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DEVELOPING TECHNOLOGICAL COMPETENCE IN VOCATIONAL TRANSPORT EDUCATION: A COMPETENCY-BASED INSTRUCTIONAL MODEL AND ITS EFFECTIVENESS

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ABSTRACT: Background: Industry 4.0 and the digital transformation of the transport sector demand that vocational learners develop technological competence—an integrated capacity to apply theoretical knowledge, use digital diagnostic tools, and solve technological problems independently. However, instruction in foundational transport courses often remains lecture-based and weakly connected to production environments.

Purpose: This study aimed to develop and empirically validate a competency-based instructional model for enhancing technological competence among vocational learners in the "Transport Vehicle Structure" course.

Methods: A quasi-experimental design with control (n=120) and experimental (n=120) groups was employed across three phases: pre-test, intervention, and post-test. The experimental group received instruction integrating problem-based learning, case studies, project-based learning, STEM elements, virtual laboratories, and digital assessment tools. Technological competence was measured across four dimensions: motivational-value, cognitive, operational-activity, and reflective-evaluative.

Results: The experimental group demonstrated significantly higher gains across all four dimensions ($p<0.05$), with the largest improvement in the operational-activity dimension ($t=4.27$, $p=0.001$). High-level performers increased from 18% to 46%, while low-level performers decreased from 40% to 10%.

Conclusion: Systematically integrating digital and practice-oriented pedagogies can effectively bridge the gap between theoretical instruction and industry requirements in vocational transport education. The study contributes a transferable instructional model for competency-based vocational teaching in technical domains.

Keywords: technological competence, vocational education, competency-based education, transport education, instructional design, digital learning

1. INTRODUCTION

Global labor markets increasingly demand professionals who can apply knowledge, adapt to new technologies, and solve complex problems independently (Delors, 1996; OECD, 2019). This shift has prompted vocational education systems worldwide to move from knowledge-transmission models toward competency-based approaches (Mulder, 2017). Technological competence—defined as the integrated capacity to use knowledge, skills, and attitudes to perform technological tasks effectively—has become a central outcome of vocational preparation (Eraut, 2018).

In the transport sector, the rapid integration of electronic control systems, digital diagnostics, and intelligent transport technologies has raised the bar for graduates (Bosch, 2018; Halderman, 2022). Learners preparing for automotive and transport careers must now not only understand mechanical structures but also work with digital diagnostic equipment, analyze sensor data, and

make informed technological decisions (Erjavec, 2020). However, in many vocational contexts—including Uzbekistan—instruction in foundational courses such as "Transport Vehicle Structure" remains predominantly lecture-based, with limited practical integration and weak alignment with industry requirements (Muslimov, 2016).

This mismatch between instructional practice and labor market demands constitutes a persistent problem. While competency-based education (CBE) has been widely endorsed, operational models for cultivating technological competence in specific technical domains remain underdeveloped (CEDEFOP, 2021). Moreover, there is a lack of empirical evidence on how digital tools, problem-based learning, and production-integrated practical work can be systematically combined to develop technological competence in vocational transport education.

This study addresses this gap by developing and testing a competency-based instructional model for the "Transport Vehicle Structure" course in vocational education institutions. The model integrates four interconnected components of technological competence—motivational-value, cognitive, operational-activity, and reflective-evaluative—and employs a range of instructional strategies including problem-based learning, case studies, project-based learning, STEM elements, virtual laboratories, and digital assessment tools.

Contemporary vocational education faces the dual challenges of digital transformation and industrial upgrading. The transport sector, as a technology-intensive domain, has witnessed the rapid proliferation of electronic control systems, intelligent diagnostic equipment, and digital maintenance tools, raising the bar for practitioners' technological competence. Technological competence is no longer limited to understanding mechanical principles; it now encompasses digital tool proficiency, diagnostic reasoning, systems thinking, and independent decision-making [1], [2].

In Uzbekistan, the vocational education system is undergoing a paradigm shift from knowledge transmission to competency-based education [3]. Technological competence is defined as an integrated quality enabling practitioners to effectively apply professional knowledge, skills, and attitudes to accomplish technological tasks [4]. However, current instructional practice in technical courses remains predominantly lecture-based, with practical components insufficiently aligned with industry needs, leaving students with limited opportunities to develop integrated competencies in authentic or simulated technological contexts [5].

Research question: To what extent does the proposed instructional model enhance learners' technological competence compared to conventional instruction?

Hypothesis: If the "Transport Vehicle Structure" course is organized on the basis of a competency-based model integrating innovative pedagogical technologies, digital resources, and production-integrated practical work, then learners' technological competence will develop significantly more effectively than under conventional instruction.

The significance of this study lies in its potential to inform vocational education practice beyond the transport domain. While grounded in a specific course, the model's emphasis on integrating digital tools, production-contextualized practice, and competency-based assessment offers a transferable framework for other technical and engineering vocational fields facing similar challenges of theory-practice integration.

1.2 Theoretical Framework

This study integrates three theoretical perspectives to construct the instructional model:

Competency-Based Education (CBE) emphasizes observable performance as the learning outcome, focusing on what students "can do" rather than "what they know" [6]. The structure of

technological competence is typically decomposed into four interrelated dimensions: motivational, cognitive, activity-based, and reflective [7].

The TPACK Framework (Technological Pedagogical Content Knowledge) posits that effective technology-integrated teaching requires a deep fusion of technological knowledge, pedagogical knowledge, and content knowledge, rather than the isolated use of technological tools [8].

STEAM and Project-Based Learning promote the development of technological thinking and design competence through interdisciplinary integration and authentic problem-solving, providing methodological support for cultivating technological competence [9], [10].

1.3 Research Questions.

This study addresses the following core question: In the context of integrating vocational education and transport education, can an improved instructional model—grounded in competency-based education principles and integrating digital tools with project-based learning—effectively promote the development of students' technological competence?

The specific hypothesis is: Students in the experimental group who receive the improved instructional model intervention will significantly outperform students in the control group who receive conventional instruction across all four dimensions of technological competence: motivational, cognitive, activity-based, and reflective.

2. METHODS

2.1 Research Design

A quasi-experimental design with pretest and posttest measures was employed. Two intact groups of second-year vocational learners in transport specialization were selected: an experimental group (n=120) and a control group (n=120). Groups were matched on prior academic achievement, instructional hours, curriculum content, and teacher qualifications. The study was conducted across three phases: (1) ascertaining (pre-test), (2) formative (intervention), and (3) control (post-test).

Technological competence is a multidimensional construct [11]. Researchers have defined its structure across different educational contexts: in vocational teacher education, technological competence has been operationalized into four dimensions—motivational, cognitive, activity-based, and reflective [12]; in primary technology education, emphasis is placed on "technological thinking"—an integrated quality encompassing problem identification, solution design, resource selection, safe operation, and outcome evaluation [13].

This multidimensional structure imposes systematic requirements for instruction: the motivational dimension requires authentic contexts and occupational relevance for activation; the cognitive dimension requires structured knowledge organization; the activity-based dimension requires ample practical opportunities; and the reflective dimension requires explicit cultivation of metacognitive strategies [14].

2.2 Participants

Participants were enrolled in vocational education institutions specializing in transport and automotive training in Uzbekistan. All were pursuing the same qualification and following identical curricula prior to the intervention. Informed consent was obtained, and ethical guidelines for educational research were followed. Inclusion criteria were: same training direction, same curriculum, same material-technical conditions, and teachers with equivalent qualifications.

Digital tools offer new possibilities for cultivating technological competence. Virtual laboratories and simulators make abstract principles visible; 3D modeling and AR/VR technologies provide immersive experiences for understanding complex systems [15]. However, the

effectiveness of digital tools depends on the quality of instructional integration—technology must be embedded in meaningful learning tasks rather than serving as an add-on "display tool" [16].

2.3 The Instructional Model

The proposed model comprises five interconnected blocks:

1. **Goal-setting block** – specifies technological competence outcomes.
2. **Content block** – covers vehicle construction, internal combustion engines, transmission, chassis, steering, braking systems, electrical and electronic control systems, diagnostics, and maintenance fundamentals.
3. **Technological block** – integrates problem-based learning, case studies, project-based learning, STEM elements, virtual laboratories, 3D models, digital simulators, and production-integrated practical tasks.
4. **Diagnostic-assessment block** – defines criteria, indicators, and levels (high, medium, low) for each competence component.
5. **Outcome block** – describes expected professional qualities.

Instruction proceeded through four phases:

- **Phase 1 – Motivational-preparatory:** stimulating professional interest through real-world scenarios, multimedia, and discussions of modern transport innovations.
- **Phase 2 – Cognitive:** interactive lectures, concept mapping, cluster techniques, 3D visualization, and virtual laboratory demonstrations.
- **Phase 3 – Practical-activity:** problem-based tasks, case analysis, project work, STEM-integrated assignments, laboratory work, and production-integrated practical tasks.
- **Phase 4 – Reflective-evaluative:** self-assessment, portfolio development, feedback, and reflection.

Project-based learning provides a structured pathway for the integrated development of technological competence through a complete "problem—inquiry—design—implementation—evaluation" cycle [17]. Research indicates that a complete project-based technological cycle—from problem identification to product presentation and reflection—promotes deeper development of technological thinking more effectively than fragmented skill training [18].

2.4 Instruments and Measures

Technological competence was assessed using a multi-method approach:

Component	Criteria	Indicators	Diagnostic Tools
Motivational-value	Professional interest	Motivation, independence, attitude to innovation	Questionnaire, interview, observation
Cognitive	Theoretical knowledge	Knowledge of construction, analysis, technical documentation	Tests, written work, oral questioning
Operational-activity	Practical skills	Diagnostics, repair, digital tools, technological decision-making	Practical tasks, laboratory work, expert evaluation

Component	Criteria	Indicators	Diagnostic Tools
Reflective-evaluative	Self-assessment	Analysis, error identification, planning	Portfolio, reflection sheets, observation

Each dimension was scored on a scale yielding three levels: high (86–100), medium (71–85), and low (0–70). Reliability was established through expert review and pilot testing.

2.5 Data Analysis

Quantitative data were analyzed using descriptive statistics (means, percentages), independent samples t-tests (Student's t), and chi-square tests (Pearson's χ^2) where appropriate. Significance was set at $p<0.05$. Statistical analysis was performed to determine whether differences between experimental and control groups were statistically significant.

3. RESULTS

3.1 Pre-Intervention Equivalence

No statistically significant differences were found between groups at pretest across any of the four dimensions, confirming baseline equivalence. Both groups had similar mean scores and similar distributions across competence levels.

A quasi-experimental nonequivalent control group pretest-posttest design was employed. The study spanned one academic year and was conducted in three phases: (1) pretest and baseline assessment; (2) intervention implementation; (3) posttest and effect evaluation. A quasi-experimental design was chosen because the research was conducted in authentic educational institutions where random assignment would disrupt existing class structures.

3.2 Post-Intervention Differences

Table 1 presents the distribution of competence levels before and after the intervention.

Table 1.

Distribution of Technological Competence Levels (%)

Group	High	Medium	Low
Experimental (pre)	18	42	40
Experimental (post)	46	44	10
Control (pre)	17	43	40
Control (post)	25	48	27

The experimental group showed a substantial increase in high-level performers (from 18% to 46%) and a sharp decrease in low-level performers (from 40% to 10%). The control group demonstrated more modest changes (high: 17% to 25%; low: 40% to 27%).

A total of 336 third- and fourth-year students from three higher education institutions participated in the study:

Table 2.

Educational Institution	Experimental Group	Control Group	Total
Termez State Pedagogical Institute	58	62	120
Shahrisabz State Pedagogical Institute	53	55	108
Kokand State Pedagogical Institute	53	55	108
Total	**164**	**172**	**336**

The two groups were equivalent at baseline in terms of specialization, curriculum content, instructional hours, physical facilities, and teacher qualifications.

3.3 Component-Level Analysis

Independent samples t-tests revealed statistically significant differences favoring the experimental group across all four components:

Table 3.
Student's t-test Results by Component

Component	t	p	Conclusion
Motivational-value	2.41	0.018	Significant
Cognitive	3.12	0.003	Significant
Operational-activity	4.27	0.001	Significant
Reflective-evaluative	2.86	0.006	Significant

The operational-activity component showed the largest effect, suggesting that the combination of hands-on laboratory work, production-integrated practical tasks, and digital diagnostic tools was particularly effective in developing procedural competence.

The improved instructional model comprises four interrelated blocks (see Figure 1):

Goal Block: To cultivate future educators who possess technological competence—the ability to understand technological principles, use digital diagnostic tools, and independently solve technological problems.

Content Block: Encompassing modules on technological principles, digital diagnostics, electronic control systems, and project design and modeling.

Process Block: Integrating the following instructional strategies:

- Problem-based learning (problem scenario creation and diagnostic reasoning)
- Project-based learning (complete design—implementation—evaluation cycle)
- Case-based instruction (analysis of authentic technological situations)
- STEAM-integrated tasks (interdisciplinary problem-solving)
- Digital tools (virtual laboratories, 3D modeling, AR/VR)

Assessment Block: Employing a multidimensional assessment system covering motivation (questionnaires/interviews), cognition (tests/written assignments), activity (practical tasks/laboratory work), and reflection (portfolios/self-assessment).

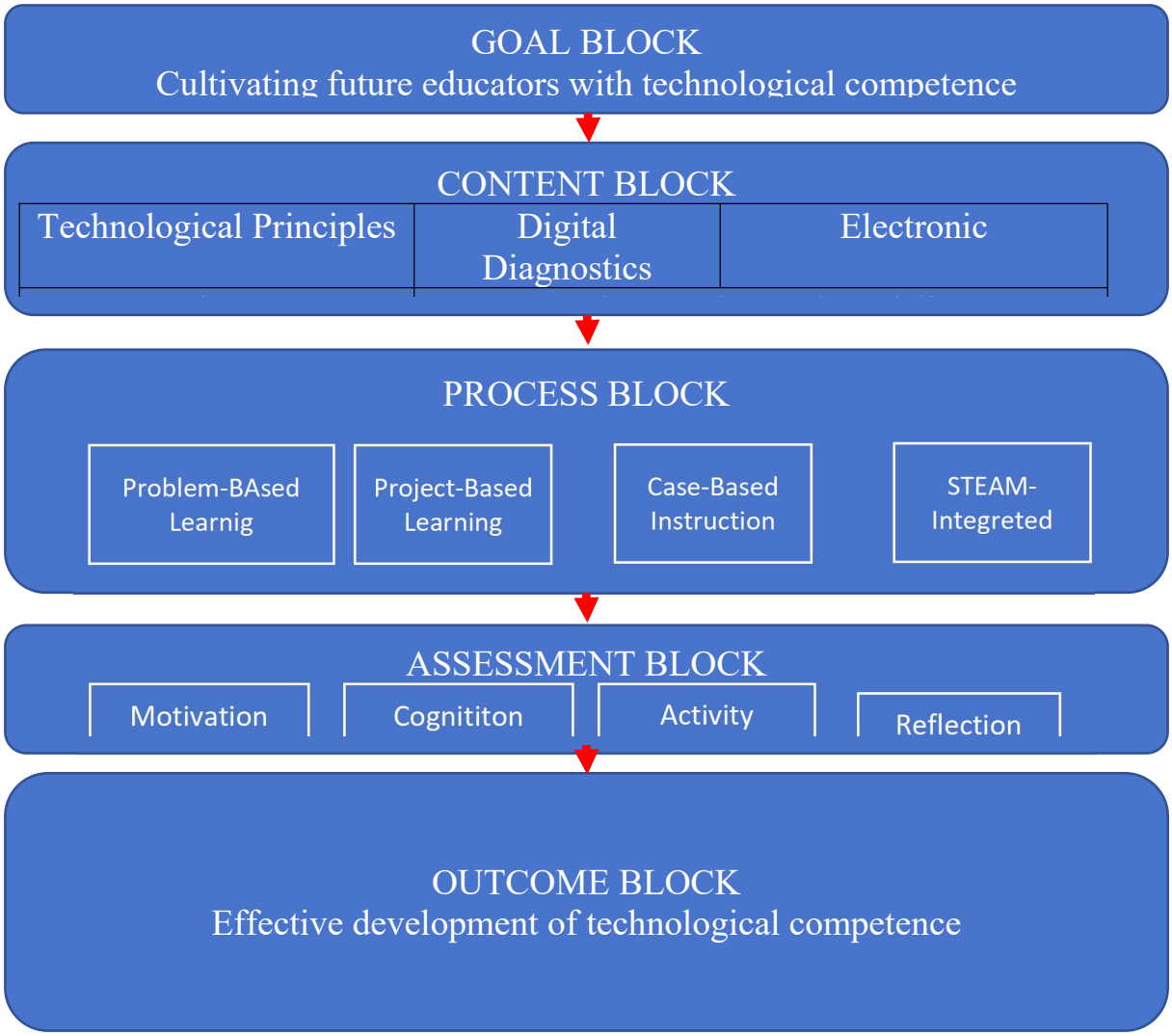


Figure 1. Instructional Model for Developing Technological Competence

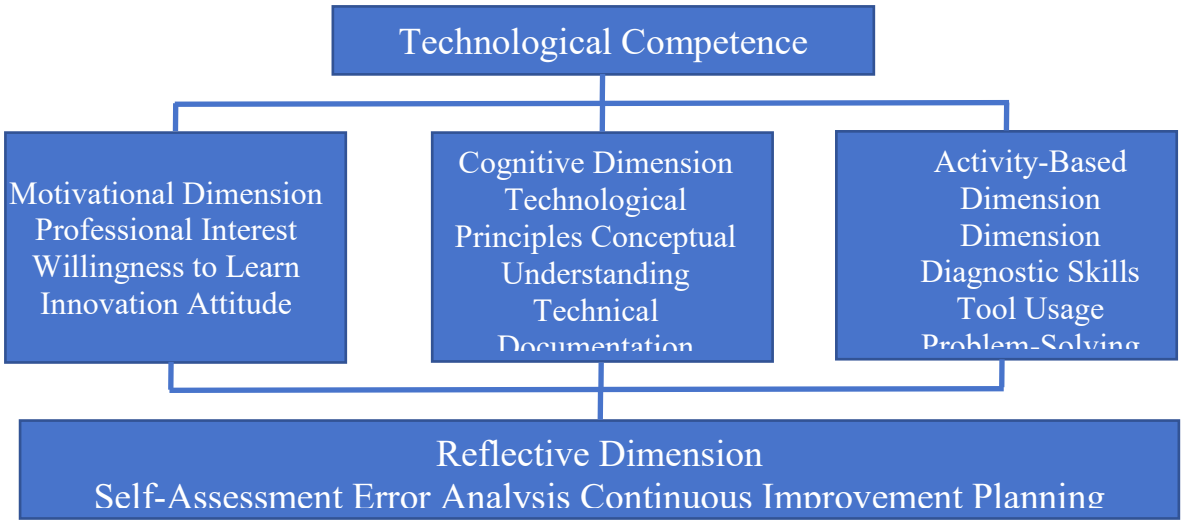


Figure 2. Four-Dimensional Structure of Technological Competence

3.4 Qualitative Observations

Observational data indicated increased learner engagement, more frequent independent problem-solving attempts, improved use of technical documentation, and greater confidence in using digital diagnostic equipment in the experimental group. Teachers also reported increased use of innovative pedagogical technologies.

4. DISCUSSION

The findings provide empirical support for the proposed competency-based instructional model. The significant gains across all four dimensions of technological competence suggest that systematically integrating digital, practice-oriented, and learner-centered pedagogies can effectively bridge the theory-practice divide in vocational transport education.

The particularly strong improvement in the operational-activity dimension aligns with prior research emphasizing the importance of authentic, production-contextualized practice for developing procedural competence (Kolb, 2015; Eraut, 2018). Virtual laboratories and 3D models appear to have served as effective bridges between conceptual understanding and physical manipulation, allowing learners to visualize and analyze complex systems before engaging with actual equipment (Fullan, 2020).

The improvement in the reflective-evaluative dimension is noteworthy, as self-assessment and portfolio use are often underemphasized in technical vocational education. The structured reflective activities may have fostered a habit of critical self-monitoring that supports lifelong learning (Schön, 2017).

From a theoretical perspective, the study contributes to competency-based education literature by operationalizing technological competence in a specific technical domain and demonstrating that its components are developmentally interrelated yet differentially responsive to instructional intervention. The four-component framework (motivational-value, cognitive, operational-activity, reflective-evaluative) offers a practical structure for designing and assessing competency-based instruction in other engineering and technical fields.

4.1 Limitations and Generalizability

Several limitations should be noted. First, the study was conducted in a single national context (Uzbekistan) and within one vocational course. While the instructional principles are grounded in international literature, direct generalizability to other contexts requires further validation. Second, the duration of the intervention was one academic semester; longer-term retention of competence gains was not assessed. Third, the study relied on performance assessments and self-report measures; future research could incorporate objective outcome measures such as employer evaluations or standardized skill certifications.

4.2 Implications for Practice

For vocational educators and curriculum designers, the study suggests that:

- Technological competence should be explicitly articulated as a multi-dimensional outcome, with each dimension addressed through targeted instructional strategies.
- Digital tools (virtual laboratories, 3D models, simulators) are most effective when integrated into a coherent instructional sequence rather than used as standalone supplements.
- Production-integrated practical work, even in limited forms, significantly enhances operational competence and should be prioritized.
- Assessment should mirror the multi-dimensional nature of competence, incorporating performance tasks, portfolios, and self-assessment alongside traditional tests.

5. CONCLUSION

This study developed and empirically validated a competency-based instructional model for cultivating technological competence in vocational transport education. The model, grounded in four interrelated competence components and implemented through integrated digital, practice-oriented pedagogies, produced significant gains across all dimensions, with the strongest effects on operational-activity competence.

The findings contribute a transferable framework for competency-based instruction in technical vocational domains and offer evidence that systematic pedagogical redesign can meaningfully enhance learners' preparedness for technology-rich occupational environments. Future research should examine the model's applicability across diverse technical fields and cultural contexts, and investigate the long-term durability of competence gains.

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