APLICAREA ECOSISTEMULUI DE ÎNVĂȚARE DIGITALĂ PENTRU ÎMPREUNĂRI CU MINTE ÎN FORMAREA PROFESIONIȘTILOR DIN TRANSPORTUL AUTO

APPLICATION OF THE SMSE DIGITAL LEARNING ECOSYSTEM IN THE TRAINING OF AUTOMOTIVE TRANSPORT PROFESSIONALS

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Rezumat: *Articolul explorează abordări pentru transformarea procesului educațional în învățământul tehnic superior în contextul digitalizării și al cerințelor Industriei 4.0. Fezabilitatea implementării unui Ecosistem Inteligent al Mediului Digital de Învățare (SMSE) este confirmată. Acest ecosistem integrează instrumente digitale moderne, tehnologii adaptive și metode pedagogice inovatoare pentru a sprijini învățarea centrată pe student și bazată pe competențe. Abordarea propusă a fost testată utilizând cursuri din specialitatea „Transport Auto", ținând cont de nivelurile de activitate cognitivă bazate pe Taxonomia lui Bloom. Rezultatele arată că implementarea SMSE promovează dezvoltarea gândirii critice, a abilităților practice și a motivației studenților, asigurând în același timp flexibilitatea și personalizarea procesului educațional. Sunt conturate provocările cheie legate de transformarea digitală în educație, împreună cu direcții pentru cercetări ulterioare legate de integrarea software-ului specializat, platformele adaptive și depășirea inegalității digitale.*

Cuvinte-cheie: *mediu digital de învățare, educație tehnică, SMSE, Industrie 4.0, Taxonomia lui Bloom, învățare centrată pe student, transformare digitală*

Abstract: *The article explores approaches to transforming the educational process in higher technical education within the context of digitalization and the demands of Industry 4.0. The feasibility of implementing a Smart Ecosystem of the Digital Learning Environment (SMSE) is substantiated. This ecosystem integrates modern digital tools, adaptive technologies, and innovative pedagogical methods to support student-centered and competency-based learning. The proposed approach was tested using courses in the "Automotive Transport" specialty, taking into account the levels of cognitive activity based on Bloom's Taxonomy. The findings show that the implementation of the SMSE promotes the development of critical thinking, practical skills, and student motivation, while also ensuring flexibility and personalization of the educational process. Key challenges related to digital transformation in education are outlined, along with directions for further research related to the integration of specialized software, adaptive platforms, and overcoming digital inequality.*

Keywords: *digital learning environment, technical education, SMSE, Industry 4.0, Bloom's Taxonomy, student-centered learning, digital transformation*

Introduction

In today's context of rapid technological advancement, digitalization of society, and transformation of the labor market, the higher education system faces new challenges that require a rethinking of the content, forms, and methods of teaching. The traditional paradigm of education, which primarily focuses on the transmission of theoretical knowledge, is increasingly giving way to a competency-based approach. This approach emphasizes the development of learners' abilities to think critically, independently acquire and analyze information, solve complex problems, and adapt to dynamic changes.

One of the key conditions for enhancing the effectiveness of the educational process is the implementation of student-centered learning. This model involves active student participation in shaping their own educational trajectory, fostering their autonomy, responsibility, and motivation for continuous professional development. In this context, the role of the teacher is also changing — they are increasingly acting as a mentor, consultant, and facilitator of the educational process.

At the same time, global trends such as the internationalization of education, the standardization of quality requirements for educational services, and the emphasis on practical training of specialists reinforce the need to modernize teaching approaches in higher education. This process is further driven by the necessity to develop not only professional competencies but also interdisciplinary and soft skills, which are crucial for graduates' success in today's labor market.

Therefore, the search for effective pedagogical strategies and innovative educational technologies becomes a priority in improving higher education, which underscores the relevance of this study.

Degree of Problem Study

The issue of modernizing teaching approaches in higher education institutions has been actively explored by both domestic and international scholars in the context of implementing a competency-based approach, ensuring education quality, and introducing student-centered learning. Numerous academic works analyze the pedagogical conditions for effectively developing professional and general cultural competencies, as well as explore innovative educational technologies such as Project-Based Learning [1], Blended Learning [2], Case Method [3], Problem-Based Learning [4], Flipped Classroom [5], and others.

Researchers also focus on the transformation of the teacher's role in the digital era, which entails a shift from knowledge transmission to facilitating the learning process, the use of information and communication technologies in teaching [6], the development of critical thinking [7], and fostering student autonomy in learning [8].

The study presented in [9] provides research findings aimed at identifying the advantages and disadvantages of e-learning in university education in the United Arab Emirates. The authors highlight improved interaction between students and instructors through distance learning systems as a key benefit.

The results of the analysis of current approaches to modernizing teaching in higher education institutions, as well as relevant issues and directions for further research in this field, are presented in [10].

Article [11] investigates key aspects of implementing digital learning in higher education institutions. The author examines how digital technologies are transforming traditional educational models, explores the characteristics of digital institutions, and identifies the challenges and opportunities for ensuring educational quality in new conditions. Special attention is given to the role of institutional strategy in supporting digital initiatives and developing competencies in both students and instructors.

Digital transformation in the field of education has become one of the key drivers of change in the 21st century, encompassing not only the implementation of new technologies but also a profound restructuring of pedagogical approaches, organizational culture, and strategic management models.

In [12], the authors emphasize that successful digital transformation in higher education institutions requires a clear strategy that includes the development of digital competencies, institutional support for innovation, and the adaptation of organizational structures. They highlight the importance of an integrated approach that combines technological, pedagogical, and cultural changes.

In their work [13], the author examines the theoretical foundations of educational innovation, focusing on how education systems must adapt to the changing world. A comprehensive model of innovation in education is proposed, which is based on the interaction of pedagogical technologies, the evolving role of the teacher, updated learning content, and the use of digital tools.

The study [14] on blended learning points to the significant potential of hybrid educational models that combine traditional and online learning to provide a deeper and more interactive learning experience.

At the same time, the use of electronic platforms in teaching technical disciplines presents specific challenges.

According to Ożadowicz [15], even the best e-learning platforms cannot always replace essential laboratory work, practical experiments, and the use of specialized equipment, all of which are critical for the training of engineers, mechanics, and technologists.

Ali notes that many platforms have limited integration with engineering programs (such as CAD, CAM, MATLAB), which complicates the full implementation of technical curricula [16].

In his work, Dhawan [17] highlights the difficulties of adapting content: courses in technical fields often require interactive simulations, modeling, and visualizations, which not all educational platforms can effectively support.

Additionally, [18] points to the issue of digital inequality: some students do not have access to sufficiently powerful devices, which makes it impossible to use demanding technical software through standard learning platforms.

Therefore, based on the analysis of previous research, the main challenges are: insufficient integration of e-learning platforms with professional engineering tools, limitations in reproducing practical skills, and unequal access to resources among students.

Research Methodology

One of the approaches to addressing the problem described above is the use of integrated learning platforms that combine pedagogical, technological, and social components, thereby creating conditions for effective learning through digital technologies—so-called **Digital Learning Ecosystems** [2], [19].

In [20], the authors highlight the importance of practice-oriented education in the context of modeling and simulation for **cyber-physical systems (CPS),** which is one of the key aspects of Industry 4.0. As part of the European project *"Development of Practice-Oriented Student-Centered Education in the Field of Cyber-Physical Systems Modeling" (CybPhys)* [21], the authors propose an educational approach that integrates theoretical knowledge with practical skills in digital modeling and the use of mathematical models for optimizing industrial systems. The article also explores the integration of educational platforms that enable students to train and apply their acquired skills in real industrial environments. The authors underscore the importance of adapting modern educational approaches to the context of Industry 4.0, particularly highlighting the development of CPS-related skills as a foundation for the effective use of digital technologies in industry. They also propose specific teaching methodologies that promote the integration of theoretical knowledge with practical activities in the modeling and simulation of complex systems.

Continuing the development of digital learning systems, in [22], the authors present a concept for a **digital learning ecosystem** designed specifically for online education in engineering fields. They highlight the importance of integrating modern digital technologies such as online courses, virtual laboratories, and simulations into the educational process to enhance the effectiveness and accessibility of engineering education. Special attention is given to the creation of interactive platforms that allow students to develop practical skills and apply theoretical knowledge in real-world conditions. The authors also highlight the necessity for flexibility and adaptability in digital learning systems to meet the needs of students and instructors across different contexts. The development of such interactive platforms and virtual laboratories for higher education learners is being carried out within the framework of the project *"Digital transformation of HEIs education process in Ukraine and Moldova for sustainable engagement with enterprises"* [23].

Modern approaches to student education in higher education institutions often rely on **Bloom's Taxonomy** [24], [25], [26], [27].

As is well known, Bloom's Taxonomy is a classification of educational objectives that divides cognitive processes into six levels that reflect increasing levels of complexity (Fig. 1).

In higher education, the effective application of these levels contributes not only to the acquisition of foundational knowledge but also to the development of students' analytical, critical, and creative thinking skills (Fig. 2).

1. Knowledge (Remembering)

Refers to the student's ability to recall previously learned information. In higher education, this level is important for mastering terminology, concepts, facts, formulas, historical events, etc.

Example activities: define, name, list, recall.

2. Understanding (Interpreting)

The student is able to explain ideas or concepts in their own words. This level forms the basis for further analysis and application of knowledge.

Example activities: explain, summarize, interpret, describe.

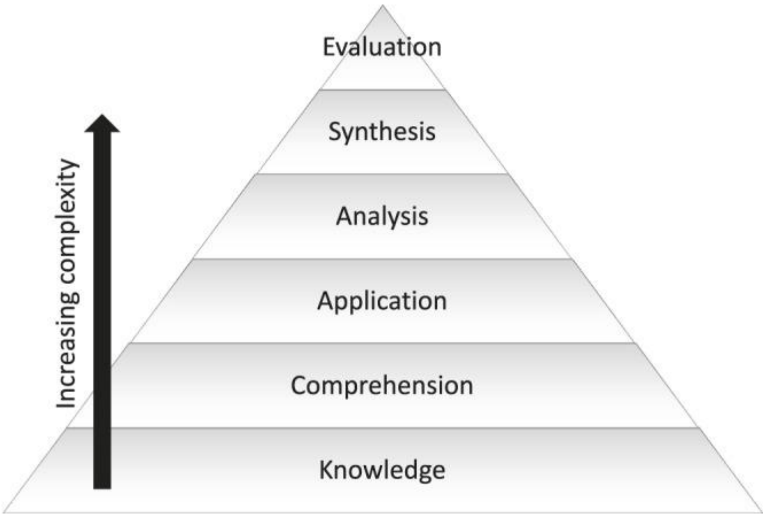

Figure 1. Bloom's Taxonomy, according to [28]

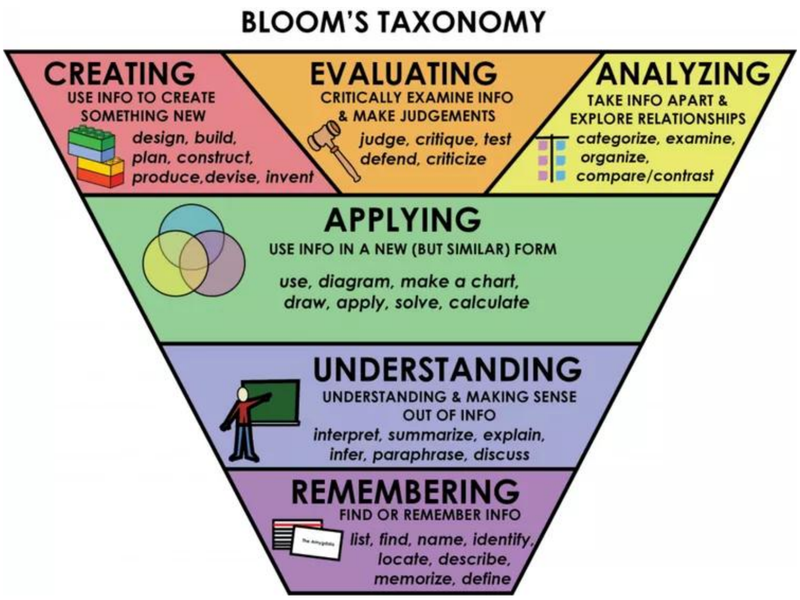

Figure 2. Using Bloom's Taxonomy for Effective Learning, according to [29]

3. Applying

Involves the use of knowledge in new situations. In higher education, this is reflected through problem-solving, conducting practical tasks, and developing projects.

Example activities: apply, demonstrate, solve, implement.

4. Analyzing

Involves the ability to break information into parts, identify relationships, patterns, and structures. This contributes to the development of critical thinking.

Example activities: analyze, differentiate, compare, classify.

5. Evaluating

Students should be able to form well-reasoned judgments and critically assess ideas, solutions, and actions. This level is particularly important in academic and research activities.

Example activities: evaluate, justify, critically reflect, assess relevance.

6. Creating (Synthesizing)

The highest level, requiring the generation of new ideas and approaches, and the creation of original intellectual products. In higher education, this may include writing academic papers, designing systems, and creating models.

Example activities: create, develop, design, formulate a hypothesis.

Based on the cognitive levels outlined in Bloom's Taxonomy, it can be assumed that a graduate of a bachelor's degree program in higher education should master at least the fourth level (analysis), a master's degree graduate—the fifth level (evaluation), and a PhD graduate—the sixth level (creation). This ensures that graduates are not merely executors but active participants in transformations within their field, capable of independent analysis, creativity, and decision-making.

To achieve such goals, a systematic approach should be applied when analyzing the educational process in higher education institutions that train specialists according to the relevant educational programs. The primary focus should be on the implementation of innovative teaching methods that contribute to the formation of modern professional competencies and practice-oriented knowledge.

To accomplish the objective of research, a set of complementary methods must be used (Table 1).

Table 1: Methods for Analyzing the Educational Process (based on the educational programs in the specialty "Automotive Transport")

Proposed Method	Description of the Method
Theoretical Methods	Analysis of scientific and methodological sources in higher education pedagogy, engineering education, methods of teaching technical disciplines; modeling the content of educational courses considering the current labor market demands in the automotive transport sector.
Empirical Methods	Surveys of lecturers and students majoring in "Automotive Transport" regarding the effectiveness of innovative teaching methods (case method, project-based learning, simulation activities, inquiry-based learning); observations of class organization using digital platforms, video analysis of technical processes, interactive modeling.
Pedagogical Experiment	Implementation of new forms of content delivery in courses such as "Vehicle Design", "Theory of Automobiles", "Technical Operation of Vehicles", "Traffic Safety and Transport Management". The results of the experimental group are compared with those of students taught by traditional methods.
Quantitative and Qualitative Analysis Methods	Processing the results of surveys and experiments using statistical methods to determine the level of professional knowledge and practical skills formed, as well as students' motivation for learning.

Thus, within the framework of the considered methods for analyzing the educational process, a decision was made to conduct a pedagogical experiment using a digital learning ecosystem focused on online education for engineering specialties [22].

Findings

As part of the project *Digital transformation of HEIs education process in Ukraine and Moldova for sustainable engagement with enterprises* [23], Lutsk National Technical University is developing a pilot course in the discipline "Theory of Automobiles", within the Bachelor's degree program "Automotive Transport", using a simulation and modeling environment (SMSE). The SMSE platform effectively integrates with various software tools, enabling diverse approaches to course delivery.

As an example of SMSE functionality, one of the laboratory assignments is presented below.

The task for students is to study the rolling resistance force of a vehicle and analyze the influence of various factors on it.

The rolling resistance force is calculated using the following formula [30]:

$$P_f = m_a \cdot 9.82 \cdot f \cdot \cos\alpha \quad (1)$$

where f - rolling resistance coefficient;

$$f = 0.005 + (1/p)(0.01 + 0.0095(V/100)^2) \quad (2)$$

where p – tire pressure, bar;
V – vehicle speed, m/s;
α – road grade angle (incline);
m_a – vehicle mass, kg.

Using the Python programming environment, a script was developed to build a graphical representation of the change in the drag force as a function of the vehicle's speed, taking into account dependencies (1) and (2) shown in Figures 3 and 4.

```
import numpy as np
import matplotlib.pyplot as plt

# Given constants
m_a = 18000          # vehicle mass in kg
g = 9.82             # gravitational acceleration in m/s^2
alpha = 0            # road incline in degrees
p = 2.8              # tire pressure in bars

# Array of speeds for plotting
V = np.linspace(1, 30, 100)  # speed in m/s

# Calculate rolling resistance coefficient f for each speed
f = 0.005 + (1 / p) * (0.01 + 0.0095 * (V / 100) ** 2)

# Calculate rolling resistance force
P_f = m_a * g * f * np.cos(np.radians(alpha))

# Plotting the graph
plt.figure(figsize=(8, 5))
plt.plot(V, P_f, label='Rolling Resistance Force P_f')
plt.title('Rolling Resistance Force vs Speed')
plt.xlabel('Speed V (m/s)')
plt.ylabel('Rolling Resistance Force P_f (N)')
plt.grid(True)
plt.legend()
plt.show()
```

Figure 3. Fragment of the program code

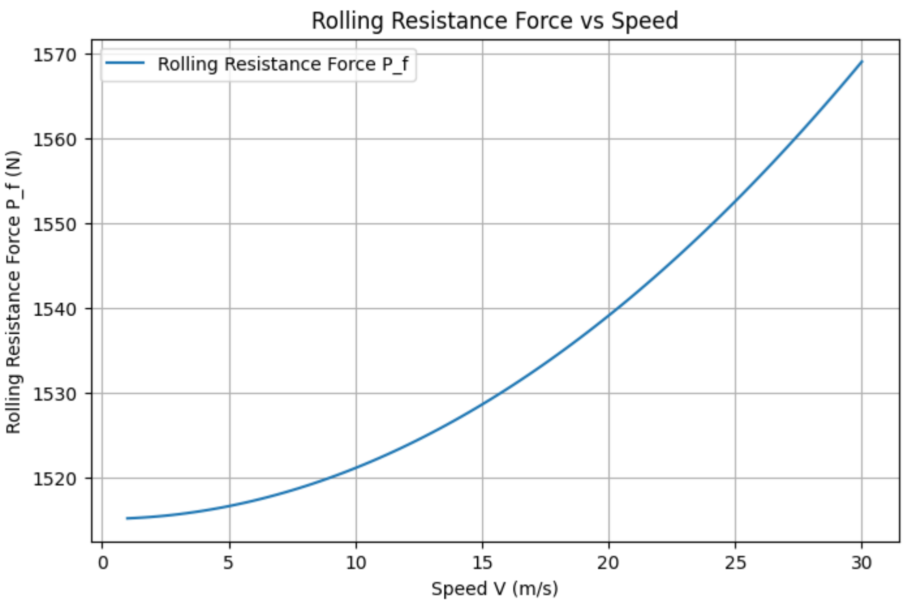

Figure 4. Graphical dependence of the drag force on the vehicle's speed

The code defines constant values for parameters such as ρ = const, α = const, m_a = const; however, these input parameters are modified by the student depending on the given task. Thus, the resulting graphs not only visually demonstrate the influence of various factors on the drag force, but also allow for their analysis and the identification of optimal values under specific driving conditions (Figure 5).

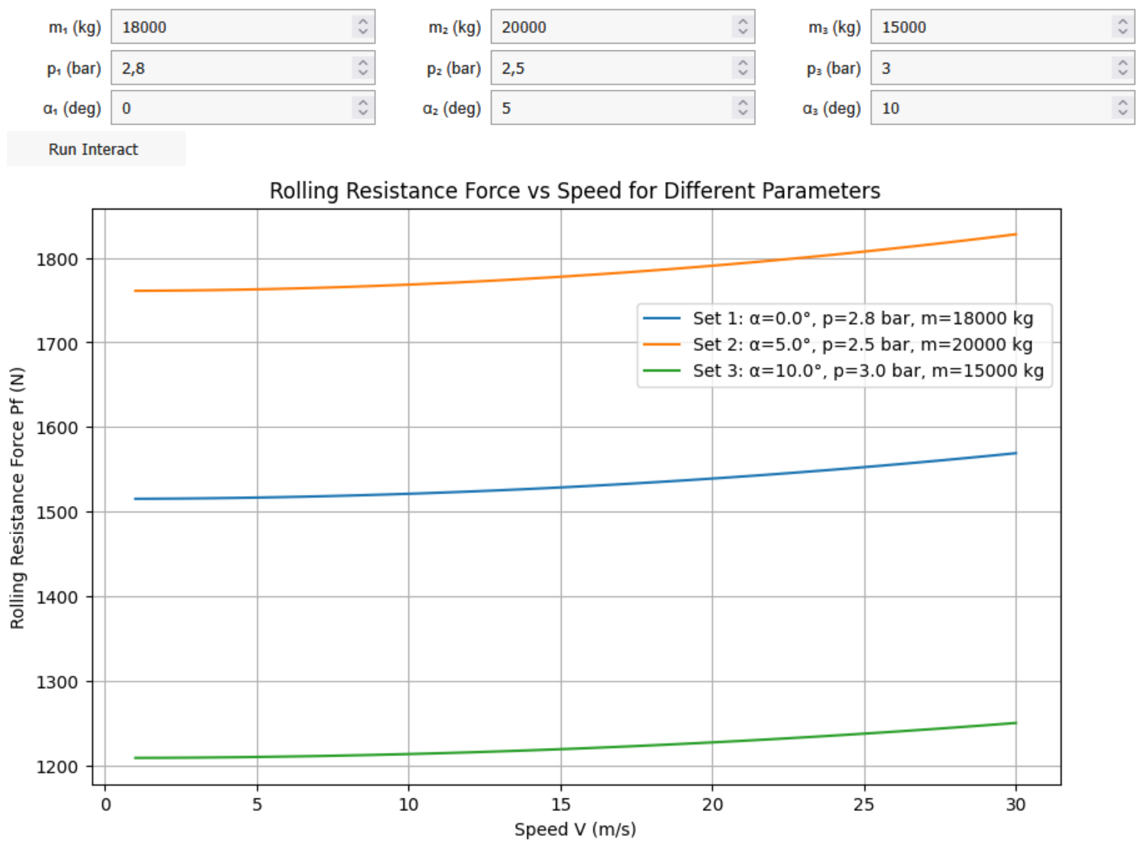

Figure 5. Example of an assignment for studying the influence of factors on the drag force acting on a vehicle

The proposed approach enables students to cover all necessary cognitive levels during the learning process: **memorization → interpretation → application → analysis → evaluation → synthesis**. The final and highest level — **synthesis** — involves the creation of new approaches and products.

Discussions

In the course of the research, an analysis was conducted and proposals were developed regarding the use of the proposed approach in teaching specific subjects within the specialty **"Automotive Transport"**, aiming to ensure that students master the required cognitive levels. The results are presented in **Table 2**.

The analysis of current approaches to the transformation of the educational process in higher education reveals a consistent trend toward rethinking the traditional teaching model in favor of student-centered, competency-based, and practice-oriented learning. The integration of digital technologies and the creation of digital learning ecosystems open up new opportunities for personalizing educational trajectories, developing soft skills, and ensuring a closer connection between theoretical knowledge and practical abilities. However, this process also presents several challenges, including technical limitations, digital inequality, insufficient integration of specialized software into general learning platforms, and the need for a fundamental shift in pedagogical approaches.

The results obtained in the course of the study confirm that effective modernization of education in technical fields requires not only an upgrade of instrumental tools but also a profound transformation of the educational paradigm. The concepts of digital learning environments described in recent literature and tested within international projects (such as *CybPhys* and *DIGITRANS*) demonstrate the potential to overcome structural limitations of the classical teaching system – particularly in the context of preparing students for the demands of Industry 4.0.

Special attention should be paid to approaches such as blended and problem-based learning, the flipped classroom model, interactive simulations, and virtual laboratories. These methods provide greater flexibility, increase student motivation, and support the development of autonomy, critical thinking, and the ability to integrate knowledge across disciplines. At the same time, their implementation requires educators to acquire new competencies, engage in continuous professional development, and rethink their roles in the learning process—from being knowledge providers to facilitators and mentors.

Table 2: Development of assignments in teaching disciplines within the "Automotive Transport" specialty using the SMSE environment.

Educational Component	Essence of Tasks
Technical Operation of Vehicles	Efficiency of technological processes of maintenance and repair, influence of factors on technological processes, determination of rational maintenance frequency, number of employees, analysis of labor intensity
Organization and Management at Enterprises of Motor Transport	Formation of the production and technical base of the enterprise, evaluation of process efficiency, managerial decisions, risk management, risk assessment, enterprise performance evaluation
Quality Management Systems at Enterprises of Motor Transport	Analysis of quality indicators of products (services), influence of various factors on product (service) quality indicators, planning of quality indicators, processing results of consumer surveys regarding products (services)
Theory of Vehicle Reliability	Analysis of reliability indicators of the vehicle fleet, influence of various factors on vehicle reliability indicators
Vehicle Diagnostics Technologies	Efficiency of diagnostic processes, selection of diagnostic equipment, determination of rational diagnostic frequency, vehicle condition forecasting, selection of diagnostic parameters
Theory of Transport Processes and Systems	Analysis of productivity and cost indicators of vehicle transportation, influence of factors that determine them
Supply Chain Management	Calculation of optimal location of a central warehouse within a specific area taking into account the location of freight carriers and cargo recipients
Auto Parts and Logistics	Efficiency of spare parts inventory management at auto service enterprises
Engineering Activity in Motor Transport	Analysis of the performed technological process of part machining and its results, assessment of errors and generalization of information
Computer Technologies in Motor Transport	Analysis of the reliability of electronic control units using modern information and computer technologies
Engineering and Computer Graphics	Formation of skills to create a rational sequence of solving problems of geometric modeling, analysis and synthesis of spatial forms

This study also emphasizes the importance of using Bloom’s Taxonomy as a methodological tool for structuring educational content based on cognitive complexity levels. This approach enables systematic course design, gradual task progression, and the development of students’ critical thinking.

Nevertheless, despite the evident advantages of digital ecosystems, further research should focus on developing mechanisms for deeper integration of specialized technical tools (such as CAD, MATLAB, SCADA, etc.) into the learning environment, as well as on creating adaptive platforms that can accommodate individual needs, students' proficiency levels, and technical capabilities. Equally important are issues of ensuring digital equity, addressing ethical aspects of remote interaction, and safeguarding personal data.

Conclusions

This study substantiates the necessity of transforming the educational process in higher technical education in response to the demands of Industry 4.0. Such transformation involves a shift toward a student-centered, practice-oriented, and competency-based learning model with active use of digital technologies.

A conceptual approach to implementing a Smart Ecosystem of Digital Learning (SMSE) is proposed. This approach integrates digital interaction tools, virtual simulations, adaptive learning, and gamification elements to develop the necessary cognitive, practical, and social competencies in students.

The study confirms that the use of Bloom’s Taxonomy as a methodological tool allows for the systematic structuring of educational content by levels of cognitive complexity and supports the gradual development of skills—from recalling basic knowledge to solving complex interdisciplinary tasks.

The proposed approach was tested in the teaching of courses in the "Automotive Transport" specialty and proved effective for designing learning tasks corresponding to various levels of students' cognitive activity. It also contributed to enhancing student motivation, critical thinking, and the ability to make independent decisions.

The results confirm that implementing digital ecosystems in the educational process requires not only technological modernization but also a significant revision of pedagogical approaches, an increase in teachers' digital competence, the development of flexible adaptive platforms, and efforts to overcome digital inequality among participants in the educational process.

Future research should focus on the creation of integrated learning environments that take into account individual learning trajectories, users' technical capabilities, and the effective integration of specialized software tools (e.g., CAD, MATLAB, SCADA) into the digital infrastructure of higher technical education.

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