УДК 378.147:62, 378.141:004.9, 331.522.4
UDC 378.147:62, 378.141:004.9, 331.522.4

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TRANSFORMATION OF ENGINEERING EDUCATION IN THE CONTEXT OF INDUSTRY 4.0: MULTI-ACTOR PERSPECTIVES AND CURRICULUM MODERNIZATION OUTCOMES

The transition towards Industry 4.0 requires a profound transformation of educational systems, with emphasis on developing transversal, digital, and technical competencies for young professionals. This article proposes an integrated framework for analysing the process of developing educational competencies in the context of the Fourth Industrial Revolution, based on: a systematic literature review, European-level statistical data on digital competencies, and results of an opinion survey administered to students, lecturers, and employers. The results highlight a significant gap between the competencies provided by current educational systems and the requirements of Industry 4.0. At the European level, only 55% of the population possesses basic digital competencies, with major variations across member states (ranging from 30% to 82%). Analysis of the questionnaires reveals that respondents consider technical competencies (data analytics, IoT, automation, cybersecurity) and transversal competencies (critical thinking, adaptability, interdisciplinary collaboration) as essential, yet report a low level of preparedness in these areas. This paper analyses the process of modernising engineering education in the Republic of Moldova, using the State University "B.P. Hasdeu" in Cahul as a case study. The research is based on a multi-actor audit conducted during 2024–2026, identifying training needs and evaluating the impact of updating core disciplines for the engineering and management profile. The results demonstrate a positive correlation between the introduction of digital tools and virtual laboratories and increased student interest in Industry 4.0 competencies such as product lifecycle management and circular economy.

KEYWORDS: Industry 4.0, curriculum modernisation, engineering education, multi-actor audit, educational competencies, digital engineering, digital transformation, professional training.

INTRODUCTION

The emergence of the Fourth Industrial Revolution, or Industry 4.0, imposes a fundamental reconfiguration of higher technical education systems, shifting from traditional educational models towards dynamic digital ecosystems. Industry 4.0, characterised by the integration of advanced digital technologies such as the Internet of Things (IoT), Artificial Intelligence (AI), Big Data analytics, cloud computing, and cyber-physical systems into production processes, represents a fundamental transformation of the industrial paradigm [1]. This technological revolution generates new and complex demands on the workforce, requiring a profound reconfiguration of educational systems to prepare professionals capable of navigating this dynamic and technologically advanced environment [2].

At the level of the European Union, several initiatives have been undertaken, particularly with regard to policies and strategies in this field. The *Digital Decade 2030* initiative sets ambitious objectives: at least 80% of the adult population should possess basic digital competencies, and the number of ICT specialists should reach 20 million [3]. Eurostat data from 2025 reveal that 94% of individuals in the EU used the internet in the last three months, while 4% spent the entire year without internet access. Mobile devices were used to connect to the internet by nearly 9 in 10 people in the EU in 2025. 74% of individuals ordered or purchased services or goods online in the EU in 2025. ICT affects people's daily lives in many ways, both at the workplace and at home — for example, when communicating or purchasing goods or services online. EU policies range from regulating entire sectors, such as e-commerce, to attempting to protect individuals' privacy. Consequently, the development of the information society is considered by many to be essential for ensuring the conditions necessary to promote a modern and competitive economy [4].

This reality demands an urgent reconfiguration of educational paradigms, especially for those categories of professionals who will form the backbone of the digital economy: engineers, economists, managers, and IT specialists. Each of these categories presents specific competency needs, but also a common core of digital and transversal skills that facilitate interdisciplinary collaboration [5].

In Ukraine and the Republic of Moldova, this process is accelerated by the need to align with European standards and by labour market pressure for specialists capable of utilising cyber-physical systems and smart technologies. The implementation of European projects responds to this imperative, aiming to increase graduates' employability by digitalising the training processes and modernising courses in areas such as engineering and industrial processes, the ecology of industrial production, industrial production management, and human resources management in industrial entities.

This article addresses three main research questions:

1. What are the key competencies required by young professionals in the context of Industry 4.0?
2. What is the gap between the current level of preparation and industry requirements, according to European statistical data and completed questionnaires?
3. What are the advantages and disadvantages of the modernised courses?

Industry 4.0 is not limited to technology; it represents an integrative way of thinking. The modern engineer must possess a hybrid profile, where solid technical expertise is complemented by advanced digital competencies, green skills, and transversal abilities such as critical thinking, creativity, and the capacity for continuous learning. This evolution is closely linked to the UN's Sustainable Development Goals (SDGs) and EU strategies such as the Green Deal and Fit for 55, which require rapid decarbonisation of industry and transport — a process impossible to achieve without a highly skilled workforce in areas such as e-mobility and energy efficiency.

For developing economies or those located in areas of geopolitical instability, such as Ukraine and the Republic of Moldova, the adoption of new technologies represents the only viable path to ensuring economic competitiveness and institutional resilience.

Aligning the engineering competency profile to these new requirements necessitates a systemic approach that goes beyond the simple updating of teaching content. A deep curricular modernisation is required, grounded in a multi-actor audit that synthesises the perspectives of the academic environment, students, and, critically, industrial partners.

The Republic of Moldova, in the context of these global trends, faces specific challenges related to limited technological infrastructure, reduced financial resources, and the gap relative to more digitally advanced economies. Nevertheless, the framework provided by European ERASMUS+ projects constitutes a valuable opportunity for accelerating the modernisation process and integrating international best practices into the national education system.

The State University "B.P. Hasdeu" in Cahul (USCH) participates in the DIGITRANS project — "Digital transformation of HEIs education process in Ukraine and Moldova for sustainable engagement with enterprises" (no. 101127683 — DIGITRANS — ERASMUS-EDU-2023-CBHE) — together with partners from Ukraine and Moldova: Chernihiv Polytechnic National University (CPNU), Kharkiv National Automobile and Highway University (KhNAHU), Lutsk National Technical University (LNTU), Technical University of Moldova (UTM), and Alecu Russo State University of Bălți (USARB). The project aims to modernise 35 courses across 9 study programmes, totalling 160 ECTS credits, with a focus on integrating Industry 4.0 technologies and creating sustainable partnerships with the business environment.

At the State University "Bogdan Petriceicu Hasdeu" in Cahul — which, as of April 2026 (following a merger process), became the "Bogdan Petriceicu Hasdeu" University Centre in Cahul, part of the Technical University of Moldova — within the study programme "Engineering and Management in Machine Building" (Automotive profile), six courses were modernised at undergraduate level. The present study focuses on analysing the results of testing these courses during the 2025–2026 academic year, examining the multiple perspectives of the actors involved and evaluating the impact of curricular modernisation on the quality of the educational process.

LITERATURE REVIEW AND PROBLEM FORMULATION

Recent academic literature consistently documents a substantial gap between the competencies provided by higher education institutions and industry requirements [1]. Students and graduates report that, although they consider Industry 4.0 competencies to be important, they feel insufficiently prepared, especially in the areas of information technology, innovation, practical experience, and inter-agency collaboration [1]. This education-industry gap is amplified by the rapid pace of technological change and the relative rigidity of traditional curricular systems [1]. The literature emphasises that the engineer of the digital era must possess a hybrid competency profile, where technical expertise is complemented by transversal, digital, and 'green' skills. Although terms such as the Internet of Things (IoT) and Big Data are well-established, their implementation in university curricula in the region faces challenges such as the rigidity of study programmes, lack of practical experience, and the gap between academic and industrial environments.

Current literature proposes multiple competency frameworks that combine technical, digital, personal, and innovation skills to align education with the requirements of Industry 4.0. Muzulon et al. (2025) [5] structure 47 competencies across seven dimensions (transversal, social, personal, cognitive, digital, green, technical), providing a comprehensive guide for curriculum design and training programmes. This framework emphasises that Industry 4.0 specialists can no longer be defined exclusively through technical competencies, but require a multidimensional profile. Ada et al. (2021) [7] propose a practical roadmap for human resources managers and workforce planning in the transition to Industry 4.0, identifying critical competencies according to industrial sector and organisational size. Soliani et al. (2025) [8] describe a competency-based educational model for professional training in Industry 4.0, integrating technical, interpersonal, and cognitive competencies into short training programmes, with measurable results regarding increased participants' confidence and interpersonal skills.

The integration of the Internet of Things, cyber-physical systems, and advanced connectivity for monitoring and control represents a central direction in modernised curricula. Kucera et al. [9] document concrete educational cases for training the „Engineer 4.0", demonstrating how monitoring and control of discrete-event systems via OPC UA protocols and cloud applications can be effectively integrated into engineering study programmes. Project-Based Learning (PBL), challenge-based methods, and agile approaches are widely used to link theoretical concepts to real industrial applications [10, 11]. Malhaire and Fougères [10] document the implementation of PBL for engineering students in the context of Industry 4.0, with an application to assembly systems in the automotive industry, demonstrating that collaborative projects with industry significantly increase students' interest and practical preparation. The competency typology identified by Piazer et al. in the Portuguese context organises competencies into six main domains: Technical, Flexibility, Inter-Agency Interaction, Soft Skills, Innovation, and Information Technology. This typology was used in empirical assessments with students, highlighting significant gaps particularly in the domains of IT, Innovation, and Inter-Agency Interaction [1].

Literature analysis enables the identification of specific competencies for different professional categories involved in Industry 4.0. Table 1 summarises the technical and non-technical competencies for the members forming the success team within industrial entities — engineers, managers, and IT specialists — based on evidence from the analysed works.

Table 1. Required Competencies by Professional Category

Professional Category	Main Technical Competencies	Non-Technical Competencies	Representative Sources
Engineers	Data analytics, automation/robotics, IoT, programming, cyber-physical systems (CPS), digital twin, additive manufacturing, cloud computing	Problem solving, adaptability, teamwork, lifelong learning, critical thinking, creativity, interdisciplinary communication	[2], [9], [10], [11]
Managers / Economists	Understanding of Industry 4.0 technologies, project management, change management, data-driven decision making, digital transformation strategy	Strategic leadership, interdisciplinary collaboration, communication, decision-making, systems thinking, change management, resilience	[12], [13], [14]
IT Specialists	Big Data, cloud computing, distributed systems, cybersecurity, VR/AR for production systems, machine learning, IoT platforms, edge computing	Systems thinking, cooperation with OT teams, continuous upskilling, agility, complex problem solving	[15], [21]

Source: compiled by the authors.

Engineers' competencies are the most complex and widely analysed in the specialist literature. Motyl et al. [12] report the results of a questionnaire administered to engineers and engineering students, identifying data analytics, automation, IoT, and programming as the most in-demand technical competencies. The study emphasises that these technical competencies must be complemented by transversal skills such as problem solving, adaptability, and the capacity for continuous learning [12]. Rocha et al. [13] analyse the Brazilian context and confirm the importance of digital competencies and the capacity to integrate cyber-physical technologies into engineering practice.

Prieto et al. [2] describe the „Engineer 4.0" curriculum, which requires competencies such as virtual collaboration, resilience, social intelligence, adaptive thinking, cognitive load management, sense-making, new-media literacy, design mindset, transdisciplinary approach, and computational skills. This extensive list reflects the growing complexity of the engineer's role in digitalised industrial ecosystems.

Managerial competencies for Industry 4.0 are analysed by Saniuk et al. [9], who emphasise the need for managers to understand emerging technologies without necessarily being technical experts, but to be able to make informed strategic decisions and lead digital transformation processes. Łupicka and Grzybowska [10] identify strategic leadership, interdisciplinary collaboration, effective communication, and data-driven decision-making as key managerial competencies. Więcek-Janka et al. [11] analyse the competencies required of managers in Polish family manufacturing enterprises, highlighting the importance of change management and resilience in the context of adopting Industry 4.0 technologies.

IT specialists require advanced technical competencies in Big Data, cloud computing, distributed systems, cybersecurity, and VR/AR support for production systems. The literature emphasises that IT education must integrate these emerging domains into the curriculum, preparing specialists capable of working in cyber-physical and smart factory environments. Systems thinking and the ability to cooperate with Operational Technology (OT) teams are identified as essential non-technical skills [10].

The literature documents multiple pedagogical strategies and models for curricular transformation in preparing the workforce for Industry 4.0. These approaches range from active laboratories and project-based learning to lifelong learning models and university-industry collaboration ecosystems.

Active laboratories and experiential learning are illustrated by the I4Tech Lab model described by Prieto et al. [2]. This engineering laboratory uses active learning, a dedicated laboratory architecture, and Industry 4.0 technologies to teach applied competencies in a hands-on environment. The implemented pedagogical model progresses through five stages: face-to-face sessions for theoretical grounding, individual practical training, group work on specific technologies, multidisciplinary problem solving, and competency assessment. This approach demonstrates the effectiveness of integrating experiential learning in engineering education.

Integration of real-world cases and blended learning is reported by Benis et al. [1] in the context of adapting engineering education during the COVID-19 pandemic. The authors describe the rapid migration to blended delivery, the integration of real industrial cases into the curriculum, and the continuous updating of content to reflect evolving technologies. This experience underlines the importance of curricular flexibility and institutions' capacity for rapid adaptation.

Competency-based curriculum design is addressed by Martynov et al. [21], who present principles, mathematical modelling, and an employer-oriented approach to designing professional educational programmes in engineering. The authors propose the use of information technologies to align graduate learning outcomes with production needs, ensuring the relevance and applicability of the developed competencies.

Lifelong learning and continuing engineering education are addressed by Chakrabarti et al. [21] and Azofeifa et al. [22]. These studies recommend building adaptive and personalised learning pathways, as well as stronger university-industry partnerships to support rapid reskilling and upskilling. Azofeifa et al. present a case study using a KSA (Knowledge, Skills, Abilities) taxonomy that illustrates personalised and adaptive approaches to continuing engineering education, visualising and mapping competencies to professional scenarios for personalised upskilling [22].

Liu et al. [2] propose an educational model that prepares students for Industry 4.0 by developing an educational ecosystem that includes faculty development, curricular alignment, and resource sharing. The model identifies the competency set required for the Industry 4.0 workforce and addresses challenges such as rapid technological change and digital skills gaps [2].

The Education-Industry Gap

Multiple empirical studies consistently document the existence of a significant gap between the competencies offered by educational systems and industry requirements in the context of Industry 4.0. This gap manifests across multiple dimensions: insufficient technical preparation, lack of practical experience, underdeveloped innovation competencies, and limited inter-organisational collaboration skills.

Gaps by competency domain are identified by Piazer et al. [1] in their study of Portuguese students. The authors report that the largest performance gaps are recorded in the domains of Information Technology, Innovation, and Inter-Agency Interaction, while behavioural competencies show smaller discrepancies. Students evaluate these competencies as important, but report a low level of preparedness, indicating an awareness of their own gaps.

Employer perceptions documented in multiple studies reveal that they consider graduates to be insufficiently prepared for the practical tasks of Industry 4.0, particularly in data analytics, systems integration, and cyber-physical competencies. Motyl et al. [12] report that employers demand not only technical competencies, but also the ability to rapidly adapt to new technologies and the capacity to work in interdisciplinary teams.

SME capacity constraints are analysed by Walaszczyk [14], who notes that small and medium-sized enterprises often lack structured competency development and require targeted public training initiatives to effectively adopt Industry 4.0 technologies. The study analyses state-funded programmes in several European countries and extracts competency themes and policy-oriented recommendations for SME training.

Pedagogical deficiencies identified in reviews include curricular rigidity, insufficient hands-on and project-based learning, and limited faculty development. Martynov et al. [21] emphasise that traditional curricular systems fail to keep pace with the rapid rate of technological change, resulting in graduates with outdated or incomplete competencies.

Collectively, these studies recommend curricular redesign, stronger work-integrated learning, and improved university-industry collaboration to reduce the documented gaps.

The central problem lies in the need to balance theoretical and applied training, in a ratio recommended by experts of 40% theory and 60% practice. Furthermore, educational transformation cannot be achieved unidirectionally; a multi-actor audit process that integrates the perspectives of all stakeholders — from lecturers and students to representatives of student organisations and industrial partners — is essential.

Despite progress registered at the global level, regional universities in transition countries such as the Republic of Moldova face specific challenges in the process of modernising engineering education for Industry 4.0: limited technological infrastructure, reduced financial resources, a gap relative to more advanced economies, and limited capacity for industry collaboration. Although European ERASMUS+ projects provide a valuable framework for accelerating modernisation, there is a lack of empirical studies documenting the processes, outcomes, and lessons learned from such initiatives in the specific context of the Republic of Moldova.

The research problem of the present study can be formulated as follows: To what extent does the curricular modernisation carried out within the DIGITRANS project at Cahul State University respond to the requirements of Industry 4.0, how do the actors involved (students, academic staff, student organisations) perceive this modernisation, and what factors facilitate or limit the effective implementation of curricular transformations?

The aim of the research is to analyse the curricular modernisation process carried out at the State University "B.P. Hasdeu" in Cahul within the DIGITRANS project, examining the multiple perspectives of the actors involved and evaluating the impact of the transformations on the quality of the educational process in engineering. The present report aims to provide a comprehensive and multi-dimensional analysis of the development of educational competencies for Industry 4.0, with the following specific objectives.

Research objectives:

- To identify and analyse international trends in the transformation of engineering education for Industry 4.0, through a systematic review of specialist literature.
- To present the European statistical context by analysing Eurostat, DESI 2023, and other official sources to highlight the current level of digital competencies, variations between member states, and progress towards the Digital Decade 2030 objectives.
- To describe the context and process of curricular modernisation at USCH within the DIGITRANS project, including the characteristics of the modernised courses and the adopted pedagogical methodologies.
- To analyse students' perspectives on the quality, relevance, and impact of the modernised courses, based on feedback questionnaire results administered in the autumn semester 2025–2026.
- To analyse lecturers' perspectives on the importance, methods, and directions for improvement of the modernised courses.
- To examine the perspectives of student organisations on the transparency, accessibility, and quality of the curricular modernisations.
- To formulate practical recommendations for continuing and extending the curricular modernisation process at Cahul State University and in other similar institutions in the region.
- To propose an educational model structured in 6 stages for the systematic development of Industry 4.0 competencies, accompanied by a detailed competency framework organised by main categories.

•To formulate practical recommendations for educational institutions, industry, and policy-makers, based on the synthesised evidence.

RESEARCH RESULTS

The emergence of the Fourth Industrial Revolution, conceptualised under the name of Industry 4.0, has triggered a fundamental reconfiguration of production and management paradigms at the global level, imposing unprecedented pressure on higher education systems to produce specialists capable of navigating a technological landscape marked by the fusion of the physical, digital, and biological spheres. At the heart of this transformation lie cyber-physical systems (CPS), the Internet of Things (IoT), Big Data Analytics, autonomous robotics, and additive manufacturing — technologies that not only streamline industrial processes, but define new business models and social interactions.

In response to these challenges, several international, regional, and national policies and programmes have been launched. The European Union has developed a complex ecosystem of policies and initiatives to address the challenges of digital competencies in the Industry 4.0 era. Three main pillars structure this strategic approach: the *European Skills Agenda*, the *Digital Education Action Plan*, and the *Digital Skills and Jobs Coalition.*

European Skills Agenda: launched in 2020 and periodically updated, establishes an integrated vision for competency development in the EU, with emphasis on reskilling and upskilling for the green and digital transition. The Agenda recognises that digital competencies are not merely an educational objective, but an essential condition for social inclusion, economic competitiveness, and societal resilience [3].

Digital Education Action Plan (2021–2027): proposes two strategic priorities: (1) promoting the development of a high-performing digital educational ecosystem and (2) improving digital competencies and skills for digital transformation. The Plan underlines the need for digital infrastructure in schools and universities, for teacher training, and for the development of high-quality digital educational content [3].

Digital Skills and Jobs Coalition: brings together member states, companies, social partners, non-profit organisations, and education providers to act together to reduce the digital skills deficit. The Coalition facilitates the exchange of good practices, mobilises resources, and coordinates initiatives at the national and regional level [3].

These programmes have served as the foundation for formulating the objectives of the DIGITRANS project and for developing the corresponding competencies in students of the study programmes included in the project. The DIGITRANS project (ID: 101127683) represents an international collaborative effort, coordinated by Riga Technical University (RTU) from Latvia, which brings together a large consortium of universities and industrial partners from five countries. The central objective of the project is to increase graduates' employability and support sustainable economic growth in Ukraine and Moldova through the implementation of support measures for modernising engineering education.

The project strategy is based on several fundamental pillars: the integration of research with practical training, the development of innovative study programmes aligned with EU standards, the implementation of Double Diploma programmes, and the complete digitalisation of the educational process through infrastructures such as the SREE (Sharing Remote Experiment Environment) platform. Particular attention is paid to the resilience of the educational system in the context of the war in Ukraine, ensuring access to education for displaced or refugee students and lecturers through the DIGITRANS digital ecosystem.

A distinctive element of the DIGITRANS project is the multi-actor audit process, integrated into Work Package WP1 (Needs Analysis). This audit aimed to precisely identify the competencies required by the labour market in the context of digitalisation and to compare these with the current training profile in Ukrainian and Moldovan universities. Two complementary project stages can thus be synthesised:

•Analysis of competencies identified at the project outset (D1.3) — based on the questioning of 16 representatives of the academic environment and employers in March 2024;

•Evaluation of results after curricular modernisation (D4.1) — based on feedback from students and academic staff on three courses tested in the autumn semester of 2025.

The targeted study programme is Engineering and Management in Machine Building (Automotive), at undergraduate level (Cycle I), which includes 6 modernised courses, totalling 26 ECTS credits. The main industrial partners involved in the initial survey included ICS DRA Draexlmaier Automotive SRL, Cahul — a leader in automotive wiring harness production.

In March 2024, a comprehensive survey was carried out among representatives of the academic environment, researchers, and potential employers from key sectors: computer engineering, industrial automation, electronics, electrical engineering, and robotics. The survey used a questionnaire structured in 12 sections, aimed at evaluating the courses proposed for modernisation, the proportion of theory versus practice, and the need for digital resources (Table 2).

Table 2. Results of the initial stakeholder needs survey (N=16, March 2024)

Evaluated Indicator	Results and Preferences (%)	Implications for Modernisation
Support for new courses	100%	Validation of the thematic relevance of the project.
Theory / Practice ratio	40% Theory / 60% Practice	Need to expand laboratory and project hours.
Interest for specialists	75% – 92%	High relevance of new curricula for employers.
Access to digital resources	> 85%	Need for online libraries and open-source simulators.
Facilitation of remote practice	67% – 92%	Justification for investment in SREE laboratories.

Source: compiled by the authors.

This needs analysis served as the basis for the D1.3 report (Studies and Report on curricula needed to the labour market of UA and MD), a document that subsequently guided the selection of content for electronic textbooks (e-books) and the configuration of virtual laboratories.

The competency profile modernised within DIGITRANS is structured to ensure a smooth transition for the graduate from the academic to the professional environment, reducing the skills gap frequently reported by employers. Competencies are classified across seven essential dimensions: transversal, social, personal, cognitive, digital, green, and technical.

The technical dimension remains the foundation, but is redefined through the lens of smart technology integration. The engineer must understand the concept of the industrial product throughout its digital lifecycle (Digital Twin), master the modelling and solving of complex engineering problems using computers, and possess advanced experimental skills. In the field of transport management, specific competencies target the management of production processes, the quality of operations, and the technical exploitation of modern vehicles, including electric and hybrid ones.

The digital component is addressed by training students in the use of specific software for diagnosing, repairing, and maintaining modern transport, as well as in the use of programming and simulation environments. Transversal competencies such as entrepreneurship and project management are integrated to form an agile mindset capable of generating innovation within enterprises.

A critical aspect highlighted by recent studies and integrated into DIGITRANS is that of 'green' competencies. The engineers of the future must be aware of the ecological impact and possess knowledge of efficient energy systems and e-mobility, thus aligning with the global sustainability objectives.

Curricular modernisation within the DIGITRANS project is materialised through the development of 35 new or updated courses, of which 6 courses were modernised at the State University "B.P. Hasdeu", integrated into 9 accredited study programmes. The process is rigorous, monitored by the Quality Assurance and Management Team (QAMT) and grounded in the project Quality Assurance Plan (PQAP).

The study programme Engineering and Management in Machine Building (Automotive) includes 6 undergraduate courses, updated within the DIGITRANS project. Table 3 presents the synthesis of the courses subject to evaluation.

Table 3. Courses evaluated in the initial competency analysis — USCH Cahul

Course Title	Status	Level	ECTS	Teaching Methodologies
Design of Electric Machines	Updated	Bachelor	4	Lectures, practicals, lab sessions, tests
CAD Products	Updated	Bachelor	4	Lectures, practicals, lab sessions, tests
CAD Technological Processes	Updated	Bachelor	4	Lectures, practicals, lab sessions, tests

& CALS				
Tools of Ecological Production	Updated	Bachelor	4	Lectures, e-learning, practicals
Human Resources Management	Updated	Bachelor	4	Lectures, e-learning, practicals
Production Management	Updated	Bachelor	6	Lectures, e-learning, practicals

Source: compiled by the authors.

All 6 courses were included in the study programme accreditation in 2018 and are an integral part of the current study plan.

To the question "Do you consider it necessary to study the disciplines listed below in the undergraduate programme?", all 16 respondents (100%) answered affirmatively for all 6 courses. This demonstrates full consensus from the academic community and employers regarding the relevance of the curriculum.

Respondents evaluated the degree to which each discipline contributes to the development of specific professional competencies. Table 5 presents the aggregated results.

Table 5. Respondents' agreement on specific professional competencies (%, N=16)

Professional Competency	Elec. Mach.	CAD Prod.	CAD Tech.	Eco. Prod.	HRM	Prod. Mgmt
Modelling and solving engineering, managerial and economic problems	75%	62.5%	68.75%	68.75%	68.75%	81.25%
Professional computer use	81.25%	75%	68.75%	50%	43.75%	62.5%
Understanding the concept of the industrial product	68.75%	68.75%	56.25%	50%	31.25%	56.25%
Understanding the concept of production systems	56.25%	50%	56.25%	50%	25%	56.25%
Knowledge of the technological manufacturing process concept	43.75%	37.5%	68.75%	50%	56.25%	68.75%
Experimental skills	31.25%	31.25%	37.5%	25%	12.5%	18.75%
Socio-humanistic, communication and linguistic skills	18.75%	12.5%	12.5%	12.5%	31.25%	31.25%
Economic-managerial skills	12.5%	12.5%	12.5%	18.75%	43.75%	37.5%
Skills in ecology and safety	18.75%	18.75%	25%	31.25%	18.75%	25%

Source: compiled by the authors.

Based on the data presented in the table, the following conclusions can be drawn regarding specific professional competencies:

•The competency with the highest average agreement is Modelling and solving engineering, managerial, and economic problems (average ~68%), followed by Professional computer use (~61%).

•The competencies related to Experimental skills (average ~29%) and Socio-humanistic competencies (average ~21%) recorded the lowest scores, indicating the need for increased emphasis on these dimensions.

•The Production Management course obtained the highest score for modelling competencies (81.25%), while Design of Electric Machines obtained the highest score for computer use (81.25%).

The general competencies of the study programme were evaluated separately, with results presented in Table.

Table 6. Agreement on general competencies (%, N=16)

General Competency	Elec. Mach.	CAD Prod.	CAD Tech.	Eco. Prod.	HRM	Prod. Mgmt
Personal and professional development	100%	87.5%	87.5%	81.25%	87.5%	81.25%
Social interaction	50%	37.5%	37.5%	56.25%	62.5%	50%
Responsibility	75%	68.75%	62.5%	68.75%	81.25%	68.75%
General Competency	**Elec. Mach.**	**CAD Prod.**	**CAD Tech.**	**Eco. Prod.**	**HRM**	**Prod. Mgmt**
Ability to learn and work independently	68.75%	62.5%	56.25%	62.5%	56.25%	50%
Study of specialised literature	68.75%	68.75%	75%	68.75%	62.5%	75%
Knowing and using specific language	50%	56.25%	50%	37.5%	31.25%	31.25%
Logical thinking	56.25%	50%	43.75%	43.75%	50%	50%
Explanation and interpretation	43.75%	25%	31.25%	50%	43.75%	31.25%
Creative-innovative behaviour	43.75%	43.75%	43.75%	31.25%	37.5%	43.75%
Critical and constructive thinking	50%	37.5%	25%	43.75%	37.5%	50%

Source: compiled by the authors.

•"Personal and professional development" recorded the highest average agreement (87.5%), with 100% agreement for the "Design of Electric Machines" course.

•"Responsibility" ranks second (average ~73%), reflecting the formative value of all courses.

•"Creative-innovative behaviour" (average ~41%) and "Critical and constructive thinking" (average ~39%) present potential for improvement.

Table 7. Preferred assessment methods by respondents (%, N=16)

Method	Elec. Mach.	CAD Prod.	CAD Tech.	Eco. Prod.	HRM	Prod. Mgmt
Tests	62.5%	68.75%	75%	75%	87.5%	87.5%
Laboratory work	75%	81.25%	81.25%	75%	50%	56.25%
Essays	6.25%	6.25%	6.25%	31.25%	37.5%	31.25%
Individual/group projects	68.75%	81.25%	68.75%	43.75%	50%	62.5%
Interdisciplinary projects	56.25%	56.25%	68.75%	50%	43.75%	50%

Source: compiled by the authors.

Based on the data presented in the table, tests (average ~73%) and laboratory work (average ~69%) are the most preferred assessment methods, reflecting the practical orientation of the programme. Individual/group projects (average ~63%) are also appreciated, particularly for CAD and Production Management courses. Essays (average ~18%) are the least preferred — the predominance of technical courses explains this tendency.

Table 8. Perceived importance of courses (%, N=16)

Course	Very important	Important	Don't know	Unimportant
Design of Electric Machines	50%	50%	0%	0%
CAD of Products	81.25%	12.5%	6.25%	0%
CAD Tech. Processes & CALS	68.75%	31.25%	0%	0%
Tools of Ecological Production	50%	50%	0%	0%
Human Resources Management	31.25%	62.5%	0%	0%
Production Management	62.5%	37.5%	0%	0%

Source: compiled by the authors.

All courses are evaluated as important or very important by 100% of respondents (with the exception of one respondent who indicated "Don't know" for CAD of products). The "CAD of Products in Machine Building" course recorded the highest percentage in the "Very important" section (81.25%).

University-Industry Partnership. The sustainability of engagement with enterprises is ensured by integrating them into all phases of the project, from curriculum definition to offering internships and support for bachelor's theses. Partners such as Dräxlmaier Automotive play a crucial role in validating competencies and providing an applied learning environment.

Resilience, Inclusion, and Social Impact in a Crisis Context. The DIGITRANS project has a pronounced social dimension, becoming an instrument of resilience in the face of challenges such as military conflict, migration, and social disparity. The capacity to maintain an active educational process through digital platforms is vital for preventing a "lost generation" of engineers. The DIGITRANS digital ecosystem offers learning opportunities for academic staff and students, allowing them to remain connected to the academic community. Furthermore, the impact extends to groups with reduced opportunities, facilitating access to elite technical education through online courses and remote laboratories that eliminate geographical and financial barriers.

Table 9. Social impact of the project

Target Group	Support Measures and Impact	Estimated Outcomes
Students (UA/MD)	Training in EU laboratories, mobilities, internships in industry.	72 students trained in EU laboratories.
Academic Staff	Teach-the-Teacher programmes, access to modern resources.	54 lecturers trained in EU; 144 in total.
Refugees / Displaced Persons	Access to DLE (Digital Learning Ecosystem) for continuity.	Integration into the remote educational process.
Enterprises	Access to qualified graduates; cooperation in research.	41 students in direct internships.

Source: compiled by the authors.

Quality Management and Long-Term Sustainability. The success of a curricular modernisation process of this magnitude depends on a robust quality assurance system. DIGITRANS has established a system of internal and external evaluation, monitored by the Erasmus+ National Offices in Ukraine and Moldova. Each partner has delegated a member to the Quality Assurance and Management Team (QAMT), responsible for evaluating deliverables, courses, and student feedback.

Project sustainability is guaranteed through several mechanisms:

•Institutional Accreditation: The new courses and programmes are integrated into the permanent structure of the universities, being accredited by the relevant national agencies.

•Exploitation of the SREE Platform: The hardware and software infrastructure will be maintained by the universities (particularly CPNU) after the end of Erasmus+ funding, serving as a resource for future generations.

•Professional Networks: The connections formed between the academic and industrial environment (reported as active in 63% of similar projects) provide the framework for future curricular updates.

•Course Certification: Modernisation concludes with the official certification of modules, allowing their delivery as part of Lifelong Learning for industry specialists.

Results of the Student Evaluation of Modernised Courses

This section synthesises the results of the course evaluation questionnaires completed by students participating in the DIGITRANS programme. Six courses were analysed, with a total of 67 respondents. The evaluation covered 11 quantitative criteria (scale 1–5) and three open-ended qualitative questions. Table 10 presents the respondent distribution per course, including gender, predominant age group, and academic status.

From the data presented in the table, it can be observed that the largest number of respondents was at the Production Management course, since this course is taught jointly to several student groups. Regarding the gender ratio, the Engineering field is predominantly attended by male students.

Table 10. Respondent profile per course

Course	Full Title	N	Gender	Age	Status
HRM	Human Resource Management	11	8M / 2F	16–21	Local
Production Mgmt	Production Management	17	8M / 9F	22–30	Local
Tools Ecolog.	Tools of Ecological Production	11	5M / 6F	22–30	Local
PACPICM	CAD of Products in Machine Building	11	9M / 2F	22–30	Local
PACPTCALST	CAD Technological Processes & CALS	6	4M / 2F	22–30	Local
PME	Electric Machines (PME)	11	8M / 2F	22–30	Local

Source: compiled by the authors.

Figure 1 presents the overall mean scores for each course (arithmetic mean of the 11 evaluation criteria). All courses obtained positive evaluations, with averages between 4.60 and 4.95 on a scale of 1 to 5.

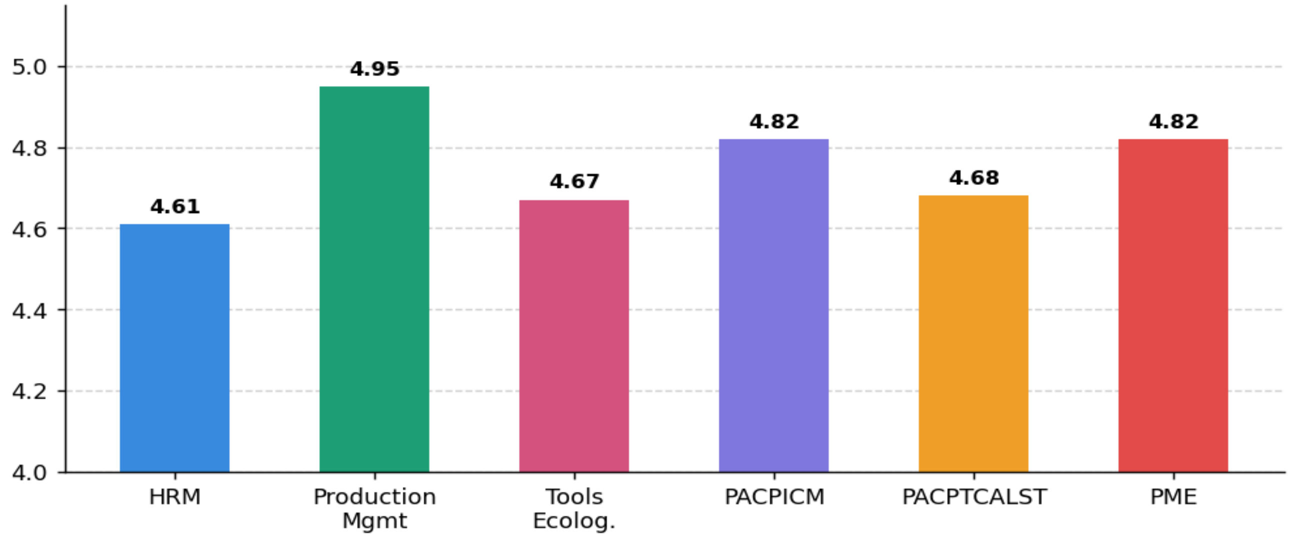

Figure 1. Overall mean scores per course

Source: compiled by the authors based on the survey

In order to detail the assessment of the courses according to the criteria established in the questionnaire, I will present in the following table the average scores for each evaluation criterion, broken down per course.

Table 11. Detailed scores by evaluation criterion

Criterion	HRM	Prod. Mgmt	Tools Eco.	PACPICM	PACPTCALST	PME
Topics covered	4.82	4.88	4.73	4.82	4.67	4.73
Well-structured course	4.64	5.00	4.64	4.82	4.67	4.82
Logical structure	4.64	5.00	4.55	4.91	4.67	4.82
Audiovisual materials	4.45	4.88	4.73	4.55	4.67	4.73
Creative thinking	4.64	4.94	4.73	4.73	4.67	4.82
Practical application	4.45	4.94	4.73	4.91	4.67	4.64
Criterion	**HRM**	**Prod. Mgmt**	**Tools Eco.**	**PACPICM**	**PACPTCALST**	**PME**
Theory/practice balance	4.73	4.88	4.55	4.82	4.67	4.73
Accessible literature	4.45	4.94	4.73	4.82	4.67	4.91
Lecturer's attitude	4.64	4.94	4.73	4.91	4.83	5.00
Sufficient time	4.64	5.00	4.73	4.82	4.67	4.91
Clear organisation	4.64	5.00	4.55	4.91	4.67	4.91
OVERALL AVERAGE	**4.61**	**4.95**	**4.67**	**4.82**	**4.68**	**4.82**

Source: compiled by the authors.

Analysis of the 67 questionnaires from the 6 DIGITRANS courses reveals a generally high level of student satisfaction. All courses obtained averages above 4.60 out of 5, indicating consistent quality of teaching and course organisation. The following observations can be made:

•Best-evaluated course: Production Management (average 4.95) — 4 criteria with a perfect score of 5.00.

•Criterion with the highest score: Lecturer's attitude — perfect score of 5.00 at the PME course, high averages across all courses.

•Criterion with the lowest scores: Audiovisual materials (4.45 at HRM) and logical structure (4.55 at Tools Ecological).

•Recurring trend in feedback: The desire for more practice versus theory — mentioned at HRM, Tools Ecological, and PME.

•Dominant student profile: Local students, aged 22–30 (exception: HRM: 16–21 years), with a mixed gender distribution.

DISCUSSION

The results obtained at Cahul State University (CSU) are consistent with the global trends documented in the specialist literature regarding the transformation of engineering education for Industry 4.0. The integration of e-learning in all modernised courses reflects the direction identified by Kucera et al. [9] regarding the need to combine physical laboratories with digital platforms and cloud applications. The use of the e-learning platform and virtual laboratories at CSU corresponds to the recommendations from the specialist literature regarding investments in hybrid laboratories.

The multi-actor approach adopted within the DIGITRANS project — involving students, academic staff, and student organisations in the course evaluation process — is in line with the theoretical perspectives on multi-actor coordination in curricular modernisation. The positive evaluations suggest that the curricular modernisation has achieved a satisfactory level of alignment between educational objectives, student needs, and industrial requirements.

The practical orientation of the modernised courses — with emphasis on real-world examples, startup-type projects, laboratory work, and concrete digital applications — corresponds to the recommendations of Malhaire and Fougères [7] regarding the importance of collaborative projects with industry, and of Caratozzolo et al. [2] regarding improving learning outcomes by combining structured and open-ended components.

The specific context of CSU presents several particularities that influence the curricular modernisation process and merit in-depth analysis.

Joint course organisation for students from different programmes (Engineering and Management in Machine Building, Engineering and Management in the Food Industry, Business and Administration) represents both a challenge and an opportunity. On the one hand, this organisation requires academic staff to adapt content and practical examples for audiences with different backgrounds. On the other hand, it facilitates the development of transversal competencies and an interdisciplinary perspective, essential for graduates who will work in complex and diverse organisational environments.

The sustainability dimension is explicitly integrated into the modernised curriculum through the "Tools of Ecological Production" course, which connects the principles of the circular economy with the technical and managerial requirements of modern engineering. This approach reflects the global trend of integrating the green dimension into the digital transformation of industry — the concept of a "twin transition" (green and digital) — which is increasingly recognised as a fundamental requirement for engineering graduates [16].

Industry collaboration represents a specific challenge for CSU, given the regional economic context. Although the "Production Management" course includes a startup-type project that simulates real business conditions, the consolidation of formal partnerships with local and regional enterprises remains a priority for the subsequent stages of the DIGITRANS project.

Technological infrastructure constitutes a recognised challenge in the context of universities in less developed regions. The use of the e-learning platform and virtual laboratories within the DIGITRANS project represents an important step in overcoming this challenge, providing students with access to modern digital tools regardless of the limitations of the physical infrastructure.

The research results generate several practical implications for continuing and extending the curricular modernisation process at CSU and in similar institutions in the region:

- Extending the practical and digital component. Lecturers' recommendations regarding extending the practical component, deeper integration of digital tools, and strengthening industry collaboration are consistent with the international trends documented in the specialist literature. Implementing these recommendations could further increase curriculum relevance and student satisfaction.
- Continuous updating of content. The accelerated dynamics of Industry 4.0 require continuous content updating mechanisms to ensure relevance vis-à-vis the most recent technological and industrial developments. Banciu and Feier [27] emphasise that curriculum adaptation is a continuous process, not a one-time intervention.
- Continuous professional development of academic staff. Effective implementation of Industry 4.0-oriented pedagogies requires continuous training of academic staff in areas such as digital tools, active teaching-learning methods, and industry collaboration. The DIGITRANS project provides a valuable framework for this training, but its long-term institutionalisation represents an important challenge.
- Systematic industry engagement. Consolidating partnerships with the business environment, to ensure curriculum relevance vis-à-vis the real requirements of the labour market, is a priority identified both in the specialist literature and in the recommendations of academic staff at CSU.

CONCLUSIONS AND RECOMMENDATIONS

This paper has provided a comprehensive analysis of the development of educational competencies for Industry 4.0, integrating perspectives from academic literature, the European policy approach, and complex results regarding the identification of students' competency training needs and students' own opinions on the modernised courses and the digital methods integrated into them, following the implementation of the DIGITRANS project.

The curricular modernisation carried out at USCH Cahul under the aegis of the DIGITRANS project represents a significant step in transforming engineering education in the Republic of Moldova. The multi-actor audit highlighted that students are prepared to adopt Industry 4.0 tools, appreciating the balance between theory and practice. The results of the curricular modernization process and multi-stakeholder audit carried out within the DIGITRANS project highlight the need for a profound transformation of engineering education to meet the demands of Industry 4.0. Aligning skills is not a singular act, but a dynamic process that requires a symbiosis between technology, pedagogy and real socio-economic needs.

The main recommendations derived from the research include:

•Extending the use of the SREE (Sharing Remote Experiment Environment) infrastructure to allow remote access to high-performance laboratory equipment.

•Implementing interdisciplinary projects that combine mechanical design with data-driven process optimisation.

•Continuing the training of academic staff through "Teach-the-Teacher" programmes to keep pace with technological innovations.

The transformation initiated at Cahul provides a replicable model for other technical education institutions, contributing to the creation of a resilient and competitive workforce in the digital era.

Recommendations for policymakers include making curriculum structures more flexible to allow for rapid updates, continuing investment in teacher training, and creating national mechanisms to encourage public-private partnerships in technical education. The DIGITRANS project provides a replicable model of good practice, demonstrating that, through digital collaboration and innovation, universities in the region can become pillars of sustainable industrial transformation. The completion of this process will mark not only an academic victory, but a fundamental contribution to the future stability and prosperity of Ukraine and the Republic of Moldova within the European family.

ACKNOWLEDGEMENTS *The research was carried out within the project: ERASMUS+ „Digital transformation of HEIs education process in Ukraine and Moldova for sustainable engagement with enterprises”. Project No. 101127683 – "DIGITRANS".*

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Дата надходження статті до видання: 15.03.2026
Дата прийняття статті до друку після рецензування: 21.04.2026
https://doi.org/10.36910/t64tm535