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Addressing the challenges associated with Industry 5.0 in higher education: a training concept approach

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Abstract

Purpose – The purpose of this study is to demonstrate the potential of a structured and competency-based instructional design approach for integrating digital and sustainable transitions into higher education curricula under the Industry 5.0 paradigm. By involving students, faculty and industry professionals, the research aims to produce training concepts that are both theoretically robust and practically grounded. This stakeholder-driven approach seeks to enhance the relevance and quality of educational offerings while addressing evolving technological, environmental and societal needs.

Design/methodology/approach – This study adopted a qualitative research design to develop training concepts aligned with Industry 5.0 in higher education. Using a structured research and development process based on the ADDIE instructional design model, the study integrated literature reviews, surveys, focus groups and workshops. The iterative process ensured stakeholder engagement and contextual alignment throughout all design phases.

Findings – The results revealed that implementing a systematic ADDIE-based model enables the effective development of Industry 5.0 training concepts. Aligning learning outcomes with context-specific competencies, practical content and evaluation strategies ensures that the designed programmes are both scalable and impactful.

Originality/value – This study offers a novel and comprehensive application of the ADDIE model tailored to Industry 5.0 in higher education. Its originality lies in addressing the lack of methodological clarity in previous studies by detailing a fully operationalised instructional process. The inclusion of academic and industry stakeholders throughout ensures that the resulting educational concepts are both context-sensitive and practically applicable, contributing significantly to the advancement of future-ready engineering education.

Keywords Higher education, Industry 5.0, Dual transition training, Competency-centred approach, Stakeholder involvement

Paper type Research article

Introduction

Modern industrial companies face a combination of external pressures stemming from the dual demands of digitalisation and green transitions. The European Commission's (2021) updated industrial strategy aims to support this shift, emphasising the adoption of smart manufacturing to safeguard Europe's competitiveness. The development of future-ready engineers equipped to redefine tasks and align skills, competencies, and qualifications with evolving industrial demands is central to this transformation (European Commission, 2021; Zsifkovits *et al.*, 2021).

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As education and workforce training have become key drivers of innovation and competitiveness, the vocational education and training sector must evolve to support digital and green transitions and respond to shifting labour market needs. Although this creates opportunities, it also presents challenges in ensuring that the workforce is prepared for the future (Straub *et al.*, 2023). Success in these socioeconomic transitions depends on the development of competencies that transcend technological advances and encompass both organisational structures and human decision-making processes (Lima *et al.*, 2023). Institutions such as the World Economic Forum (2024) highlight the need to prioritise reskilling and upskilling, particularly for engineers, as technology and environmental concerns reshape industries. Strengthening operational management competencies is critical for professionals in manufacturing value chains. These competencies bridge the gap between technical systems and business goals, enabling sustainable problem solving in digitalised environments (Pacher *et al.*, 2024).

Engineering education under Industry 4.0 focused heavily on technology. However, the emergence of Industry 5.0 demands a new synergy between technology and human-centred values (Pacher *et al.*, 2024). Therefore, educational institutions must integrate ethical, sustainable, and humanistic principles to prepare engineers for a resilient and people-focused industrial future (Díaz Lantada, 2020; Gürdür Broo *et al.*, 2022; Leng *et al.*, 2022).

Higher education institutions (HEIs) face the challenge of equipping students with the skills necessary to navigate the complexities of a rapidly evolving industrial landscape. A structured instructional design (ID) model is essential in this regard, as it provides a systematic approach for developing educational programmes that effectively integrate technological advancements, sustainability, and human-centred competencies (Dick, 2009). This ensures that learning outcomes are measurably and effectively achieved, thereby enhancing the quality of education and preparing students for real-life challenges.

In the rapidly evolving landscape of higher education, effective and efficient ID models are essential for creating high-quality learning and teaching materials (Halupa, 2023). HEIs are complex organisations with diverse stakeholders and varying definitions of quality. ID models provide a structured approach for designing, developing, and delivering effective, efficient, and engaging training materials. They ensure that the content has clear objectives, help quickly identify and fix flaws, save time and resources, and foster collaboration between experts. ID boosts engagement by tailoring materials to learners' needs and preferences and includes ongoing evaluations to refine and improve instruction.

However, IDs must align with the three key components of the learning system: study content, delivery method, and assessment system (Biggs, 1996). According to Biggs (1996), a misalignment between these components can lead to several issues, such as students perceiving their education as unproductive, adopting a superficial approach to learning, and experiencing frustrated expectations. Thus, ID models provide a systematic and structured approach and ensure that each phase of the process is thoroughly planned and executed.

Despite extensive discussions on ID models in the literature, a significant gap persists in respect of the methodologies have not been sufficiently described to support their practical implementation (Abuhassna and Alnawajha, 2023). This gap is particularly evident in the alignment of ID processes with key Industry 5.0 drivers, including technology, sustainability, resilience, and human-centred competencies (Andres *et al.*, 2022; Jaedun *et al.*, 2024). Addressing this gap is crucial for developing effective educational programmes that prepare students for the challenges and opportunities of Industry 5.0.

Furthermore, achieving a constructive alignment in dynamic contexts remains a key challenge for HEIs. In this context, ID offers a systematic approach for aligning learning objectives, instructional methods, and assessments, allowing for continuous refinement and improved learning outcomes (Dick, 2009). ID supports consistent programme development (Abuhassna and Alnawajha, 2023), promotes effective strategy selection, and fosters collaborative and autonomous learning environments (Abdolahi *et al.*, 2021; Chang *et al.*, 2007; Jung *et al.*, 2022).

In addition, ID models enhance motivation and engagement (Vagianou *et al.*, 2021), support the integration of information and communication technologies, and improve student performance (Halupa, 2023; Lee *et al.*, 2017). Various models shaped by learning theory, pedagogy, and context are available (Farres and MacDonald, 2005; Park, 2015). The analysis, design, development, implementation, and evaluation (ADDIE) model remains one of the most widely used (Hsu, 2013; Ngo, 2024; Vagianou *et al.*, 2021).

A recent study compared ADDIE with traditional and emerging models and demonstrated its effectiveness in terms of student satisfaction and academic outcomes (Senadheera *et al.*, 2024). However, its application frequently remains at a conceptual level, with limited translation into practical or procedural approach. Many educators encounter difficulties in operationalising the ADDIE model, largely due to a lack of clear guidance on selecting appropriate model variants, adapting them to specific educational contexts, and implementing concrete, actionable steps (Abuhassna and Alnawajha, 2023).

One of the primary challenges for HEIs is the need to adapt their curricula to incorporate the principles and technologies of Industry 5.0. This requires a shift from traditional teaching methods to innovative approaches that emphasise interdisciplinary learning, problem solving, and critical thinking (Andres *et al.*, 2022; Jaedun *et al.*, 2024). Moreover, HEIs must identify strategies to incorporate the development of Industry 5.0 skills into their programmes. This includes technical as well as soft skills, such as communication, teamwork, and emotional intelligence (Ciolacu *et al.*, 2023).

Industry 5.0 offers opportunities for HEIs to foster innovation and inclusivity, thereby driving sustainability in alignment with the digital and green transitions (Stuchlikova and Marek, 2022; Supriya *et al.*, 2024). In this context, the ADDIE model provides a robust framework to address these challenges (Büth *et al.*, 2020). In the analysis phase, HEIs identify learning needs and align them with Industry 5.0 demands, including transversal competencies (Lambrechts *et al.*, 2017; Zhao *et al.*, 2021). In the design phase, HEIs plan strategies, content, and assessments while engaging stakeholders and integrating problem-based learning (Pacher *et al.*, 2024). In the development phase, HEIs ensure the quality of content through collaboration designed for adaptability and scalability. In the implementation phase, HEIs prepare resources, train instructors, and ensure a supportive environment. Finally, in the evaluation phase, HEIs apply formative and summative assessments and use feedback to refine programmes and align them with societal and industrial needs.

Although some studies have applied the ADDIE model in specific industrial contexts such as intelligent control systems (Yao *et al.*, 2022), comprehensive models tailored to Industry 5.0 are scarce. Analysis phases often lack concrete methodologies (Wilke and Magenheim, 2017), and most research continues to focus on Industry 4.0 or general advanced teaching rather than addressing the unique demands of Industry 5.0 (Boussakssou *et al.*, 2020; Dlamini *et al.*, 2023).

Existing literature on the implementation of the ADDIE model in Industry 5.0 education has a significant gap. Most papers describe ID efforts without providing a detailed methodology for each step of the ADDIE model. Moreover, few studies have examined the use of the ADDIE model in the context of Industry 5.0. Addressing this gap requires developing comprehensive and detailed strategies for each phase of the ADDIE model that are tailored to the unique challenges and opportunities of Industry 5.0 education.

Therefore, this study aimed to develop and implement a structured ID process tailored for higher education to address the emerging challenges of Industry 5.0. This process focused on aligning technology, sustainability, resilience, and human-centred competencies to prepare future engineers and industrial managers for the evolving demands of the industry.

This study posed the following research questions (RQs):

RQ1. How can ID models be effectively operationalised to design training concepts for Industry 5.0?

RQ2. How can Industry 5.0 training concepts be implemented to upskill students with competencies aligned with technology, sustainability, resilience, and a human-centred approach?

RQ3. How can the insights of relevant stakeholders, such as students, professors, and industry experts, be effectively integrated into the design and development of these training concepts?

Materials and methods

Research context

This study was conducted at the Engineering Faculty of Mondragon University to enrich educational experiences by integrating the ADDIE model. Mondragon University is known for its renowned innovative approach to education, strong university–business cooperation, and commitment to continuous improvement in teaching methodologies (Markuerkiaga *et al.*, 2018).

The participants comprised students enrolled in master's programmes in supply chain, manufacturing, and logistics management as well as lecturers and professors in telematics and cybersecurity, artificial intelligence (AI), information systems, innovation, organisational model and strategic human resources management, and logistics and productive operations management. The participation of these diverse departments ensured a comprehensive research approach that leveraged expertise from multiple fields to enhance process quality and relevance.

Moreover, professionals from regional companies contributed their expertise in logistics and supply chain management, product design, production development, industrial marketing, and entrepreneurship. Collaboration between academia and industry enriched this study by providing practical insights and fostering innovation.

Questionnaires and focus groups were the primary tools for collecting field data from stakeholders and conducting preliminary analyses.

Research design and methodology

The research timeline spanned 18 months, from January 2023 to June 2024, and adopted a progressive elaboration approach. This iterative process allowed the project and its phases to evolve dynamically, with new elements and insights incorporated across successive versions. This flexibility enabled the research to adapt to emerging information and refine its focus throughout its duration.

The phases and steps of development were adapted from the 5-phase ADDIE model (Branch, 2010; Dick, 2009; Richey and Klein, 2014). A mixed-methods approach combining quantitative and qualitative techniques was employed at various stages of the training concept development, with multiple instruments distributed across the five main phases (Figure 1).

Figure 1 presents a detailed overview of the elements addressed during each phase of the process. The analysis phase comprised identifying digital and sustainable competencies as well as the challenges of Industry 5.0. A literature review was conducted to identify the challenges of Industry 5.0 and the digital and sustainable competencies needed to address them. The literature review was conducted within the framework of the European ERASMUS + Engineering Excellence for the Mobility Value Chain (EE4M) project and

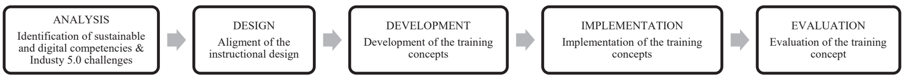

Figure 1. Phases of the methodological approach. Source: Authors' own construct

focused on the competencies needed to implement smart and sustainable operations management. The review followed the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) approach (Page *et al.*, 2021). The search strategy used terms such as "sustainab*," "digi*," "smart*," "operation and management," and "skill*" or "competenc*" in the Scopus and Web of Science databases. A total of 105 articles were initially identified, of which 38 articles were finally selected (Supplementary file: "Supplementary Tables").

Based on this review, an online survey was conducted to assess the identified competencies and themes among three key groups at Mondragon University: university students ($n = 73$), university professors ($n = 15$), and industry experts ($n = 17$). The survey was distributed via email with prior notification. The questionnaire was structured into three sections: transversal, digital, and sustainability-related competencies. This approach ensured that the survey captured the specific needs and perspectives of the local academic and professional communities and reflected the unique context of Mondragon University.

Industry representatives rated the importance of skills for companies and the need for training on a 5-point Likert scale (1 = not important; 5 = very important). Professors and students evaluated how well the curricula addressed these skills according to a 5-point Likert scale (1 = not at all; 5 = very much). In addition, industry professionals assessed the urgency of the training needs on a five-point Likert scale (1 = no immediate need; 5 = urgent need). Cronbach's alpha exceeded 0.7 across all measures, confirming the reliability of the survey.

After collecting the responses, a data analysis was conducted to prioritise the results. Quantitative data were analysed using descriptive statistics to allow for a clear and concise interpretation of numerical trends and insights into participants' perspectives. Based on these results, a focus group was conducted with industry experts, comprising a representative from an original equipment manufacturer (namely, automotive) company, one expert in digital applications in industry, one supply chain consultant, one car chain supplier expert, one CEO of a multi-sector company, and one university professor. Finally, a workshop was conducted with students focusing on the future challenges of Industry 5.0. The focus group and workshop aimed to obtain their perspectives on the findings and gather additional inputs. Moreover, qualitative data were analysed using narrative analysis, which helped identify the underlying themes and patterns from the participants' responses.

Next, the findings were synthesised, and Industry 5.0 competencies and challenges, as well as key content areas of digital and green transformation, were identified and contextualised. In addition, key elements, such as programme level, duration, educational framework, and instructor expertise, were contextualised.

Figure 2 illustrates the process followed for the identification and prioritisation of competencies, along with the number of participants involved in each step.

This groundwork enabled progression to the next phase, which comprised aligning the ID and validating the process. The design phase focused on aligning the ID with the competencies identified in the previous phase. To achieve this, key focus areas for development were selected. Following the selection and adaptation of competencies to the contextual conditions, the training concept was designed based on Biggs' (1996) constructive alignment framework. This approach ensured that teaching methods and assessment tasks were systematically aligned with the intended learning outcomes, thereby promoting effective and meaningful learning experiences and addressing the identified gaps and needs. This need was analysed by two academic experts in the field, who proposed a series of topics and competencies. Their input was compared through interviews with industrial companies in the region. Potential focus areas were identified and validated through interviews with industry representatives to ensure that they addressed the identified gaps and needs. After finalising them, the course structure and definitions were developed in collaboration with academic experts. This course definition involved outlining the preliminary learning outcomes, assessment tasks, and teaching and learning activities. These elements were then reviewed against the learning outcomes previously defined by the teaching staff to avoid redundancies and ensure coherence

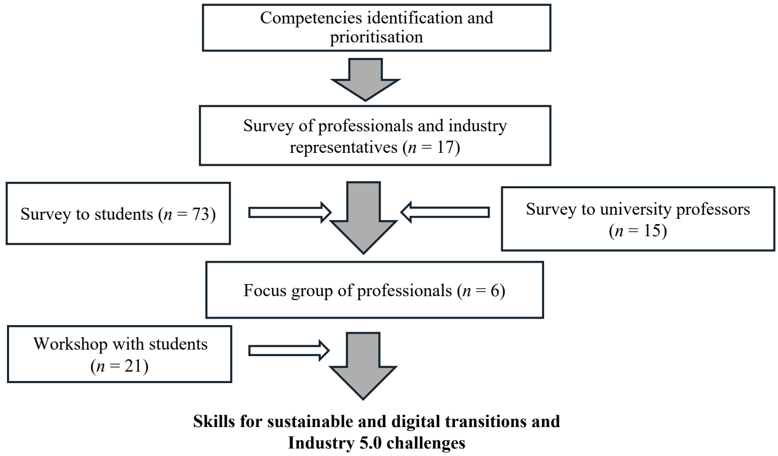

Figure 2. Process to identify and prioritise key competencies for transitions. Source: Authors' own construct

within courses and degree programmes. Final validation with academic staff led to the refinement of assessment tasks and teaching and learning activities, ensuring alignment with the learning outcomes for further development.

During the development phase, a preliminary version of the training concept was created. The materials were tested by teachers and refined based on their feedback (Figure 3). Once this process was completed, learning modules were developed, including content creation, assessment tools, and case studies based on local industries. In a dedicated session focused on defining the training concept, professors conducted a triangulation process to ensure that the teaching and learning activities and assessment tasks were fully aligned with the established learning outcomes.

For the validation, the proposed course design was contrasted at the following levels:

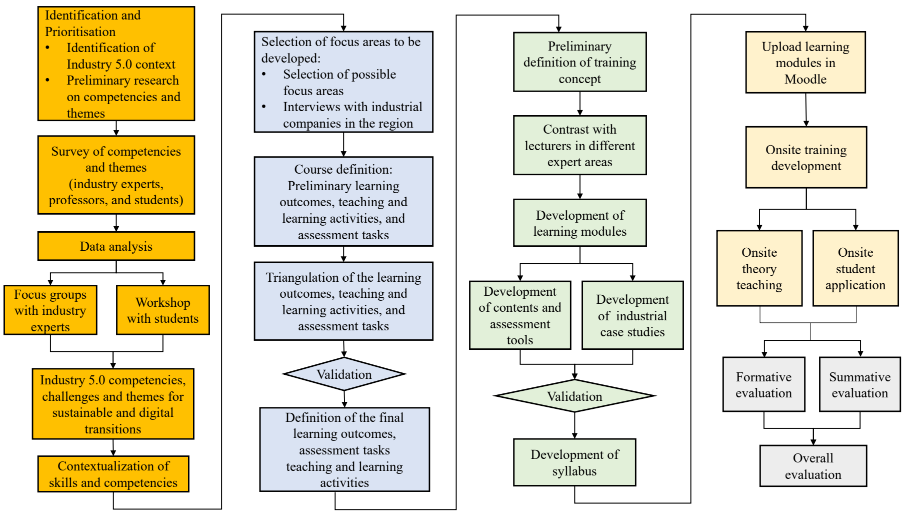

Figure 3. ADDIE model for Industry 5.0. Source: Authors' work

(1) Master's degree coordinating committee: The goal of this contrast was to ensure that the proposal complied with the regulatory conditions. The duration, content, mode of teaching, relationships with other courses, and prerequisite conditions were considered adequate, considering the overall master's curriculum.

(2) Academic committee of the university: This was conducted to ensure that the regulatory academic conditions were met and to submit the presentation to government institutions for approval.

(3) Ministry of Education: The final course design was validated and approved by the highest government education body.

After review and validation, a course syllabus was developed. During the development phase, two instructional designers collaborated with lecturers from various academic departments to create a 3-block training concept.

During the implementation phase, the modules were uploaded to an online platform, allowing students to continuously access the learning materials. In addition, an on-site training session was conducted, incorporating theoretical lectures alongside the application of case studies.

Finally, during the evaluation phase, the effectiveness of the curriculum was assessed using summative evaluations. The data analysis measured the effects on the students' knowledge, skills, and attitudes and identified areas for improvement. Various methods were employed to assess improvements in students' abilities and mastery of knowledge and skills. The primary tool used for evaluation was a questionnaire completed by lecturers and students that included both quantitative and qualitative components. Students rated various aspects, such as the content and applicability of the subject, organisation, teaching materials and resources, work of the teaching staff, and personal dedication of students outside the classroom. Quantitative data were collected through a five-point Likert scale to assess various aspects of the course, including its content and applicability, organisational structure, instructional materials and didactic media, the instructor's performance, and the students' attitudes and personal engagement. Additionally, open-ended questions were employed to gather qualitative insights, inviting participants to highlight positive aspects and provide suggestions for improvement, thereby enabling a more comprehensive understanding of their perspectives. Learner performance was assessed using a five-level categorisation scheme by comparing the percentage ratio between the achieved and expected scores (Figure 3). For the lower-performing categories, the training concept design was revised to enhance the learning outcomes.

Results and discussion

Analysis

The review highlighted that the integration of smart technologies, such as AI, the Internet of Things (IoT), and cyber-physical systems, significantly reshaped operations management. These technologies enable real-time data acquisition, enhance analytics, and promote automation, thereby fostering efficient, adaptive, and sustainable practices (Fujimoto *et al.*, 2023; Lobova and Bogoviz, 2019; Woschank *et al.*, 2021).

Digital competencies, such as data management (Brock and von Wangenheim, 2019; Umachandran *et al.*, 2019), data processing (Lyytinen *et al.*, 2023), statistics (Blomster and Koivumäki, 2022; Konanahalli *et al.*, 2022), cybersecurity (Behie *et al.*, 2023; Suhasini and Santhosh Kumar, 2019), and information and communication technology (ICT) infrastructure applications (Ajibade and Mutula, 2020), are essential for navigating this complex technological landscape. Furthermore, competencies in digital strategy and business development support the alignment of technological change with strategic organisational goals (Brock and von Wangenheim, 2019; Nadeem *et al.*, 2018).

The importance of transversal competencies was underscored. These are skills that bridge digital and sustainable domains and enable individuals to operate in diverse contexts. Key examples are decision-making (Gupta *et al.*, 2022; Török, 2020), target orientation (Tezcan and Kuleyin, 2019), innovation competencies (Estrada and Reyes Álvarez, 2023; Huq *et al.*, 2016), critical thinking (Lyytinen *et al.*, 2023; Zhu *et al.*, 2020), resilience (Behie *et al.*, 2023), and information management (Fan and Li, 1998).

Participants acknowledged that Industry 5.0 reshaped the expectations of workforce competencies by integrating human-centric innovation, sustainable value creation, and digital infrastructure. For instance, smart solutions, such as digital twins, green supply chains, and circular economy models, require a workforce that possesses technical and digital skills as well as the ability to make strategic, sustainability-focused decisions (Gandomkari *et al.*, 2023).

The review indicates that developing integrated competency profiles is critical for preparing professionals for the challenges of a rapidly evolving operations management landscape (Pacher *et al.*, 2024).

Surveys. Table 1 presents the survey results regarding the importance of skills, curriculum alignment, and the need for training.

The survey results revealed that industry representatives prioritised training in digital competencies over other areas. Previous studies have identified the alignment of curricula with the digital skills required in the industry as a significant area of concern (Ramakrishnan *et al.*, 2023). This aligns with the findings of Brezeanu and Lazarou (2020) and Salminen *et al.* (2024), who argued that companies seeking a leading role in the AI era must prioritise skill development and collaborate with universities to align their curricula with evolving industry demands. Although training in transversal- and sustainability-related skills was considered important, it was perceived as less urgent than training in digital skills. However, the significance of transversal skills, which are highly valued by the industry, must be emphasised.

Both professors and students perceived a relatively low alignment between the curriculum and digital skills, with ratings below 4. Students rated curriculum alignment for digital skills lower than that for transversal and sustainability-related skills, whereas professors rated curriculum alignment for digital skills lower than that for sustainability skills. This suggests that academic institutions have not yet fully integrated the latest digital competencies required by the industry into their curricula.

Table 2 summarises the mean scores of the evaluations of competencies' importance, curriculum alignment, and training needs.

The survey results revealed several opportunities for improvement. Industry representatives highlighted the relevance of digital skills, particularly in applying ICT infrastructure, new digital technologies such as AI and IoT, and data management, as well as management, interpersonal, cognitive, and adaptability skills. Students stated that managerial, interpersonal, and cognitive skills were well covered in the curricula, whereas digital skills were insufficiently addressed, prompting calls for additional training. Perceptions among

Table 1. Importance and need for training of industry experts and curriculum alignment for professors and students

Skill category	Industry Importance	Need for training	Professors Curriculum alignment	Students Curriculum alignment
Transversal	4.08	3.85	3.18	3.84
Digital	4.07	4.20	3.28	3.53
Sustainability-related	3.63	3.73	3.37	3.76

Source(s): Authors' own work

Table 2. Most important competencies, need for training and curriculum alignment by category

		Industry Importance	Need for training	Professors Curriculum alignment	Students Curriculum alignment
Managerial skills	Strategic skills	3.94	3.59	3.27	*3.99*
	Target orientation skills	*4.29*	3.29	*3.73*	*3.97*
	Leadership skills	*4.35*	3.88	3.27	3.86
	Decision-making skills	3.76	3.41	*3.73*	*4.05*
	Problem-solving skills	3.76	3.59	*3.87*	*4.18*
	Crisis management skills	3.47	3.82	2.73	3.56
	Risk management skills	3.76	3.76	3.33	3.66
	Financial management skills	3.65	3.82	3.07	3.34
Interpersonal skills	Communication skills	3.88	*4.24*	*4.00*	*4.30*
	Negotiation skills	3.88	*4.29*	2.80	3.67
	Foreign language skills	3.94	3.47	3.33	3.60
	Emotional intelligence skills	3.94	3.76	2.33	3.53
	Time management skills	4.18	3.35	3.00	3.68
	Ability to be open minded	*4.29*	3.71	3.40	*4.00*
	Stress management skills	*4.35*	*4.47*	2.33	3.49
Cognitive and adaptability skills	Innovation competencies	4.18	4.35	3.33	3.92
	Critical thinking skills	4.00	4.06	2.93	3.84
	Analytical thinking skills	4.18	3.65	2.93	3.85
	Proactivity	4.18	3.41	3.33	*3.97*
	Ability to adapt to changes	*4.65*	4.12	3.13	*4.08*
	Ability to learn from incidents	*4.53*	4.00	3.13	*4.12*
	Resilience	*4.41*	*4.41*	2.73	3.78
	Information management skills	4.24	4.00	3.40	3.90
Digital skills	Apply ICT infrastructure	*4.29*	*4.18*	*3.53*	3.75
	Apply new digital technologies (AI or IoT)	*4.41*	*4.53*	3.07	3.52
	Digital strategy and business development	3.88	*4.35*	3.00	3.58
	Data management skills	*4.71*	*4.53*	*3.47*	3.85
	Data processing	*4.47*	*4.35*	3.40	3.59
	Statistic skills	3.88	*4.18*	*3.67*	3.51
	Digital marketing skills	3.00	3.53	2.80	3.15
	Cybersecurity skills	3.94	3.94	3.27	3.26
Sustainability-related skills	Environment management skills	3.71	3.88	*3.60*	3.66
	Supply chain sustainability strategies and tech. Comp	3.88	4.06	3.20	3.77
	Awareness of trends and drivers of change	3.47	3.76	3.20	3.73
	Understand and apply principles of sustainability	4.06	3.88	*3.60*	3.82
	Establish and explain visions of sustainable development	3.41	3.59	3.33	3.68
	Implement sustainability projects	3.47	3.29	3.20	3.85
	Implement corporate culture for green HR management	3.71	*4.18*	*3.53*	3.81
	Develop employees' environmental skills	3.29	3.18	3.27	3.78

Note(s): Competencies highlighted in italics represent those that received the ten highest evaluations from various groups in each column

Source(s): Authors' own work

students were corroborated by industry representatives, who identified digital competencies as the most urgently needed area for training, highlighting a clear opportunity for development.

A notable difference was observed in the perceptions of students and professors regarding curriculum coverage. Although both groups agreed regarding curriculum coverage for managerial skills, students rated the curriculum coverage of interpersonal and cognitive skills higher than professors. Conversely, professors rated the curriculum coverage of digital and sustainability skills higher than students. In addition, industry representatives did not prioritise sustainability skills as an urgent training need. This may indicate a misalignment between industry demands and academic priorities.

Focus group. The focus group confirmed the necessity of aligning digital and green transformation with business strategy and financial success. The participants emphasised the importance of developing personal, technological, and environmental skills to overcome economic challenges and resistance to change. The focus group highlighted the significance of digital skills for organisational digital transformation and operational efficiency. Industry professionals stated that digital skills affected career progression and workforce adaptability, whereas professors stressed the need to incorporate digital skills into curricula to support student development. Consequently, upskilling and reskilling strategies should align with these evolving demands.

Furthermore, professionals noted that the greatest impact of these transitions resulted from shifts in operational processes, ultimately transforming the methods of value creation among businesses. The main challenges identified were high implementation costs, limited knowledge of new technologies and their applications, difficulty in finding skilled workers, and employee resistance to change.

Workshop. In the workshop, students emphasised that automation, AI, and IoT were essential for efficient and resilient operations; cleaner production and renewable energy served as pillars of future factories; and strong cybersecurity measures were crucial for companies transitioning to digital-first operations. Moreover, they identified digital proficiency, problem-solving, and adaptability as indispensable competencies.

According to the results obtained in the analysis phase and considering the strong emphasis on digital competencies during the workshop, prioritised skills were selected based on the questionnaire responses (Table 3). The selection criteria focused on skills identified as having

Table 3. Description of the target competencies considering the contextualisation process

	Skills	Defined competencies
Digital skills	New digital technology applications, such as AI, IoT, cyber-physical systems	Be able to understand and apply new digital technologies
	Data management skills Data processing skills Statistical analysis skills	Be able to understand and apply data processing and management technologies and methods with robust statistical foundations
	ICT infrastructure application Cybersecurity skills	Be able to understand ICT architecture technologies and diagnose architecture cybersecurity
	Digital strategy and business development	Be able to describe and understand the differences between traditional business models and Industry 4.0 strategies
Transversal skills	Target orientation skills Decision-making skills Innovation competencies skills Critical thinking skills Resilience skills Information management skills	Be able to consider the strategic, human, sustainable, and resilient effects of decisions

Source(s): Authors' own work

the greatest need for training in the industry, with scores of 4 out of 5 or higher. The competency labelled "cybersecurity skills," which received a rating slightly below average (3.94 out of 4.0), was included due to its integral role in the application of information and communication technologies and the perception of its importance. The conclusions of this process were similar to those of Bohashko and Bohashko (2024).

Contextual elements considered. After identifying the competencies requiring development, the contextual elements that influenced their integration into the learning process were considered, namely:

(1) The programme level (e.g. degree, master's, secondary, or vocational training) determined the depth of competency development, aligning objectives with students' prior knowledge and desired proficiency;

(2) Training concepts must complement the broader educational framework, with proper sequencing of prerequisites;

(3) Programme duration limited competency development (e.g. the programme allocated three European Credit Transfer and Accumulation System (ECTS) credits, affecting the proficiency achieved);

(4) Available equipment and instructor expertise must guide the clustering of knowledge areas requiring similar resources;

(5) Curricula must promote interdisciplinary connections to avoid compartmentalising competencies within individual courses;

(6) The educational process model included face-to-face (presential), virtual (online), and hybrid (blended) models.

The treatment of the competencies selected for the development of the training concept required adaptation to the students' levels and expected objectives regarding the depth of these competencies. This training concept was aimed at master's level students, and the degree of depth established as an objective is presented in Table 3 The terms used to articulate the levels of the selected competencies were derived from Bloom's taxonomy (Anderson and Krathwohl, 2001).

The core skills addressed in the course were understanding and applying new digital technologies (e.g. AI, IoT, and cyber-physical systems), managing and processing data with statistical foundations, and applying ICT architecture and cybersecurity tools. Future engineers were trained to develop digital strategies and innovative business models to bridge the gap between traditional and Industry 4.0 practices. To avoid compartmentalisation, an integrative "Challenge" module consolidated competencies across subjects, fostering an interdisciplinary approach, as recommended by Drake and Reid (2020). Transversal skills, such as adaptability, strategic thinking, and human-centric decision-making, were also emphasised to ensure that students considered sustainable and resilient impacts. The training model was face-to-face, with competencies tailored to three 3 ECTS credit course durations, thereby balancing the program's overall structure and resource requirements.

The analysis phase concluded that the involvement of relevant stakeholders in the process of designing the training concept for Industry 5.0 could be effectively integrated, adding value to this phase (RQ3).

Design

A preliminary definition of learning outcomes was developed based on the identified competencies and Bloom's taxonomy (Anderson and Krathwohl, 2001). Learning outcomes were defined as the process of designing an environment that fosters activities aimed at achieving specific educational goals (Biggs, 1996). Learning outcomes were required to demonstrate students' capacity to achieve a certain competency after a certain period.

Table 4 presents the defined learning outcomes of the course.

Development

During the development phase, two instructional designers collaborated with lecturers from various academic departments to create a 3-block training concept worth three ECTS credits. This training concept incorporated six key dimensions from the IMPULS model (Grufman *et al.*, 2020), emphasising human-centric and sustainable approaches, value orientation, and resilience for Industry 5.0. The training was structured into three sequential blocks, each building on the previous block, to progressively enhance the students' competencies and skills through practical application in an industrial case (Figure 4).

The first block, Industry 5.0 maturity model, focused on the IMPULS model. The contents developed and taught included Industry 4.0 concepts and models, maturity models, and assessment, highlighting the factors of strategy, organisation, sustainability, and resilience towards an Industry 5.0 approach. This block also featured two application activities: an industrial case assessment and the identification of improvement areas. Both activities were related to a real industrial case that was developed throughout the training. The second block, Industry 5.0 technologies, concentrated on the training concept regarding technologies. The content covered technologies and industrial applications, considering the impacts on strategy, organisation, people skills, sustainability, and resilience, with data analytics as a core component. This block included two application activities: a roadmap proposal and

Table 4. Learning outcomes defined for each competency

Defined competencies	Defined learning outcomes
Be able to describe and understand the differences between traditional business models and Industry 4.0 strategies	Identify and explain the concepts and evolution of Industry 4.0 Evaluate the impact of Industry 4.0 on supply chain models and maturity frameworks Analyse and assess maturity levels of Industry 4.0 using IMPULS methodology
Be able to understand and apply new digital technologies	Understand the principles and applications of collaborative robotics Define the principles and applications of additive manufacturing Analyse the advantages, disadvantages, and practical applications of additive manufacturing Explain and apply machine vision technologies in industrial contexts Explore the role and use of augmented and virtual reality in industrial processes Understand blockchain technology and its industrial applications
Be able to understand and apply data processing and management technologies and methods with robust statistical foundations	Understand and apply the principles of big data in industrial settings
Be able to understand ICT architecture technologies and diagnose architecture cybersecurity	Describe and analyse the architecture and applications of cyber-physical systems Understand cybersecurity principles and apply them to enhance network security
Be able to consider the strategic, human, sustainable, and resilient effects of decisions	Make decisions based on strategic, human, sustainable, and resilient factors

Source(s): Authors' own work

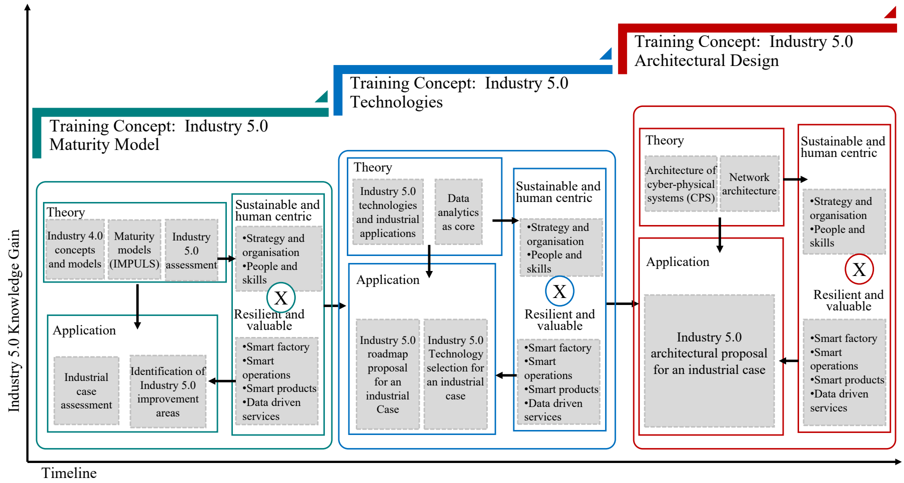

Figure 4. Digital enterprises course structure. Source: Adapted from Büth *et al*. (2018)

technology selection for an industrial case. Both activities were applied to the developed industrial case. Finally, the third block, Industry 5.0 architectural design, focused on the architecture of cyber-physical systems and network architecture, culminating in an architectural proposal for the developed industrial case.

This structured approach ensured that the training was comprehensive, practical, and aligned with the latest advancements in Industry 4.0 and 5.0, thereby providing students with the necessary skills and knowledge to excel in their fields.

At this stage, we considered that the operationalisation of the training concept for Industry 5.0 was achieved (RQ1).

Implementation

In the implementation phase, we focused on transforming a meticulously developed training plan into actions. This phase involved the deployment of comprehensive on-site training designed to be intensive and completed over six weeks. During this phase, we developed comprehensive on-site teaching using the Moodle Learning Management System (LMS), integrating pre-class, in-class, and post-class stages. During the pre- and in-class stages, lecturers used task-driven teaching to present and review relevant knowledge points. They published courseware on the Moodle platform for students to learn. Students could complete their learning using various methods, such as consulting learning materials, asking lecturers for advice, searching for information online, and conducting practical observations.

During the in-class teaching stage, a combination of case analysis and relevant regional industrial examples were analysed and contextualised. Lecturers selected industrial cases for discussion based on the industrial challenges and content that the students had learned independently. Through analogy with cases, Industry 4.0 and 5.0 knowledge points were organically connected to establish a complete knowledge system. Furthermore, students' enthusiasm for learning and practical skills were enhanced through the application of an industrial case study. In the post-class learning stage, students received feedback on their practical applications.

This structured approach ensured that the training was comprehensive, practical, and aligned with the latest advancements in Industry 4.0 and 5.0. Throughout the 6-week intensive training (75 h of student workload), lecturers provided on-demand support to students, facilitating their learning process and ensuring that they could effectively apply the concepts that they were taught.

Evaluation

The assessment results demonstrated that 4 out of 5 students performed excellently on the questionnaire that evaluated their theoretical knowledge, whereas the other student's performance was considered good. The performance of all the students in the application to the industrial case was excellent.

The questionnaire results reflected high satisfaction with most indicators: content and its applicability received an average score of 4.5 out of 5, whereas organisation, materials, and teaching resources achieved the highest score of 5. The aspect that received a relatively low score was personal dedication outside of teaching hours, with an average score of 3.5. These results reinforced the effectiveness of the pedagogical model, as they suggested that most learning occurred efficiently during classroom sessions, reducing the need for significant additional effort on the part of students outside class hours.

In addition, face-to-face interviews with lecturers and students shed light on the effectiveness of teaching implementation, reflecting various aspects of the teaching design. This continuous feedback loop allowed for ongoing improvement of the training model, ensuring that the educational experience was continuously enhanced. This evaluation method helped promptly identify problems and promoted continuous improvement and enhancement of the training model.

The results of the implementation and evaluation confirmed that Industry 5.0 training concepts had been successfully implemented to upskill students' competencies (RQ2).

Conclusions

The operationalisation of the ADDIE model in the context of Industry 5.0 is a challenge that many HEIs should address to ensure stakeholder satisfaction and engagement and enhance the quality of the services they provide to society. Future engineers must integrate knowledge into sustainability, resilience, and a human-centred perspective while also developing competencies in digital tools and skills.

The process developed in this study ensured that each phase of the ID process (analysis, design, development, implementation, and evaluation) was meticulously planned and executed. Furthermore, the integration of stakeholder perspectives, including those of students, professors, and industry professionals, enhanced the relevance and applicability of training concepts. The results of the practical application of this process were highly positive. All participating stakeholders, including students, professors, and industry experts, rated the training experience favourably. Students demonstrated significant improvements in their competencies and skills, whereas professors highlighted the coherence and effectiveness of the process of teaching complex concepts. Industry experts reported the relevance and applicability of training concepts in real-world contexts.

This study highlights the importance of adopting an integrative and competency-centred approach to analysing educational gaps, defining learning outcomes, and aligning these with teaching and learning activities and evaluation strategies. Identifying educational gaps from a skills and challenges perspective ensures that training programs remain relevant and effective. Furthermore, this study emphasises the value of stakeholder participation in the ID process, highlighting the importance of diverse perspectives in creating comprehensive and practical training concepts.

This study demonstrated that the ADDIE ID model can be effectively operationalised to design training concepts for Industry 5.0 by meticulously planning and executing each phase. The implementation phase demonstrated that Industry 5.0 training concepts could be effectively delivered through a combination of online and on-site training sessions, integrating theoretical lectures with practical applications. Moreover, this study highlighted the importance of involving diverse stakeholders in the ID process. By incorporating the insights and perspectives of students, professors, and industry professionals, training concepts were made more relevant and applicable to real-life contexts.

The implications of our findings extend across several critical domains. First, this study highlights the need for HEIs to adopt structured pedagogical design models to effectively integrate Industry 5.0 principles into their curricula. This approach will ensure that students are equipped with competencies necessary to navigate the complexities of rapidly evolving industrial landscapes. Second, the results underline the importance of aligning educational programmes with the key drivers of Industry 5.0, such as technology, sustainability, resilience, and human-centred skills. This alignment is crucial for developing relevant and effective educational materials. Third, this study demonstrates the value of involving various stakeholders, including students, teachers, and industry professionals, in the training design process. Their ideas and perspectives are essential for creating practical and applicable training concepts for real-life contexts. Fourth, this study reveals that the iterative nature of the ADDIE model allows for the continual refinement and improvement of educational programmes. This ensures that training concepts are kept up-to-date with technological advances and evolving industry needs. Finally, the findings indicate that the structured approach of the ADDIE model facilitates the development of scalable and adaptable educational programmes. This is particularly important for HEIs that aim to prepare students for the dynamic and interdisciplinary nature of Industry 5.0.

This study has several limitations. First, the reliance on qualitative data stemming from the number of participants and the focus on a single case within one institution and country limited the generalisability of our findings. In addition, the dual role of the researchers in the design and implementation phases may have introduced a confirmation bias that could have influenced the observed results. To address these limitations, future research should include a diverse group of participants from various institutions and industries and use independent evaluators to assess the effectiveness of training concepts. Also, the continuous evolution of technology requires educational programmes to be continually updated, presenting an additional challenge in terms of how training concepts can be effectively updated and scaled. Future research could explore the application of the ADDIE model in a variety of contexts and educational institutions to broaden the understanding of its effectiveness and adaptability. Furthermore, investigating adapted versions of the model tailored to specific industry sectors and training levels would provide valuable insights into its practical utility and contextual relevance.

Supplementary material

The supplementary material for this article can be found online.

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