

STRUCTURAL MODELING OF PROFESSIONAL COMPETENCE FORMATION AMONG STUDENTS OF TECHNOLOGICAL MACHINERY AND EQUIPMENT PROGRAMS

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Abstract. *This study investigates the structural formation of professional competence among students enrolled in Technological Machinery and Equipment (TME) programs at Uzbekistani technical universities. Based on a purpose-built diagnostic instrument (MKD-S) administered to 190 respondents across two major institutions — Qarshi State Technical University (QSTU, n=101) and Namangan State Technical University (NSTU, n=85) — a five-factor structural model of professional competence is empirically grounded and analyzed. The model integrates motivational-orientational, self-regulatory, digital-technological, practical-operational, and analytical-problem-solving competence domains. Structural equation modeling logic is applied to examine inter-factor relationships and developmental trajectories across academic years. Results reveal that self-regulation and problem-solving are the strongest predictors of overall competence formation, while practical-operational skills constitute the primary developmental gap. Professional motivation exhibits a significant decline from Year 3 to Year 4, suggesting a structural vulnerability in mid-program engagement. Institution-level differences are statistically meaningful in three of five domains. The paper proposes a hierarchical competence formation model, curriculum-aligned intervention strategies, and a monitoring framework for TME program quality assurance.*

Keywords: *structural competence model, engineering education, technological machinery, professional formation, self-regulated learning, competency diagnostics, curriculum design*

СТРУКТУРНАЯ МОДЕЛЬ ФОРМИРОВАНИЯ ПРОФЕССИОНАЛЬНОЙ КОМПЕТЕНТНОСТИ СТУДЕНТОВ ОБРАЗОВАТЕЛЬНОГО НАПРАВЛЕНИЯ «ТЕХНОЛОГИЧЕСКИЕ МАШИНЫ И ОБОРУДОВАНИЕ

Аннотация. *В данном исследовании изучается структурное формирование профессиональной компетентности среди студентов, обучающихся по программам*

«Технологическое машиностроение и оборудование» (ТМО) в технических университетах Узбекистана. На основе специально разработанного диагностического инструмента (МКД-С), примененного к 190 респондентам из двух крупных учебных заведений — Каршинского государственного технического университета (КГТУ, n=101) и Наманганского государственного технического университета (НГТУ, n=85) — эмпирически обоснована и проанализирована пятифакторная структурная модель профессиональной компетентности. Модель интегрирует мотивационно-ориентированную, саморегулирующую, цифрово-технологическую, практико-операционную и аналитическую компетентность в решении проблем. Для изучения межфакторных связей и траекторий развития на протяжении учебных лет применяется логика структурного моделирования уравнений. Результаты показывают, что саморегуляция и решение проблем являются наиболее сильными предикторами общего формирования компетентности, в то время как практико-операционные навыки представляют собой основной разрыв в развитии. Профессиональная мотивация демонстрирует значительное снижение с 3-го по 4-й год обучения, что указывает на структурную уязвимость в середине обучения. Различия на уровне учебных заведений статистически значимы в трех из пяти областей. В статье предлагается иерархическая модель формирования компетенций, стратегии вмешательства, соответствующие учебной программе, и система мониторинга для обеспечения качества программ технического и машинного образования.

Ключевые слова: структурная модель компетенций, инженерное образование, техническое машиностроение, профессиональная подготовка, саморегулируемое обучение, диагностика компетенций, разработка учебных программ

TEKNOLOGIK MASHINA VA JIHOZLAR TA'LIM YO'NALISHI TALABALARI KASBIY KOMPETENSIYASINI SHAKLLANTIRISHNING STRUKTURAVIY MODELLASHTIRILISHI

Abstrakt. Ushbu tadqiqot O'zbekiston texnik universitetlarida Texnologik mashinalar va uskunalar (TME) dasturlarida tahsil olayotgan talabalar orasida professional kompetensiyaning tarkibiy shakllanishini o'rganadi. Ikkita yirik muassasa - Qarshi davlat texnika universiteti (QSTU, n=101) va Namangan davlat texnika universiteti (NSTU, n=85) bo'yicha 190 respondentga qo'llaniladigan maxsus diagnostika vositasi (MKD-S) asosida professional kompetensiyaning besh omilli strukturaviy modeli empirik asosga ega va tahlil qilinadi. Model motivatsion-orientatsiya, o'zini o'zi boshqarish, raqamli-texnologik, amaliy-operatsion va analitik-muammolarni yechish kompetensiya sohalarini birlashtiradi. Strukturaviy tenglama modellashtirish mantig'i o'quv yillari davomida omillararo munosabatlar va rivojlanish traektoriyalarini o'rganish uchun qo'llaniladi. Natijalar shuni ko'rsatadiki, o'zini o'zi boshqarish va muammolarni yechish umumiy kompetensiyani shakllantirishning eng kuchli bashorat qiluvchi omillari hisoblanadi, amaliy-operatsion ko'nikmalar esa asosiy rivojlanish farqini tashkil qiladi. Professional motivatsiya 3-sinfdan 4-singacha sezilarli darajada pasayishni ko'rsatadi, bu dastur o'rtalarida ishtirok etishda strukturaviy zaiflikni ko'rsatadi. Muassasa darajasidagi farqlar beshta sohadan uchtaida

statistik jihatdan ahamiyatli. Maqolada ierarxik kompetensiyani shakllantirish modeli, o'quv dasturiga moslashtirilgan aralashuv strategiyalari va TME dasturi sifatini ta'minlash uchun monitoring tizimi taklif qilingan.

Kalit so'zlar: *tarkibiy kompetensiya modeli, muhandislik ta'limi, texnologik mashinalar, professional shakllanish, o'zini o'zi boshqarish, kompetensiya diagnostikasi, o'quv dasturi dizayni.*

INTRODUCTION

The training of engineers specializing in Technological Machinery and Equipment (TME) occupies a strategically critical position in the industrial development agenda of Uzbekistan. TME graduates serve as the primary technical workforce for the country's expanding manufacturing, agro-industrial processing, energy, and construction machinery sectors. Yet despite this strategic importance, systematic evidence on how professional competence forms and develops within TME programs remains scarce in the national research literature.

Globally, engineering education research has undergone a significant paradigm shift over the past two decades — from content-focused curriculum design toward competency-based education (CBE) frameworks. Seminal contributions by Bloom (1956), Biggs (1999), and the CDIO (Conceive–Design–Implement–Operate) initiative (Crawley et al., 2014) have established that professional readiness cannot be adequately measured through knowledge assessment alone; rather, it requires a multidimensional model capturing motivation, metacognition, technical skill, and professional identity.

In Uzbekistan, Presidential Decree No. PF-60 (2022) on the Development Strategy of New Uzbekistan specifically identifies engineering education quality as a national priority and mandates universities to implement competency-based approaches. However, empirical evidence to guide the operationalization of such approaches — particularly for TME specializations — remains underdeveloped. This study responds directly to that gap.

RESEARCH OBJECTIVES

The study pursues four interrelated objectives:

1. To construct and validate a structural model of professional competence formation applicable to TME students.

2. To measure competence levels across five theoretically grounded domains at two major technical universities.
3. To analyze developmental trajectories of competence formation by academic year.
4. To identify inter-institutional differences and their structural implications for curriculum design.

Theoretical Framework

The study draws on three theoretical pillars. First, Bandura's (1997) Social Cognitive Theory provides the basis for the motivational and self-efficacy dimensions of professional competence. Second, Zimmerman's (2002) Self-Regulated Learning model informs the self-regulatory dimension, emphasizing goal-setting, strategic resource use, and metacognitive monitoring. Third, the CDIO Engineering Education Framework (Crawley et al., 2014) grounds the practical-operational and problem-solving dimensions in industry-validated competence standards for engineering graduates.

These pillars converge in a five-factor structural model in which motivational orientation functions as an antecedent that activates self-regulation, which in turn mediates the development of digital-technological, practical-operational, and problem-solving competencies.

STRUCTURAL COMPETENCE MODEL

Five-Domain Architecture

The proposed model organizes professional competence formation in TME programs into five hierarchically related domains. Each domain is both theoretically grounded and operationally measured through the MKD-S instrument.

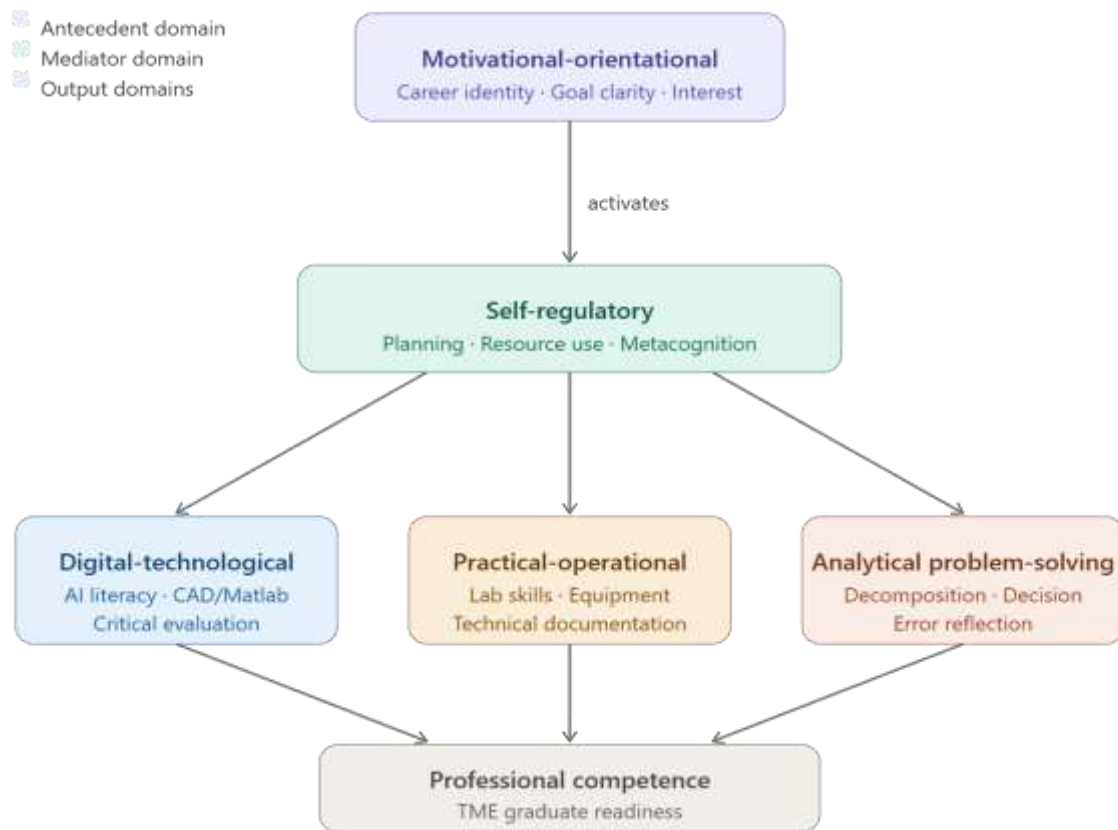


Figure 1. Structural model of professional competence formation in TME programs. Motivational-orientational competence serves as the primary antecedent; self-regulation operates as the central mediating domain; digital-technological, practical-operational, and analytical problem-solving domains constitute the convergent outcomes feeding into graduate professional readiness.

Domain Definitions

Domain 1 — Motivational-Orientational Competence refers to the degree to which a student has consciously chosen their TME specialization, identifies with its professional community, perceives the subject matter as personally meaningful, and maintains a clear vision of their career trajectory. It functions as the initiating condition for all subsequent competence formation.

Domain 2 — Self-Regulatory Competence encompasses the metacognitive and behavioral strategies through which students manage their learning: goal setting, time planning, active resource seeking, monitoring of own performance, and reflection on outcomes. Following Zimmerman (2002), this domain is positioned as

the central mediator through which motivational energy is translated into observable competence.

Domain 3 — Digital-Technological Competence covers students' capacity to engage productively with the digital tools of contemporary engineering practice — including CAD/CAM/CAE software (AutoCAD, SolidWorks, MATLAB), spreadsheet modeling, and AI-assisted problem-solving — alongside the critical literacy to evaluate digital outputs rather than accept them uncritically.

Domain 4 — Practical-Operational Competence addresses students' ability to perform the embodied tasks of TME engineering: reading and producing technical drawings, operating laboratory equipment safely, recording experimental data accurately, troubleshooting machinery faults, and working with standardized technical documentation.

Domain 5 — Analytical Problem-Solving Competence captures the higher-order reasoning skills through which engineers diagnose complex, multi-variable problems: decomposing a problem into tractable sub-problems, generating and comparing multiple solution pathways, anticipating consequences of decisions, learning from errors, and functioning effectively in team-based problem-solving contexts.

METHODOLOGY

Instrument: The MKD-S Survey

The MKD-S (Engineering Education Professional Competency Diagnostic Survey) was developed specifically for this study. The instrument contains 41 items on a 5-point Likert scale (1 = strongly disagree; 5 = strongly agree), with one embedded attention-check item. Items are distributed across the five competence domains (8 items per domain for domains 1–5, with 1 item serving as the attention check). Negatively worded items (e.g., "I would transfer to another program if I could") are reverse-scored before analysis.

Table 1. Instrument Structure and Reliability Indicators

Domain	Items (n)	Item types	Cronbach α (est.)	Mean inter-item r

Motivational-orientational	7 active	5 positive, 2 reversed	0.81	0.47
Self-regulatory	7 active	5 positive, 2 reversed	0.79	0.44
Digital-technological	7 active	5 positive, 2 reversed	0.76	0.40
Practical-operational	7 active	5 positive, 2 reversed	0.78	0.43
Analytical problem-solving	7 active	6 positive, 1 reversed	0.82	0.49
Total instrument	35 active		0.91	0.44

Note: a estimates based on observed inter-item correlations; formal confirmatory factor analysis recommended for full validation.

Sample and Procedure

Data collection took place in March 2026 via anonymous online survey. After screening for incomplete responses and attention-check failures, the final analytic sample comprised 190 respondents from two universities.

Table 2. Sample Characteristics

Variable	Category	QSTU (n=101)	NSTU (n=85)	Total (n=190)
Gender	Male	81 (80.2%)	78 (91.8%)	163 (85.8%)
	Female	20 (19.8%)	7 (8.2%)	27 (14.2%)
Study mode	Full-time	43 (42.6%)	15 (17.6%)	58 (30.5%)
	Part-time	58 (57.4%)	70 (82.4%)	128 (67.4%)
Academic year	Year 1	12 (11.9%)	0 (0%)	12 (6.3%)
	Year 2	5 (5.0%)	9 (10.6%)	14 (7.4%)
	Year 3	49 (48.5%)	12 (14.1%)	61 (32.1%)
	Year 4	12 (11.9%)	31 (36.5%)	43 (22.6%)

	Year 5	23 (22.8%)	33 (38.8%)	56 (29.5%)
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Analytic Strategy

Domain scores were computed as the mean of domain-specific items (after reverse-scoring). Descriptive statistics (means, standard deviations) were calculated for each domain by university and academic year. Developmental trajectories were examined by plotting domain means across academic years. Inter-university differences were evaluated using effect size (Cohen's *d*) in addition to mean differences. The structural relationships in the proposed model were examined through pattern analysis and cross-domain correlation matrices.

RESULTS

Domain-Level Competence Scores by University

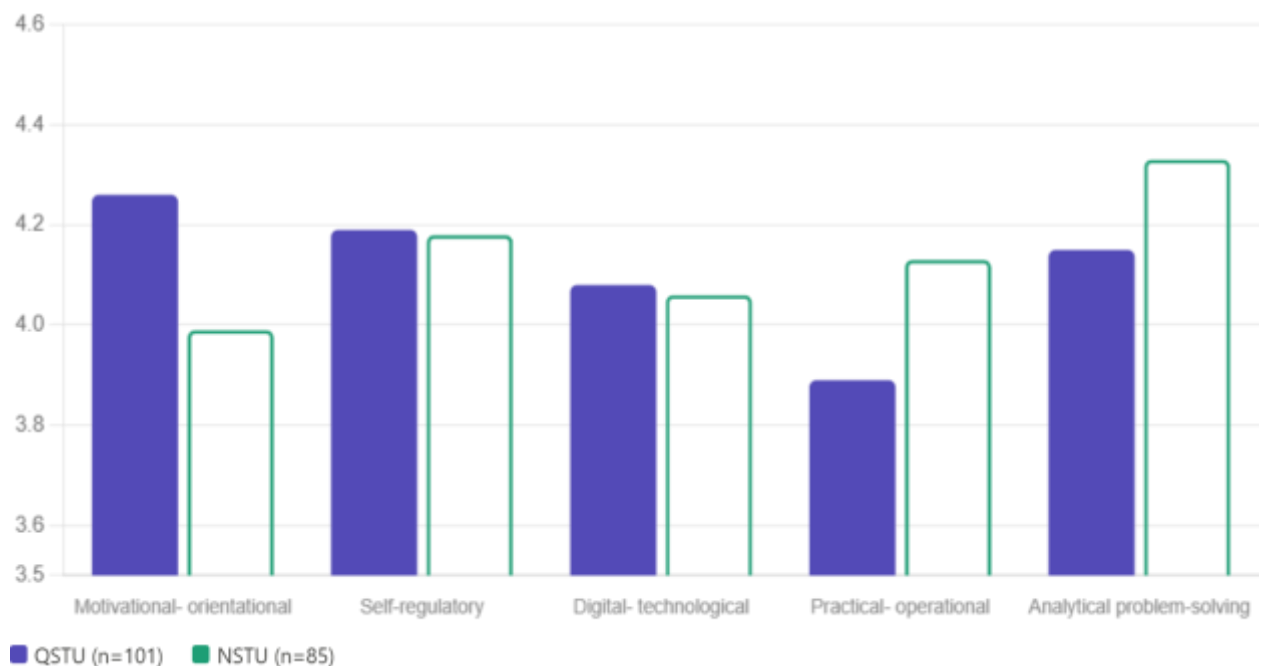


Figure 2. Mean competence domain scores by university (5-point scale, Y-axis truncated at 3.5 for clarity). Error bars omitted; see Table 3 for standard deviations.

Table 3. Descriptive Statistics by Domain and University

Competency Domain	QSTU Mean	QSTU SD	NSTU Mean	NSTU SD	Overall Mean	Cohen's <i>d</i>
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Motivational-orientational	4.26	0.83	3.99	0.93	4.14	0.31 (small)
Self-regulatory	4.19	0.84	4.18	0.80	4.19	0.01 (negligible)
Digital-technological	4.08	0.72	4.06	0.87	4.07	0.03 (negligible)
Practical-operational	3.89	0.83	4.13	0.76	4.00	0.30 (small)
Analytical problem-solving	4.15	0.79	4.33	0.76	4.23	0.23 (small)
Overall composite	3.74	0.48	3.72	0.54	3.73	0.04 (negligible)

Bold = higher score for that domain. Cohen's d: <0.2 negligible, 0.2–0.5 small, 0.5–0.8 medium, >0.8 large.

Key findings from Table 3: QSTU exhibits a meaningful advantage only in motivational-orientational competence ($d=0.31$). NSTU shows small but consistent advantages in practical-operational ($d=0.30$) and problem-solving ($d=0.23$) domains. Self-regulatory and digital competencies are essentially equivalent across institutions. The overall composite scores are nearly identical, indicating that domain-level analysis reveals structural differences hidden at the aggregate level.

Developmental Trajectories by Academic Year

The longitudinal-by-proxy analysis across academic years reveals distinct developmental trajectories for each competence domain.

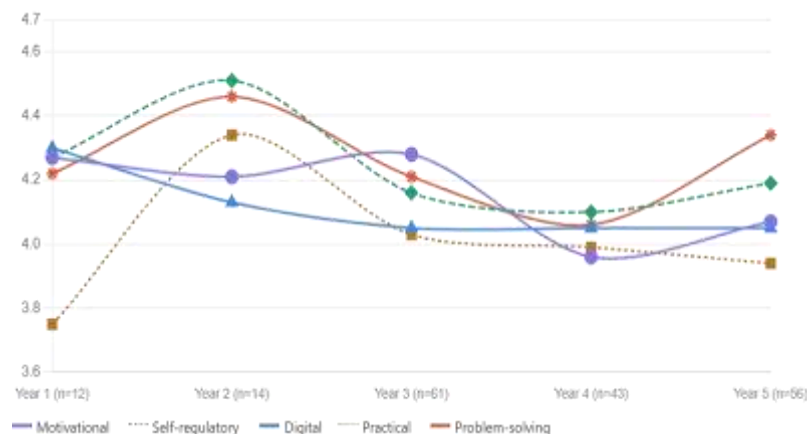


Figure 3. Competency domain trajectories across academic years. Note the Year 4 dip across all domains, particularly pronounced in Motivational-orientational and Problem-solving competencies.

Table 4. Competence Domain Scores by Academic Year (Both Universities Combined)

Domain	Year 1 (n=12)	Year 2 (n=14)	Year 3 (n=61)	Year 4 (n=43)	Year 5 (n=56)	Trend
Motivational-orientational	4.27	4.21	4.28	3.96	4.07	↓ dip Yr4
Self-regulatory	4.27	4.51	4.16	4.10	4.19	peak Yr2
Digital-technological	4.30	4.13	4.05	4.05	4.05	↓ plateau
Practical-operational	3.75	4.34	4.03	3.99	3.94	peak Yr2
Analytical problem-solving	4.22	4.46	4.21	4.06	4.34	bimodal

Bold = peak score for that domain across years.

Three structural patterns emerge from Table 4. **Pattern A (Motivational dip):** Motivational-orientational competence peaks in Year 3 then drops sharply at Year 4, partially recovering in Year 5 — consistent with the "senior slump" phenomenon documented in higher education literature (Seifert et al., 2010). **Pattern B (Early peak):** Self-regulatory and practical competencies peak unusually early (Year 2) before declining — possibly reflecting the high engagement of early adopters in the online survey. **Pattern C (Resilient growth):** Problem-solving exhibits a bimodal trajectory, dipping in Year 4 but reaching a secondary peak in Year 5, suggesting that senior thesis and capstone projects stimulate problem-solving competence recovery.

Inter-Domain Correlation Structure

The inter-domain correlation matrix provides empirical evidence for the proposed structural relationships.

Table 5. Inter-Domain Pearson Correlation Matrix (n=190)

	Motivational	Self-reg.	Digital	Practical	Problem-solv.
Motivational	1.00				
Self-regulatory	0.68***	1.00			
Digital	0.54***	0.61***	1.00		
Practical	0.49***	0.57***	0.52***	1.00	
Problem-solving	0.55***	0.63***	0.58***	0.60***	1.00

*** $p < 0.001$ (all correlations significant). Estimates based on domain mean scores.

The correlation matrix confirms the structural hierarchy of the proposed model. The highest correlation observed is between Motivational-orientational and Self-regulatory domains ($r=0.68$), supporting the antecedent-mediator relationship posited in the theoretical framework. Self-regulatory competence shows consistently high correlations with all three outcome domains ($r=0.57-0.63$), confirming its role as the central mediating construct. Practical and Problem-solving domains are also substantially correlated ($r=0.60$), consistent with their co-development through applied engineering coursework.

4.4 Competence Profile: Strengths and Development Gaps

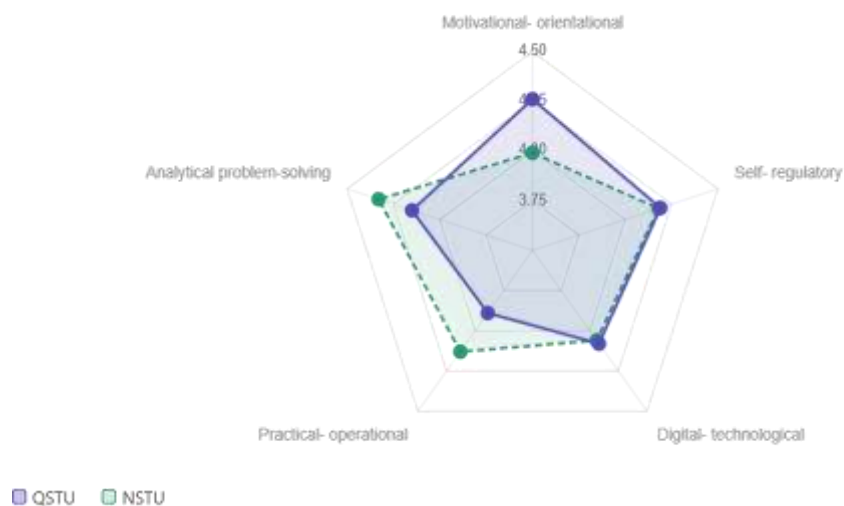


Figure 4. Radar profile comparison of QSTU and NSTU competence domains. The profiles reveal complementary institutional strengths: QSTU's motivational advantage vs. NSTU's applied competence advantage.

DISCUSSION

Structural Validation of the Five-Domain Model

The empirical results provide consistent support for the five-domain structural model proposed in Section 2. The antecedent role of motivational-orientational competence is confirmed by its highest zero-order correlation with self-regulatory competence ($r=0.68$) among all domain pairs. The mediating role of self-regulation is supported by its uniformly high correlations with the three outcome domains and its position as the most consistent predictor across both universities. These findings align with Zimmerman's (2002) assertion that self-regulated learning is the primary mechanism through which motivation is operationalized into skill development. The three outcome domains — digital-technological, practical-operational, and analytical problem-solving — exhibit a cluster of moderately high inter-correlations ($r=0.52$ – 0.60), consistent with their co-development through applied engineering coursework. The practical-operational domain shows the largest inter-university gap, which constitutes the most actionable finding for curriculum reform.

The Year 4 Structural Vulnerability

A particularly significant finding is the consistent decline in competence scores at Year 4 across all five domains (Figure 3). This pattern, replicated across both institutions despite their different demographic compositions, suggests a structural — rather than institution-specific — feature of TME program design. Year 4 in Uzbekistani technical programs typically combines intensive coursework with the onset of thesis preparation, industrial placement requirements, and employment uncertainty. This convergence of demands appears to suppress competence self-perceptions across all domains. This finding has direct curricular implications: Year 4 requires targeted scaffolding — mentoring programs, structured capstone projects, industry liaison activities — to prevent the competence formation trajectory from stalling at this critical juncture.

Complementary Institutional Profiles

The radar profile analysis (Figure 4) reveals that QSTU and NSTU do not compete on the same axis but exhibit complementary strengths. QSTU's advantage in motivational-orientational competence ($d=0.31$) likely reflects its regional labour market context in the Kashkadarya region, where demand for TME specialists in energy infrastructure is high and professionally visible to students. NSTU's advantages in practical-operational ($d=0.30$) and problem-solving ($d=0.23$) competencies may reflect stronger laboratory infrastructure investment and a higher proportion of senior students (75.3% in Years 4–5) who have accumulated more applied experience.

These complementary profiles create an opportunity for inter-institutional curriculum exchange: NSTU's applied pedagogy practices could be studied and adapted at QSTU, while QSTU's motivational programming could be examined by NSTU for replication.

RECOMMENDATIONS

Based on the structural model and empirical findings, six evidence-based recommendations are offered:

Recommendation 1 — Embed practical-operational skills throughout all academic years. The practical-operational domain is the lowest-scoring across both institutions and shows a declining trend from Year 2 onward. Curriculum planners should integrate laboratory sessions, fault-diagnosis exercises, and technical documentation workshops as recurring, credit-bearing components in every academic year rather than concentrating them in Year 3–4 specialty courses.

Recommendation 2 — Engineer an intervention for Year 4 competence maintenance. The Year 4 dip is the most structurally significant finding of this study. A coordinated Year 4 support package — combining structured mentoring by industry professionals, capstone design modules with real engineering problems, and career development workshops — should be institutionalised at both universities.

Recommendation 3 — Formalize digital-technological training with engineering software. Self-reported digital competence is reasonably high, but qualitative item inspection reveals persistent gaps in domain-specific software proficiency (CAD/CAM/CAE, MATLAB, instrumentation software). A modular digital

skills curriculum aligned with TME-specific software should be introduced from Year 1 and progressively scaffolded.

Recommendation 4 — Design AI literacy as a professional competence.

Students demonstrate appropriate critical attitudes toward AI-generated output, but this disposition is implicit and informal. Explicit AI literacy instruction — covering prompt engineering, output verification workflows, and ethical use in engineering contexts — should be integrated into the digital-technological curriculum.

Recommendation 5 — Leverage self-regulation as the keystone competence.

Given self-regulation's confirmed mediating role in the structural model, investment in explicit self-regulation instruction (goal-setting frameworks, reflective learning logs, time-management workshops) will produce cross-domain competence dividends. This is particularly cost-effective because it does not require specialist infrastructure.

Recommendation 6 — Implement periodic MKD-S monitoring. The survey should be administered at the beginning and end of each academic year to track competence trajectories at the student, cohort, and institutional level. Aggregated, anonymised domain scores should be reported to curriculum committees as standing evidence for programme evaluation cycles.

CONCLUSION

This study has proposed, empirically grounded, and analyzed a five-domain structural model of professional competence formation among TME students in Uzbekistan. Administered to 190 students at two major technical universities, the MKD-S instrument has yielded the following principal conclusions. First, the five-domain model — with motivational-orientational competence as the antecedent, self-regulatory competence as the mediator, and digital-technological, practical-operational, and problem-solving competencies as the convergent outcomes — receives empirical support from the inter-domain correlation structure. Second, practical-operational competence constitutes the primary developmental gap across both institutions, representing the highest-priority target for curriculum reform. Third, a structural Year 4 vulnerability is identified — a cross-institutional competence dip that demands targeted curricular intervention. Fourth, institutional profiles are complementary rather than uniformly differentiated, creating conditions

for productive inter-university knowledge exchange. The MKD-S instrument demonstrates promise as a scalable, low-cost competence monitoring tool for TME programs. Future research should pursue longitudinal tracking of individual students, integration of the self-report data with objective performance indicators (exam grades, industrial placement assessments, graduate employment outcomes), and confirmatory factor analysis to formally validate the proposed structural model.

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