

# Industry 5.0 and Higher Education: Towards a Human-Centric and Sustainable University

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**Abstract** – This paper discusses the shift from Industry 4.0 to Industry 5.0 and its impact on higher education, focusing on evolving educational paradigms, key technologies, and the move toward human-centric innovation, sustainability, and resilience. It examines implications for curricula and institutional strategies in higher education.

**Keywords** – Industry 4.0, Industry 5.0, Education 5.0, University 5.0.

## I. INTRODUCTION

The rapid evolution of industrial revolutions, from Industry 1.0 to Industry 4.0, has reshaped economic, social, and educational systems. Industry 4.0 (I4.0) introduced Cyber-Physical Systems (CPS), the Internet of Things (IoT), Cloud Computing, and Artificial Intelligence (AI), shifting production toward human-machine collaboration, flexibility, and efficiency—unlike earlier automation-focused models such as Computer Integrated Manufacturing (CIM). This transformation demands corresponding changes in education, ensuring graduates are equipped with advanced digital skills and adaptable mindsets.

Higher education institutions (HEIs) play a crucial role in fostering technological literacy, interdisciplinary skills, and innovation. However, the rapid pace of technological advancement requires HEIs to continuously update curricula, integrating digital competencies, smart manufacturing principles, and agile methodologies. The COVID-19 pandemic further accelerated digitalization in education, revealing both opportunities and challenges in virtual learning and remote collaboration.

With the emergence of Industry 5.0 (I5.0), a human-centric approach to industrial and technological advancements is gaining momentum. I5.0 builds on the digital foundations of I4.0 while emphasizing sustainability, resilience, and human-technology symbiosis.

Higher education institutions, especially universities, should examine the distinct roles of each stakeholder and establish performance indicators to assess their compatibility and effectiveness within the evolving educational landscape. Figure 1 presents an overview of the triple helix model encompassing University 5.0, Education 5.0, and Industry 5.0: (a) governments play a regulatory role in fostering green

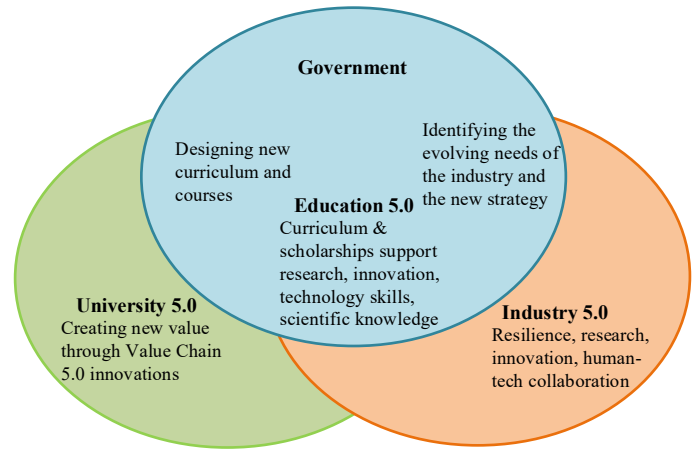


Fig. 1. A triple helix framework integrating University 5.0, Education 5.0, and Industry 5.0

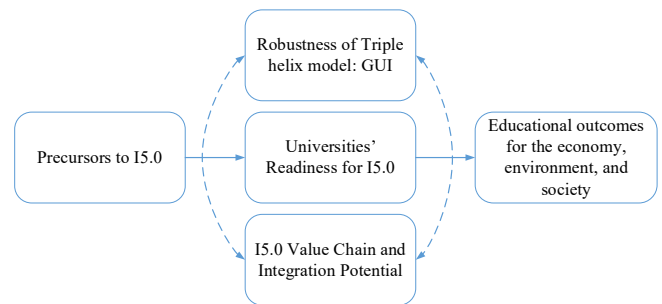


Fig. 2. Core Model Framework

infrastructure and shaping the transition to I5.0, (b) universities serve as society's knowledge hubs, and (c) the rise of I5.0 serves as a catalyst for advancing sustainable and intelligent technological innovations [1]. As a converging paradigm, I5.0 integrates green technologies, energy efficiency, and human-centered intelligence, shaping a more resilient and sustainable future.

At this stage, it is essential to analyze the impact of I5.0 on HEIs, particularly universities, through contemporary literature. This approach facilitates the transition from a fundamental model to an empirical model (variable-based) for practical implementation. A comprehensive evaluation of I5.0's influence on universities requires considering both macro and micro environmental factors. Figure 2 presents a foundational model that explains how universities and the education sector generate societal value by integrating I5.0's core principles into their value chain [1]. The findings confirm that I5.0 has a direct, substantial, and positive impact on higher education, shaping its strategy, mechanisms, and operations.

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This transition demands a re-evaluation of educational strategies to ensure that graduates are not only technically proficient but also capable of ethical decision-making, interdisciplinary thinking, and adaptive learning in complex environments. As universities navigate this transition, the role of education in fostering sustainable, inclusive, and human-centered technological development becomes increasingly critical.

This paper provides an overview of how I4.0 and I5.0 are transforming higher education. It examines their impact on learning, teaching, and workforce readiness, highlighting the need for universities to adapt to industry demands and stay innovative. The paper is structured as follows: Section II examines I5.0's impact on universities and the shift to an empirical model. Section III reviews key environmental factors and a foundational integration model. Section IV discusses educational adaptations for future graduates. Finally, Section V summarizes key findings, highlighting I5.0's role in sustainable, human-centered development.

## II. KEY TECHNOLOGIES AND THE TRANSITION FROM INDUSTRY 4.0 TO INDUSTRY 5.0

The evolution of industrial and digital technologies has led to the widespread adoption of I4.0, characterized by automation, smart manufacturing, and the integration of cyber-physical systems, the Industrial Internet of Things, Big Data, and Augmented Reality. As technology progresses, I5.0 has emerged, building on I4.0 while emphasizing human-centric, sustainable, and resilient development across sectors, including education.

### A. Fundamental Technologies of Industry 4.0

Industry 4.0 integrates several key technologies that drive digital transformation in both industrial and educational settings.

The *Industrial Internet of Things* (IIoT) connects smart devices and cyber-physical systems to enable real-time data exchange, process automation, and minimal human intervention.

*Digital Twin* (DT) Technology creates virtual replicas of physical systems, allowing predictive analytics and process optimization through integrated data flows.

*Augmented Reality* (AR) enhances user experience by overlaying virtual information onto the real world, supporting applications in manufacturing, education, healthcare, and maintenance.

*Big Data and Cloud Computing* facilitate the collection, storage, and analysis of vast datasets, improving decision-making and operational efficiency in industries and higher education institutions (HEIs).

Specifically, the Industrial Internet of Things comprises interconnected sensors, instruments, and cyber-physical assets, enabling real-time communication and data-driven optimization of production processes, energy management, and service delivery (Fig. 3) [2].

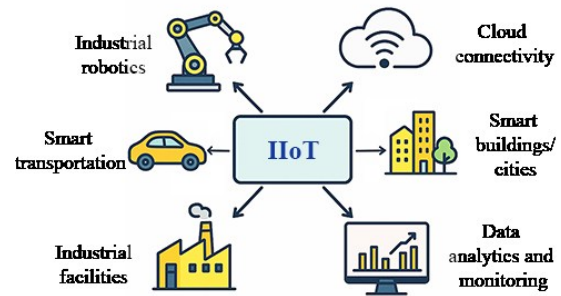


Fig. 3. Industrial Internet of Things

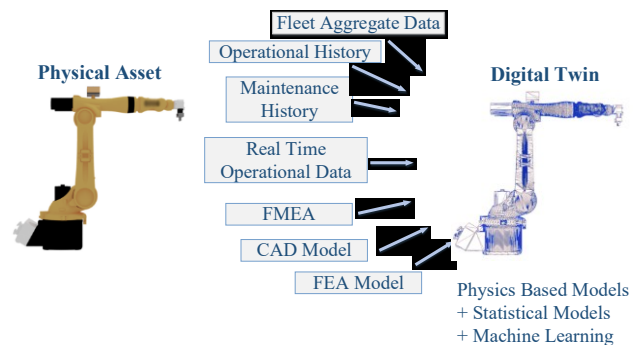


Fig. 4. Digital twin of a product as a physical object

Digital representations fall into three categories: *digital models* without automated data exchange, *digital shadows* with one-way data flow from physical to digital, and *digital twins* (Fig. 4) with fully integrated, bidirectional data exchange [3].

A digital twin is a virtual replica of a physical system, linked to its real-world counterpart. Initially used to mimic products (Fig. 4), it now extends to processes like manufacturing and production. By modeling real-world behavior, it enables data-driven decisions and real-time insights.

Augmented Reality technology further supports users by providing virtual data overlaid on their real-world environment, enhancing efficiency and sensory experience across various sectors [4].

The rapid growth of global data, driven by IoT and technology, has led to Big Data – complex datasets needing real-time analysis. Cloud computing is essential for processing this data, though it often exceeds current IT capacities. In industry, data boosts productivity, lowers costs, and adds value for businesses and consumers [5].

Integrating IoT, Big Data analytics, and AI into manufacturing is key to improving resource efficiency and overcoming under-digitization. An interdisciplinary curriculum is also vital to prepare future professionals with Industry 4.0 skills to tackle challenges in digitization, resource use, and sustainability [6].

### B. Transitioning from Industry 4.0 to Industry 5.0

While I4.0 emphasized automation and efficiency, I5.0 shifts focus towards integrating human intelligence with

advanced technologies. The transition is driven by several factors:

- *Human-Centric Innovation*: Unlike I4.0's techno-centric approach, I5.0 prioritizes human-machine collaboration, ethical AI, and user-centered automation.
- *Sustainability and Green Technologies*: I5.0 emphasizes environmental responsibility through renewable energy, e-waste reduction, and the adoption of the Green Internet of Things (G-IoT).
- *Resilience and Adaptability*: HEIs and industry must adopt agile frameworks to accommodate digital transformation while ensuring long-term sustainability and social well-being.

In education, the shift to I5.0 fosters digital literacy, innovation, and sustainability, requiring HEIs to integrate emerging technologies into curricula. However, this transition demands strategic investments in digital infrastructure, sustainable energy solutions, and bridging skill gaps in areas like AI, robotics, and green technologies. Furthermore, policies on e-learning, data security, and resource management are essential. Despite challenges, universities can harness I5.0 to enhance teaching, research, and collaboration, supporting a resilient, knowledge-driven, and sustainable future [7].

### III. EDUCATION 4.0 AND THE TRANSITION TOWARDS EDUCATION 5.0

Rapid technological advancements driven by I4.0 have transformed both industrial production and education. By integrating mechanical engineering, electronics, and software, I4.0 demands an educational shift toward interdisciplinary knowledge and practical skills. This need has led to the emergence of Education 4.0, focused on preparing professionals for the challenges of the fourth industrial revolution.

Educational paradigms have evolved with society and technology. *Education 1.0* focused on rote learning in agrarian societies, *Education 2.0* introduced standardized instruction for industrial needs, and *Education 3.0* embraced self-directed learning with digital resources. *Education 4.0* now delivers personalized learning experiences using AI, machine learning, and natural language processing to adapt to individual needs, moving beyond one-size-fits-all approaches.

#### A. Key Characteristics of Education 4.0

Education 4.0 has been built upon experience-based learning and the integration of digital technologies to deliver personalized, flexible, and student-centered education. Unlike traditional methods focused on memorization and uniformity, Education 4.0 emphasizes:

- *Personalized Learning*: Digital tools tailor content to individual needs and pace.
- *Mentorship over Instruction*: Teachers guide students in critical thinking, problem-solving, and digital skills.
- *Practical Application*: Knowledge is applied through virtual models and real-world projects.

- *Continuous Assessment*: Ongoing evaluations track progress comprehensively.
- *Technological Integration*: Advanced technologies like AI, Big Data, Cloud Computing, robotics, AR/VR, and IoT enrich learning.

Despite its benefits, Education 4.0 faces challenges such as resistance to change, social isolation, and high infrastructure demands.

#### B. Transitioning Towards Education 5.0

As technology advances, Education 4.0 is evolving into Education 5.0 – an approach aligned with Industry 5.0 and the needs of a globally connected society. Education 5.0 focuses on holistic learner development, combining values, skills, creativity, and technology. It builds on Education 4.0 by emphasizing adaptive learning, where AI personalizes content, pace, and assessments based on real-time feedback to optimize outcomes [8].

Core Pillars of Education 5.0:

- *Coherent and Relevant Curriculum*: Multidisciplinary, industry-aligned, and competency-focused.
- *Innovative Delivery and Assessment*: Hands-on learning, real-world problem-solving, and practical assessments.
- *Meaningful Learning Experience*: Activity-based, technology-supported, and industry-connected learning.
- *Transformative Learning*: Applied environments, smart classrooms, and immersive technologies.

Globalization, driven by ICT advancements, has positioned education as a crucial element in competitive, knowledge-based economies. Education 5.0 responds by developing professionals who can navigate global markets through lifelong learning and practical experience. While addressing modern needs, it faces challenges including inequality, job insecurity, and digital divides. Successful implementation requires careful planning to ensure equity and inclusivity, ultimately creating learning systems that mirror the flexibility and diversity of our interconnected world.

### IV. THE EVOLUTION OF HIGHER EDUCATION: FROM UNIVERSITY 4.0 TO UNIVERSITY 5.0

#### A. University 4.0: Digital Transformation in Higher Education

The development of higher education mirrors the stages of industrial revolutions, progressing through distinct phases: *University 1.0* established formal institutions, *University 2.0* advanced research-driven education, and *University 3.0* fostered entrepreneurship, innovation, and technology transfer. *University 4.0*, shaped by digital transformation, integrates AI, Cloud Computing, learning analytics, and personalized digital learning tools such as MOOCs (Massive Open Online Courses), mobile learning, flipped classrooms, gamification, and wearable technologies [9].

University 4.0 embraces technological advancement through flexible, continuous learning using digital platforms

## V. CONCLUSION

Industry 4.0 brought personalized, tech-driven production requiring Education 4.0 with digital integration. Industry 5.0 builds on this foundation by prioritizing human-centric innovation, sustainability, and resilience, requiring universities to adopt flexible approaches and develop graduates with both technical and ethical skills.

Universities face the challenge of creating sustainable business models that balance public and private dynamics. State-funded institutions depend on government support, while private universities must compete strategically. Transforming to meet global education demands and align with Industry 5.0 requires substantial resources and institutional mindset shifts.

The transition to Industry/Education/University 5.0 necessitates a holistic approach aligned with societal and environmental goals. While integrating these principles promotes sustainability, wellbeing, and innovation, success ultimately depends on universities effectively balancing technological advancement with human-centered development to become leaders in both innovation and sustainability.

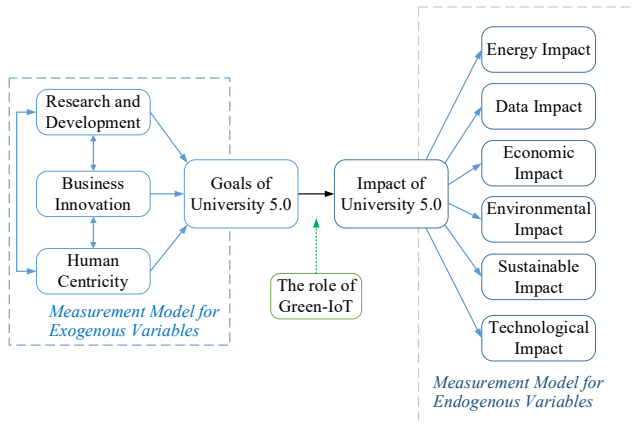


Fig. 5. Influence of Industry 5.0 on Higher Education

and virtual classrooms for personalized education. Universities function as innovation hubs aligned with Industry 4.0 to meet digital era demands.

### B. University 5.0: Socially and Digitally Engaged Institutions for Sustainable Futures

Building on the digital foundation of University 4.0, the concept of *University 5.0* introduces a more holistic and human-centric approach aligned with the EU Digital Strategy for a democratic, inclusive, and sustainable digital society. This model views universities not only as digital transformation leaders but also as key players in societal wellbeing, sustainability, and innovation ecosystems. The fundamental model (Fig. 5) shows the impact of Industry 5.0 on universities and their educational delivery [1].

University 5.0 is built on the concept of socially and digitally engaged universities, acting as hubs for social and digital transformation (SDT). Inspired by the Quintuple Helix Model, it integrates ecological, economic, social, and digital priorities into university missions, fostering transdisciplinary and public engagement [7].

Key pillars of University 5.0 include:

- **Sustainable Integration:** Aligning university strategies, curricula, and research with societal and environmental priorities, including the Sustainable Development Goals (SDGs).
- **Strong Academic Leadership:** Cultivating leaders who champion academic values and foster collaborative networks across sectors.
- **Green and Digital Culture:** Promoting digital and green literacy, interdisciplinary collaboration, and innovation through Fab Labs, Living Labs, and Digital Social Innovation (DSI) curricula.

University 5.0 also advocates for ethical and sustainable use of technologies, such as AI, and encourages responsible innovation, open science, and inclusive learning systems. By integrating green and digital transitions, universities contribute to innovation ecosystems that address global challenges, shaping a more human-centric, sustainable future.

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