions similar to industrial tasks. Competence forms gradually—from conscious performance to automated professional behavior.

Methodological Foundations of Competence Formation

1. Competency-Based Learning Framework

Engineering curricula must align with competency-based standards defined by national and international qualification frameworks (e.g., ESCO, ECTS, ENAEE). The framework requires:

- clearly defined learning outcomes,
- performance-based indicators,

- evaluative criteria linked to professional tasks,
- iterative diagnostic assessment.

Teaching is structured around competencies, and assessment must measure not knowledge itself but the ability to apply knowledge.

2. The Multi-Component Model of Professional Competence

Roziyev's research proposes a scientifically grounded model comprising:

- Motivational-value component, shaped through professional identity and ethical orientation;
- Cognitive-theoretical component, built through lectures, principles, diagrams, models;
- Operational-practical component, formed during laboratory work, simulations, design tasks;
- Creative-innovative component, developed through case-studies and engineering design challenges;
- Reflexive-evaluative component, strengthened through self-assessment and peer review.

The model ensures that competence evolves consistently through the integration of theoretical and practical learning.

3. Pedagogical Conditions Supporting Competence Formation

Several pedagogical conditions enhance the formation of engineering competence:

- implementation of active and interactive methods (project-based learning, problem-solving labs, simulation);
- use of digital platforms for modelling technological processes;
- organization of multi-stage learning, progressing from basic understanding to independent engineering solutions;
- integration of industry-based tasks and dual education principles, enabling workplace-like learning;
- applying kvalimetric tools to objectively measure competence development.

Optimal pedagogical conditions create an educational environment where students gradually internalize engineering actions.

Assessment and Kvalimetry in Engineering Competence.

1. Kvalimetric Tools for Measuring Competence

Kvalimetry provides a scientific basis for evaluating complex learning outcomes. Assessment does not rely on single tasks but measures competence through multiple indicators and criteria.

A kvalimetric approach uses [10]:

- multi-level scales (low, medium, high);
- quantitative and qualitative descriptors;
- weight coefficients for different indicators;
- diagnostic tests measuring mental and practical abilities.

This allows for objective, mathematically justified assessment of students' mastery.

2. Three-Stage Assessment Model

Roziyev's methodology applies a three-stage system of pedagogical diagnostics:

1. Initial assessment: determining basic knowledge and cognitive readiness;

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2. Formative assessment: monitoring competence development during learning;
3. Summative assessment: final evaluation of readiness for professional activity.

Each stage uses distinct tools—tests, practical assignments, case-analysis, lab work, and reflexive journals.

3. Integrating Cognitive Diagnostics

Modern assessment must also include cognitive diagnostics. Engineering tasks rely on accurate perception of data, analytic capacity, and decision-making under pressure. Tests measuring:

- operational memory,
- processing speed,
- attention focus,
- cognitive flexibility,

help identify students' strengths and weaknesses. This ensures individualized competence development.

Pedagogical Model for Competence Formation.

1. Structure of the Model

The scientific model includes interconnected blocks:

- Goal block: alignment with national standards and industrial requirements;
- Methodological block: activity-based, competency-based, and cognitive principles;
- Content block: engineering concepts, professional tasks, simulations;
- Process block: stepwise implementation of learning activities;
- Diagnostic block: kvalimetric assessment, cognitive tests, performance tasks.

2. Implementation Stages

The model develops competence through three stages:

1. Introductory stage: formation of basic concepts and motivational interest;
2. Core stage: active engagement in simulation tasks, modelling, laboratory practice;
3. Reflective-analytical stage: consolidation of engineering identity, self-assessment, decision-making tasks.

3. Expected Outcomes

Upon completion, a student should demonstrate:

- understanding of theoretical foundations;
- ability to design technical solutions;
- decision-making proficiency;
- capacity for innovation;
- professional values and norms;
- readiness for independent engineering activity.

This outcome aligns with international engineering accreditation frameworks.

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Discussion

Engineering competence formation is a complex process requiring an integrative approach. Traditional knowledge-oriented teaching cannot prepare students for modern engineering roles. Instead, competence emerges when students engage in meaningful professional activities, supported by cognitive and motivational development [9].

The research analyzed here emphasizes that competence develops:

- not through isolated learning, but through systematic integration of knowledge, action, thinking, and reflection;
- not via rote memorization, but through active problem-solving;
- not by teacher-centered instruction, but learner-centered engineering design;
- not by simple testing, but multi-stage kvalimetric assessment.

The use of cognitive diagnostics is particularly valuable, as engineering work heavily depends on mental capacities such as memory, attention, and analytical processing. By combining cognitive assessment, kvalimetric models, and competency-based curricular design, engineering education can produce highly prepared graduates.

Conclusion

The scientific foundations of developing professional competence in engineering education require a multi-component, integrated approach that synthesizes cognitive psychology, activity theory, competency-based learning, and kvalimetric assessment. Engineering competence is a dynamic system shaped by motivational factors, theoretical understanding, practical action, creative problem-solving, and reflexive evaluation.

A scientifically grounded pedagogical model must therefore incorporate:

- clear competency goals,
- a structured developmental process,
- active and practice-oriented learning methods,
- cognitive diagnostic tools,
- kvalimetric systems for objective assessment.

Only such an integrative framework can ensure that engineering graduates possess the intellectual, practical, and value-based qualities essential for modern industrial environments.

Future research may focus on expanding predictive assessment methods, integrating artificial intelligence for monitoring competence development, and designing adaptive learning trajectories tailored to individual cognitive profiles.

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