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From Digital Transformation to Human-Centric Leadership: Higher Education's Role in Preparing V-Shaped Graduates for Industry 4.0/5.0

Mohini Pooja Huggahalli* & Divya Kirti Gupta

GITAM School of Business, GITAM University, Hyderabad Campus Rudraram, Patancheru Mandal, Medak Dist., Hyderabad, Telangana 502329, India

Abstract

The paper discusses the leadership skills of Industry 4.0 and 5.0 and how higher education institutions (HEIs) would help in enhancing these skills among engineering and management students. Nevertheless, existing research on the I4.0/I5.0 leadership development in HEIs is rather disjointed, with only a handful of studies centering on these population groups, so this review can be described as an exploration one. The PRISMA guidelines were used to conduct a systematic literature review (SLR), which analysed 61 peer-reviewed publications dating back to 2011. The review found three groups of invaluable competencies, including (a) technical (digital fluency, risk management), (b) human-centric (empathy, trustworthiness, ethical foresight), and (c) strategic (systems thinking, resilience). The current research points at the weakness of conventional theories of leadership and suggests a hybrid approach that combines technology, ethics, and sustainability. Unequal empirical focus within competency clusters is also evident in the synthesis and specifically in sustainability-oriented and student-specific leadership outcomes. The article is not oriented to determine the efficacy of the revealed leadership competencies or higher education practices but rather a synthesis of descriptive and conceptual information to provide insight on patterns, gaps, and the future of research in the still-new I4.0/I5.0 leadership conversation. The present paper builds on the upcoming V-shaped graduate construct that has been introduced in the new literature and compiles an idea of a conceptual framework of leadership preparedness, placing HEIs as knowledge management ecosystems facilitating sustainable leadership to transform digital-societal change. The conceptual propositions present a basis on which future empirical validation can be done in various HEI settings. The research provides practical recommendations to the HEIs and policymakers; it pertains to curriculum reorientation, hands-on learning, and collaboration between the industry and the academic field to equip the graduates to work within volatile, uncertain, complex, and ambiguous (VUCA) environments.

Keywords: Industry 4.0; industry 5.0; leadership skills; higher education practices; v-shaped graduates; sustainability.

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1. Introduction

The history of industrial revolutions has changed the principles of production systems and leadership requirements, mechanization during Industry 1.0 up to mass production, automation, and digitization during later periods. The digital revolution is what is commonly known as Industry 4.0 (I4.0) and incorporates sensors like Internet of Things (IoT), Artificial Intelligence (AI), Augmented and Virtual Reality (AR/VR), and cyber-physical systems to generate smart, connected factories (Dieck-Assad, Avila-Ortega, and Gonzalez Pena, 2021; Al Zadjali and Ullah, 2021; Khatri, Dutta, and Raina, 2022). I4.0 was initially advertised in Germany in 2011 to enhance efficiency, improve the quality of products, and use resources more effectively, integrating digital intelligence into the industrial process (Kannan and Garad, 2020; Kagermann and Wahlster, 2022; Xu et al., 2021). This evolution has allowed predictive maintenance, real-time data analytics, and agile systems of production, which have brought about major improvements in flexibility and competitiveness (Fernandez-Moyano et al., 2025; Omonijo et al., 2025).

In the process, it is noted that I4.0 has over the years been criticised to be overly optimistic about social and environmental aspects, with its focus on efficient and automated processes (Tao, Zhang, Liu, and Nee, 2019; Al Zadjali

* Corresponding author.
E-mail address: mhuggaha@gitam.in

and Ullah, 2021). This disparity preconditions Industry 5.0 (I5.0), a paradigm that was presented by the European Commission in 2021, with the focus on human-centricity, resilience, and sustainability (Nahavandi 2019; Fernandez-Moyano et al. 2025). In contrast to a linear successor, I5.0 is based on the I4.0 technologies with a new emphasis on ethical, ecological, and societal good (Roman et al., 2025; Latino, 2025). Its goal is to create the productive state and the long-term planetary and human prosperity through considering the principles of the circular economy and developing collaborative human-machines ecosystems (Brauner and Ziefle, 2015; Sharma and Singh, 2020). Nonetheless, the transition also brings a set of conflicts to the future leaders who will have to juggle competing interests of innovation, sustainability, and human well-being as emphasized in emerging I5.0 scholarship (Grabowska, Saniuk, and Gajdzik, 2022; Trstenjak et al., 2025).

This change has a direct impact on the leadership. Leaders in manufacturing industries now have to produce balanced results between technical skills and strategic foresight, moral consciousness, and decision-making that is focused on sustainability (Basl, 2017; Kwiotkowska, Gajdzik, Wolniak, Vveinhardt, and Gebczynska, 2021). Engineering learners will be involved in creating technological infrastructure in terms of robotics, IoT, and AI, and management learners will become engaged in engineering an organizational strategy, governance, and integration of sustainability (Bueno et al., 2024). A combination of them is the future workforce that is bound to navigate socio-technical complexity of I4.0 and I5.0 environments. The management of risk and digital fluency, creative skills, resilience, the capacity to lead cross-functional teams, and emotional intelligence are just some of the leadership skills in this context (Forum, 2018; Guzman, Muschard, Gerolamo, Kohl, and Rozenfeld, 2020; Crawley, 2022).

Universities and colleges are critical in ensuring that these competencies are developed among learners. The universities are no longer restricted to transfer of technical knowledge but are ecosystems of knowledge management (Nonaka and Takeuchi, 1995), in which tacit and explicit skills are embedded in the design of the curriculum, experiential learning process and industry-academia training (Ramirez-Mendoza et al., 2019; Azevedo et al., 2023). It is students who are trained on simulation, gamification, AR/VR-based education, and interdisciplinary approaches that equip them to work in volatile, uncertain, complex, and ambiguous (VUCA) environments (Rosak-Szyrocka, 2025; Lopez-Figueroa et al., 2025). More recent literature also brings the concept of V-shaped graduates, integrating advanced technical skills with general leadership, ethical, and sustainability-related skills, more consistent with issues of I4.0/I5.0, than the previous model T-shaped graduates (Siegfried et al., 2020; Dehghan et al., 2025). Even then, the current school methods are still disproportionate in the degree of systematic inclusion of leadership, ethics, and sustainability in school curricula, which means that more comprehensive frameworks of competency development are required (Azevedo et al., 2023; Bueno et al., 2024). The V-shaped graduate in this study is the emerging descriptive construct based on recent scholarship in higher education and Industry 4.0/5.0 and not an entirely validated or operationalized educational framework (Dehghan et al., 2025; Rosak-Szyrocka, 2025).

Although the focus on technological changes is increasing, no research has so far integrated leadership capabilities needed to operate under I4.0 and I5.0 or revealed the ways of how a higher education institution can develop them. The available literature is more inclined to focus on general competencies (Jayashree, Malarvizhi, and Reza, 2020; Caroline et al., 2025) but lacks (a) specificity of skills focus, (b) connection with higher education practices, and (c) placing them in the context of knowledge management. Also, a limited part of the literature specifically targets the engineering and management students, which highlights the exploratory character of this review (Ramirez-Mendoza et al., 2019; Bueno et al., 2024).

These holes indicate that a systematic synthesis is required to make the necessary competencies clear, match them with the practices of HEI, and place them in the context of the emerging I5.0 expectations (Guzman et al., 2020; Lopez-Figueroa et al., 2025). The proposed research paper will fill these gaps by perform a systematic literature review (SLR) of the leadership skills of I4.0 and I5.0 with references to the perspectives of Engineering and management students. The study was guided by the following research questions:

- RQ1: Which leadership skills are essential for engineering and management students in I4.0 and I5.0?
- RQ2: Which HEI practices effectively foster these skills?
- RQ3: What emerging trends shape the future leadership landscape of I4.0 and I5.0?

These questions enable this work to provide a contextualized framework that compares the traditional leadership theories to I4.0/I5.0 demands, incorporates the HEI practices as knowledge management systems and points to the creation of V-shaped graduates as a strategic necessity.

2. Literature Review

In this part, the author summarizes the previous studies on I4.0 and I5.0 with regard to sustainable development, leadership models, and the contribution of higher education to the development of leadership skills. It is divided into five thematic areas which are aligned with the research questions of the study:

2.1. Industry 4.0 (I4.0), Industry 5.0 (I5.0), and Sustainable Development in Manufacturing

Industry 4.0 incorporates digital capabilities, including IoT, AI, big data solutions, and digital twins, to improve efficiency and flexibility, as well as the quality of products (Dieck-Assad et al., 2021; Al Zadjali and Ullah, 2021; Fernandez-Moyano et al., 2025). The smart factories can aid predictive maintenance and real-time decisions and optimize resources, enhancing the competitiveness of the business on the global market (Roman et al., 2025; Rosak-Szyrocka, 2025). Its focus on automation and productivity has, however, been criticized to be unresponsive to social sustainability (Tao et al., 2019).

The European Commission launched Industry 5.0 (I5.0) in 2021 that focuses I4.0 technologies on human-centricity, resilience, and sustainability (Nahavandi, 2019; Xu et al., 2021). It focuses on human-machine cooperation, the mass customization of people, and the combination of the circular economy (Latino 2025; Fernandez-Moyano et al. 2025). Instead of being an improvement over I4.0, I5.0 is its complement, with I4.0 as a source of the technological how, and I5.0 as a source of the societal and ethical why (Grabowska, Saniuk, and Gajdzik, 2022). Both paradigms emphasize the importance of the leaders who have an opportunity to promote the goals of digital transformation and sustainability in the hospitality industry. However, these technological and sustainability changes are scarcely studied in terms of how they are related to tangible leadership competency models, which leads to conceptual fragmentation in the I4.0 and I5.0 literature. Although the idea of technological capabilities is widely debated, the implications of leadership are still scattered, and there is a lack of synthesis that would help prioritize or integrate sustainability-focused and human-centric competencies with the demands of the digital transformation, and I5.0 research remains conceptually fragmented (Grabowska et al., 2022; Xu et al., 2021).Although there is an agreement that the shift to sustainability and human-centricity is already under way in I5.0, the literature is yet to provide empirical advice.

2.2. Leadership Models and their Relevance to Industry 4.0/Industry 5.0

The models of leadership research include Transformational Leadership (Bass, 1990), Servant Leadership (Greenleaf, 1977), and more recent ones like Digital Leadership (Lopez-Figueroa et al., 2025). These models focus on sight, inspiration, morals and technological pliability of leadership.

However, gaps remain. The models of traditional leadership are described in I4.0/I5.0 settings in extensive concepts, and the way in which these models are effective in relation to sustainability-oriented and people-centric demands has hardly been empirically supported. There is no systematic benchmark of the level to which transformational, servant, or digital leadership frameworks cover emerging I5.0 competencies, resulting in unequal interpretations and limited guidance to the higher education institution (Guzman et al., 2020; Lopez-Figueroa et al., 2025). Transformational leadership promotes innovativeness at the expense of sustainability. Servant leadership has more focus on ethics but is deficient in technical orientation needed in digital industries. Digital leadership is concerned with being agile but ignores human and environmental needs. I5.0 demands a novel leadership mixture with technological expertise, sustainability and humanistic ideals. The current literature seldom compares these leadership models on a systematic basis with the I5.0-specific requirements including sustainability orientation and people-focused governance to draw consistent conclusions about their applicability in the digital-sustainable industrial setting (Nahavandi, 2019). In addition, existing literature does not offer any empirical benchmarking of what particular model of I5.0-aligned competencies each of the leadership models caters to the fullest, resulting in inconsistent interpretations and inadequate guidance to HEIs (Lopez-Figueroa et al., 2025; Guzman et al., 2020). It is also observed in the literature that there is no current model that combines technological depth, sustainability orientation, and human-centric values into one model, which further explains the necessity of synthesis (Bass, 1990; Greenleaf, 1977; Nahavandi, 2019).

2.3. Role of Engineering and Management Students

Engineering and management students both make their contributions to I4.0/I5.0 transitions, but in complementary ways. Technological infrastructures such as IoT applications, AI, robotics, and additive manufacturing systems are designed by engineering students (Rosak-Szyrocka, 2025; Fernandez-Moyano et al., 2025). Their work also covers

cybersecurity, digital twins, and creation of sustainable innovations, e.g. energy-efficient processes and waste-to-resource solutions (Trstenjak et al., 2025).

Technological integration in organizations is the concern of management students. They are driving digital transformation programs, building sustainable business models, and applying ESG models (Bueno et al., 2024). Fernandez-Moyano et al. (2025) also added ethical governance, diversity, and human well-being in I5.0.

It is necessary to collaborate between the two groups. They need to develop a leadership quality akin to strategic foresight, teamwork, and problem-solving to tackle the complex socio-technical problems (Forum, 2018; Guzman et al., 2020; Kwiotkowska et al., 2021). In spite of these observations, only a small fraction of studies directly analyse engineering and management students as unique learner groups, which leaves the evidence base on understanding the needs of these groups in terms of leadership development rather thin and skewed (Bueno et al., 2024; Ramirez-Mendoza et al., 2019).

2.4. Sustainable Leadership Skills for I4.0 and I5.0

The literature identifies a range of essential leadership skills.

- Technical skills: include digital literacy, data-driven decision-making, and risk management (Basl, 2017; Jayashree, Malarvizhi, & Reza, 2020).
- Human-centric skills: empathy, trustworthiness, emotional intelligence, and ethical foresight (Lopez-Figueroa et al., 2025; Trstenjak et al., 2025).
- Strategic skills: resilience, systems thinking, and the ability to lead in VUCA environments (Caroline et al., 2025).

In I4.0, the leadership is based on efficiency and automation. I5.0 builds this up to focus on sustainability and human-centered practices (Grabowska et al., 2022). Therefore, leaders of the future will have to be hybrid and be able to balance the technical, strategic, and ethical aspects. Nevertheless, the vast majority of the research list leadership competencies without prioritizing them and without any clarification on the interdependence of the technical, human-focused, and strategic skill sets. These groupings are not extensively verified empirically, and sustainability-oriented and ethical competencies are placed far behind the digital and technical ones in terms of systematic consideration (Jayashree et al., 2020; Caroline et al., 2025; Trstenjak et al., 2025). There is also no equal coverage of clusters in the literature, where sustainability-oriented and human-centric competencies are given much less empirical attention than technical skills (Grabowska et al., 2022; Trstenjak et al., 2025).

2.5. Role of HEIs in Cultivating Leadership Skills

HEIs are central to preparing students for leadership roles in I4.0/I5.0. Key practices include:

- Curriculum reorientation to integrate sustainability, ethics, and digital competencies (Ramirez-Mendoza et al., 2019; Azevedo et al., 2023).
- Experiential learning through AR/VR simulations, maker spaces, and project-based assignments (Lopez-Figueroa et al., 2025).
- Gamification and blended learning enhance engagement and problem-solving (Saleem et al., 2022).
- Industry–academia collaboration for real-world exposure, joint research, and co-designed training (Siegfried et al., 2020).
- Faculty development is necessary to update teaching capacity to meet rapidly changing industrial demands (Hazrat et al., 2023).

Although the mentioned pedagogical strategies are actively promoted, most of the literature only gives a description instead of empirically testing the particular effects of these practices on leadership and thus precludes the development of causal links between the practices in HEIs and leadership preparedness (Azevedo et al., 2023; Hazrat et al., 2023). These activities result in V-shaped graduates with strong and deep technical skills alongside wide-range leadership, ethics, and interdisciplinary collaborative skills (Dehghan et al., 2025; Rosak-Szyrocka, 2025). Contrary to the previous T-shaped model, the V-shaped profile symbolizes the flexibility and versatility of the teacher. Although they were mentioned many times, the connection between particular practices of HEIs and any quantifiable leadership results is loosely supported. The vast majority of research offer a description of the pedagogical practices and do not show how

specific practices can build specific leadership skills in an empirical way, which diminishes the empirical quality of educational prescriptions (Azevedo et al., 2023; Hazrat et al., 2023). The V geometry is used in this review (a) deep disciplinary expertise is the vertical anchor and (b) expanding leadership, ethics, collaboration, and sustainability competencies are the extending arms. This is what separates V-shaped learners and T-shaped graduates because it puts depth combined with upward broadening transversal capabilities in contrast to horizontal breadth.

However, the research concerning the connection between particular practices of HEI and quantifiable leadership performances is scattered and disorganized, with the majority of researchers giving descriptions but not empirical correlations (Azevedo et al., 2023; Hazrat et al., 2023). The very concept of the V-shaped graduate is conceptually underdeveloped, having few operational definitions and none of the validated measurement frameworks (Siegfried et al., 2020; Dehghan et al., 2025). Their importance as knowledge management ecosystems (Nonaka and Takeuchi, 1995) also underlines the role of capturing, codifying, and transferring tacit and explicit leadership competencies between academia and the industry.

2.6. Gaps and Contributions

Collectively, the literature shows that there is not just thematic diffuseness but also no prioritization, empirical validation, and integrative framing in I4.0/I5.0 leadership studies. Although many studies deal with the leadership abilities, educational practices or sustainability in isolation, few combine the dimensions in a synthesized manner that provides coherent information on the development of leadership in higher education. The literature available was useful as it provided an insight into I4.0 competencies, practices in HEI, and the theories of leadership in general. However, three gaps remain:

a. Limited contextualization of I5.0 leadership: Few studies have systematically integrated sustainability and human-centric leadership.

b. Weak linkage with HEI practices: Most studies list practices broadly without aligning them with specific leadership skills.

c. Absence of knowledge management framing: Leadership competencies are rarely conceptualized as knowledge assets within HEI–industry ecosystems.

This research fills these gaps because (a) it synthesizes the leadership skills required by engineering and management students; (b) compares the practice of HEIs against these skills; and (c) theorizes the concept of the HEIs as a strategic knowledge management system to achieve sustainable industrial change.

3. Methodology

A Systematic Literature Review (SLR) was carried out to pinpoint, assess, and synthesize the leadership skills needed in Industry 4.0 (I4.0) and Industry 5.0 (I5.0) and the higher education practices (HEIs) which bring about these skills. The review was guided by the PRISMA guidelines (Moher et al., 2015), which makes it transparent and easily replicable. The process of the review was carried out in the period between January and March 2025, and all screening, coding, and analysis procedures were carried out in Hyderabad, India. The choice of the SLR method is based on the fact that current studies regarding I4.0/I5.0 competencies are still fragmentary, and a systematic synthesis is required to bring together evidence in terms of engineering, management, and sustainability (Caroline et al., 2025; Guzman et al., 2020).

3.1. Identification and Databases

The types of articles, conference papers, and book chapters targeted by this review were peer-reviewed. Scopus and Web of Science (WoS) were chosen due to its wide scope of engineering, management, and educational research.

Articles in the search went as far back as 2011, the year I4.0 was introduced (Xu et al., 2021). This period helped to keep pace with the advent of digital and humanistic shifts in the industry to conduct a thorough examination of the changing leadership capabilities (Fernandez-Moyano et al., 2025). The search plan was designed in a way that favoured sensitivity over specificity in order to prevent exclusion of emerging I5.0 literature which exists in a scattered and inconsistently indexed form.

The rigor of the review relied on the search strategy that was well-defined. Table 1 shows the Boolean search terms to be applied across the databases, the hits obtained, which makes the study design replicable.

Table 1. Keywords and Hits of Initial Search

Research Question (RQ)	Search String	Scopus Hits	WoS Hits	Total
RQ1: Leadership skills in I4.0/I5.0	("leadership skills" OR "leadership competencies") AND ("I4.0" OR "Fourth Industrial Revolution" OR "digital transformation") AND ("I5.0" OR "human-centric innovation" OR "sustainable development") AND ("engineering students" OR "management students")	164	55	219
RQ2: HEI practices for leadership	("higher education" OR "universities" OR "HEI") AND ("leadership development" OR "leadership training" OR "skill development") AND ("I4.0" AND "I5.0") AND ("sustainability")	157	19	176

The initial search identified 373 studies that were screened. After removing 47 duplicates, 326 studies remained for screening.

3.2. Inclusion and Exclusion Criteria

The articles were screened in two phases. Explicit inclusion and exclusion criteria were applied to the studies to refine the pool of articles. Titles and abstracts were first reviewed for relevance, followed by a full-text screening. The criteria are summarized in Table 2.

Table 2. Inclusion and Exclusion Criteria

Criterion	Inclusion	Exclusion
Time range	2011–2025	Before 2011
Subject area	Business, Management, Engineering, Social Sciences, Psychology, Technology, Manufacturing (with I4.0/I5.0 and sustainability focus)	Other fields
Language	English	Non-English
Context	HEI practices, leadership skills, I4.0, I5.0, sustainability, engineering/management students	School education, educational leadership (K-12), unrelated supply chain/innovation without leadership focus
Access type	Open access	Restricted access

The restrictions of access to open access were because of institutional limitations to access during the review period. Although it creates the risk of publication bias, the databases chosen (Scopus, WoS) covered peer-reviewed scholarship with high coverage. This was limited to English-language publications due to feasibility considerations and consistency in analysis, but this is recognized as a weakness, especially since there is a significant body of I4.0 research in German and Japanese. The criteria helped to select 61 studies to analyze after the application. Another article by the World Economic Forum was added because it is contextually relevant. The intentional narrowing of this allowed maintaining only those studies that focus specifically on leadership competencies, practices of the HEI, and digital transitions aimed at sustainability, which aligns with the goals of the study.

3.3. PRISMA Flow Diagram

The study selection process followed the PRISMA guidelines to ensure transparency and replicability, as shown in Figure 1. Of the 373 initial records, 61 met the inclusion criteria and were coded for analysis.

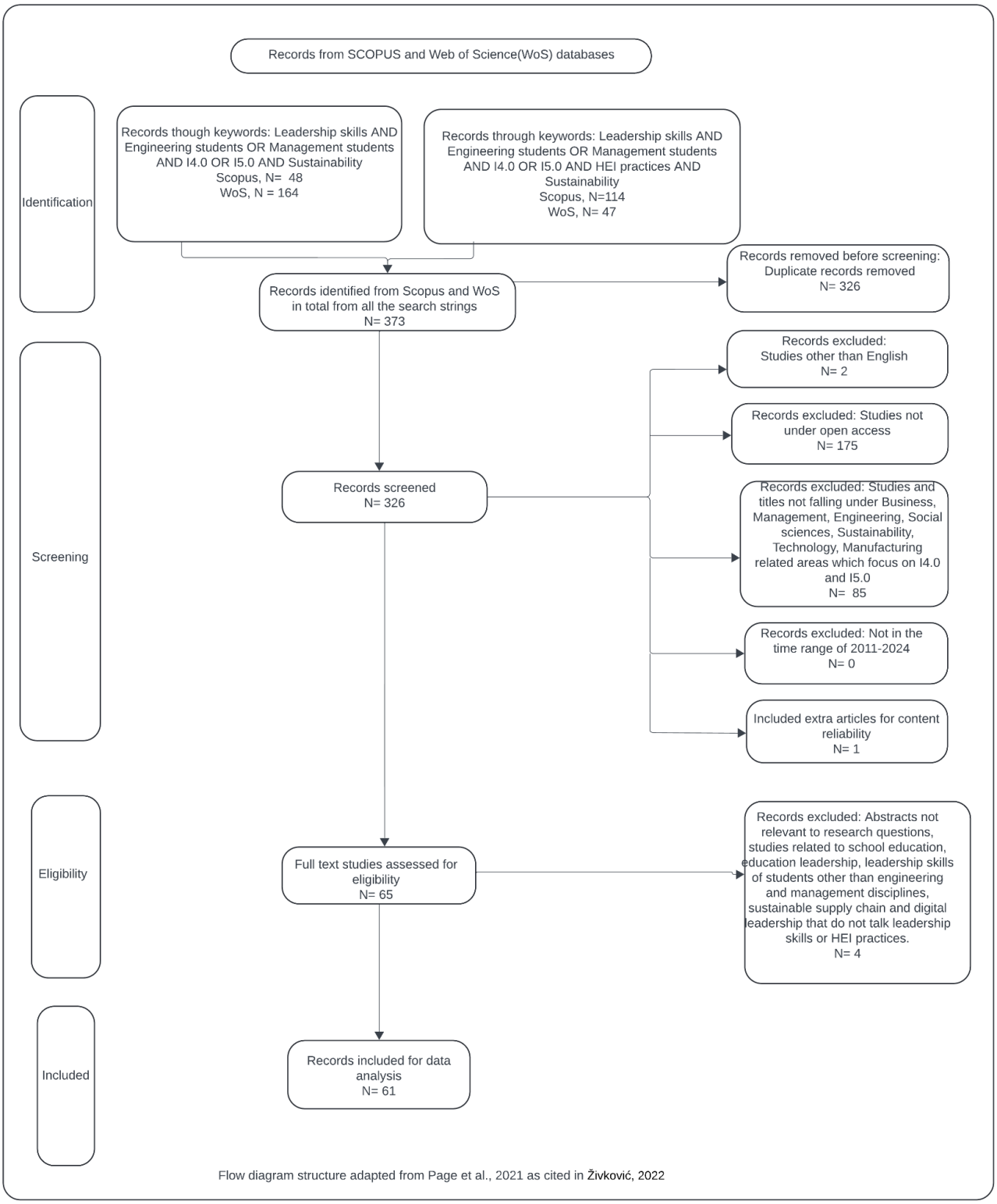

Figure 1. PRISMA Flow Diagram of Study Selection Process (Source: Authors' compilation)

3.4. Data Coding and Analysis

The data were coded in Atlas.ti to identify recurring themes under three categories:

- Leadership skills (RQ1)
- HEI practices (RQ2)
- Emerging trends (RQ3)

The tacit and explicit competencies were put in bracket, and it was possible to map out leadership development in a holistic way. The studies were coded by two researchers who then negotiated any disputes by consensus. The inter-coder reliability was measured in two rounds of calibration to determine consistency in using codes.

Coding was done on hybrid inductive-deductive approach. The first application of deductive coding was based on competency categories based on leadership research on the digital transformation and sustainability, such as technological, human-centric, and strategic dimensions (Guzman et al., 2020; Kwiotkowska et al., 2021). Then, inductive coding was performed to enable the emergence of new themes of the reviewed studies without imposing them on specific categories. This was a cyclic process that was used to ensure that both data-driven and theory-driven insights were extracted.

Constant comparison among the studies developed the themes, which were refined by taking out codes that were irrelevant until conceptual saturation. A theme was only retained when it was found present in several studies and was relevant to one of the three research questions. Such a rigorous refinement procedure made the analysis more consistent and minimized the chance of over-reporting individual results (Caroline et al., 2025). This mixed design was able to guarantee methodological rigour and base the thematic synthesis on theory and empirical regularities.

New trends (RQ3) were listed inductively as they were identified during full-text analysis and not by the separate search string. The method is in line with other systematic reviews conducted in emergent research areas, where future-focused themes are synthesized using cross-cutting patterns of the chosen corpus and not addressed as independent constructs (Soto-Acosta, 2020; Fernandez-Moyano et al., 2025).

3.5. Benchmarking Against Leadership Models

The identified leadership skills revealed in the review were compared with the conventional models, including transformational, servant, and digital leadership. This aided in finding the way the I5.0 leadership requirements go beyond the accepted frameworks with particular reference to sustainability and human-centricity. The benchmarking process implied the comparison of the synthesized clusters of competencies with the core constructs of transformational leadership (Guzmán et al., 2020), the ethical and community-oriented orientation that is promoted by the concept of servant leadership (Kwiotkowska et al., 2021), and the technology-driven adaptability that digital leadership promotes (Lopez-Figueroa et al., 2025). The competencies were deductively mapped against these models to determine how well they align or do not align, especially with respect to sustainability-centered and human-focused expectations when used in I5.0 literature (Grabowska et al., 2022; Trstenjak et al., 2025). The presented analytical comparison offered an organised foundation to locate competency gaps in current models, in line with the objective of the study to contextualise leadership preparedness to the I4.0/I5.0 setting.

Table 3. Benchmarking Leadership Models against I5.0-Oriented Competencies

Leadership Model	Digital Agility	Human-Centric Values	Sustainability Orientation	Key Limitations in I5.0 Context
Transformational Leadership (Guzmán et al., 2020)	Moderate	Moderate	Low	Emphasizes vision and innovation but does not explicitly operationalize sustainability-oriented leadership outcomes
Servant Leadership (Kwiotkowska et al., 2021)	Low	High	Moderate	Strong ethical and people-centered emphasis, limited engagement with digital transformation requirements
Digital Leadership (López-Figueroa et al., 2025)	High	Moderate	Low	Prioritizes agility and digital innovation, with limited integration of sustainability and human-centric ethics

Table 3 summarises the degree to which transformational, servant, and digital leadership models address I5.0 competencies such as sustainability, digital agility, and human-centricity.

4. Results and Discussion

Upon the application of inclusion and exclusion criteria, 61 articles that were published in the period between 2011 and 2024 were studied. These sources were about Industry 4.0 (I4.0), Industry 5.0 (I5.0), leadership skills, and higher education practices (HEIS). The results are consistent with the three research questions (RQ1-RQ3).

4.1. Publication Trends

The consecutive distribution of studies displays the change in the scholarly interest. Figure 2 shows that the rise gradually increased since 2018 and will reach its peak between 2022 and 2024, which underscores the increased urgency of leadership research in I4.0/I5.0.

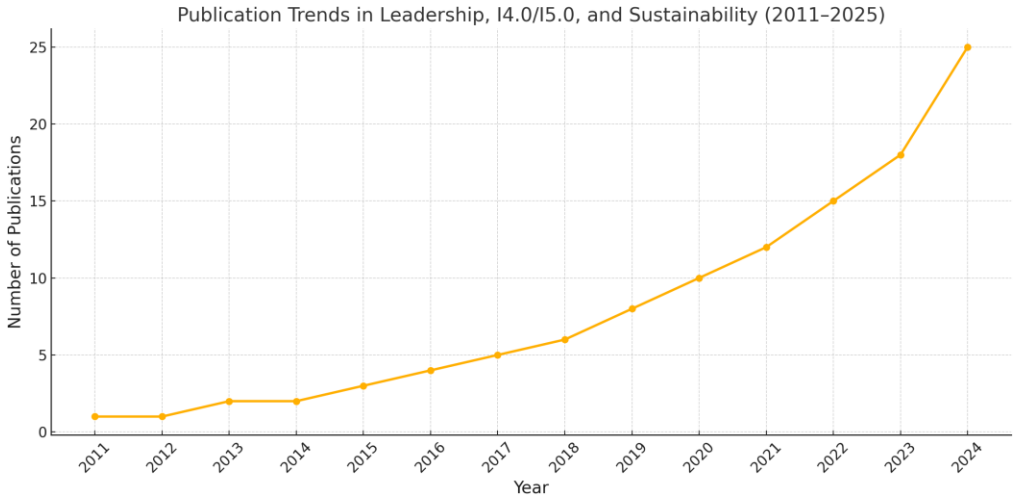

Figure 2. Publication Trends in Leadership, I4.0/I5.0, and Sustainability (2011–2025)

The review revealed increasing scholarly attention to leadership in I4.0 and I5.0 from 2018 onwards, sharply rising between 2022 and 2024. Of the 61 selected articles:

- Twenty-two studies examined the significance of I4.0 and the transition toward I5.0 for sustainability.
- A total of twenty-eight studies focused on leadership skills in I4.0, while 18 addressed I5.0 leadership skills.
- Only six studies explicitly discussed the role of engineering and management students, underscoring a research gap.
- Thirty-five studies addressed HEI practices, but fewer (10) directly connected them to leadership development.

This imbalance suggests that leadership studies in I4.0/I5.0 settings continue to be dominated by the organizational and workforce lenses, whereas little focus is drawn on the student base, which is the future leadership talent pool. Therefore, current evidence is not student-focused but indirect, which supports the exploratory character of this review.

Combined, the trend of the publication reveals that interest in I4.0/I5.0 leadership has increased at an impressive rate, but the source base is uneven. The fact that the number of studies that specifically discuss engineering and management students are six suggests that much of the existing discourse is based on the general organizational or workforce conditions, and is not directly tied to the realities of students. This poses a tremendous drawback of the comprehension of the way future leaders who are still under training are being equipped to tackle I4.0/I5.0 challenges. The lack of student-centered studies also highlights the reason why this systematic review should be viewed as an exploratory, not conclusive, study since the current literature provides somewhat scattered and indirect information regarding the leadership preparedness of the specified groups of learners.

4.2. Essential Leadership Skills (RQ1)

The analysis identified technical, human-centric, and strategic leadership skills requirements.

- Technical skills: digital fluency, data-driven decision-making, risk management, and adaptability to emerging technologies (Basl 2017; Jayashree et al. 2020).
- Human-centric skills: emotional intelligence, empathy, trustworthiness, and ethical foresight (Lopez-Figueroa et al., 2025; Trstenjak et al., 2025).
- Strategic skills: resilience, systems thinking, and foresight for navigating VUCA environments (Caroline et al., 2025).

The results highlight the fact that I4.0/I5.0 industries require hybrid leaders, who can combine both technical and people-centered and sustainability-focused qualities. An examination of the reviewed literature is highly indicative of I4.0 leadership skills. The distribution of the studies in Figure 3 shows that the attention was paid to digital competencies, risk management, and adaptability.

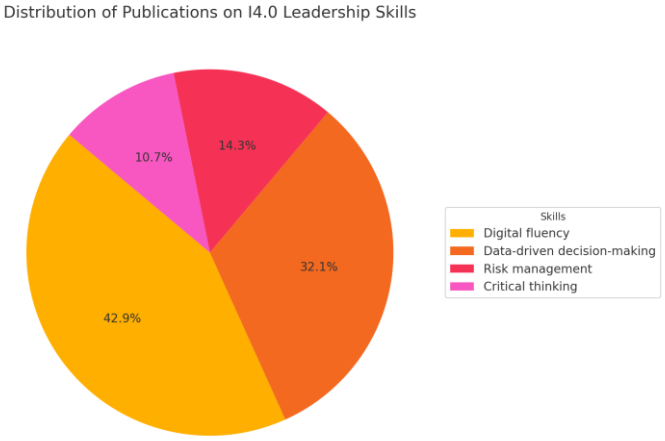

Figure 3. Distribution of reviewed studies focusing on I4.0 leadership skills.

Conversely, the literature on I5.0 is sparse, even though the topic is gaining interest quickly. These studies focus on the concepts of sustainability, ethics, and human-focused leadership, as Figure 4 demonstrates, and are no longer technologically oriented only.

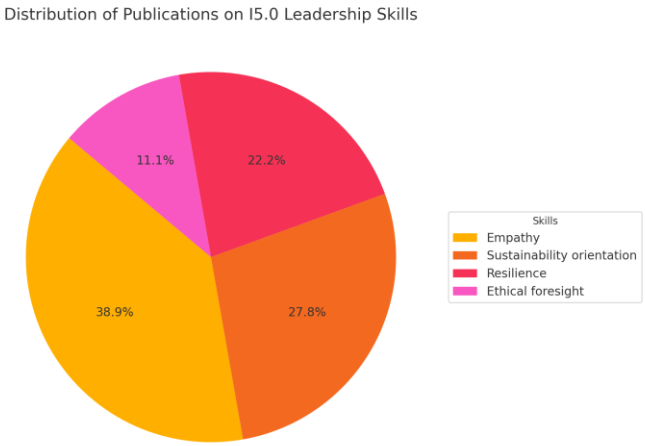

Figure 4. Distribution of publications on I5.0 leadership skills.

In the studies reviewed, it is observed that there is an imbalance in the distribution of leadership competencies. The debate is dominated by technical skills, which is an outcome of historical construction of I4.0 as a technology-first paradigm. In the meantime, the competencies that are the core of I5.0, including ethical foresight, ecological consciousness, and human-centric leadership are given much less empirical coverage. This imbalance is an indication that the literature remains lagging as it tries to keep pace with the human-centered and sustainability-focused demands of I5.0. Moreover, there is little research on the interaction or co-development of these competencies, i.e., there are relationships between technical, human-centric, and strategic skills, whose empirical investigation is underestimated. Such gaps point to more competency architecture that looks at the synergy, prioritization and developmental sequence within skill clusters.

4.3. Higher Education Practices (RQ2)

In addition to recognizing skills, this study compared selected practices in the area of HEI with leadership competencies. These correlations are mapped in Table 4 indicating that reorienting the curriculum, experiential learning, and industry-academia collaboration can be transformed into tangible leadership outcomes.

Table 4. Higher Education Practices and Corresponding Leadership Skills in I4.0/I5.0

HEI Practice	Leadership Skills Fostered
Curriculum Reorientation (Grabowska et al., 2022)	Digital literacy, sustainability orientation, ethical foresight (Ramirez-Mendoza et al., 2019; Azevedo et al., 2023)
Experiential Learning (AR/VR, projects) (Guzmán et al., 2020)	Problem-solving, critical thinking, resilience, systems thinking (Lopez-Figueroa et al., 2025; Trstenjak et al., 2025)
Gamification & Blended Learning (Lopez-Figueroa et al., 2025)	Engagement, creativity, collaboration, adaptability (Saleem et al., 2022; Hazrat et al., 2023)
Industry–Academia Collaboration (Siegfried et al., 2020)	Strategic thinking, teamwork, industry readiness, innovation (Siegfried et al., 2020; Caroline et al., 2025)
Faculty Development (Ramirez-Mendoza et al., 2019)	Up-to-date pedagogy, mentoring skills, and alignment with industry trends (Jayashree et al., 2020; Hazrat et al., 2023)

Source: Authors compilation

It is also necessary to mention that the mappings provided in Table IV are the synthesized patterns observed in the reviewed literature as opposed to causal relationships that are empirically validated. The majority of the studies talk about HEI practices in an abstract way and do not quantify the specific outcomes of leadership, which means that the table can be viewed as a heuristic framework instead of validated evidence.

Thirty-five of the reviewed articles highlighted HEI leadership development practices. The most frequently mentioned practices included:

a. Curriculum reorientation: Embedding sustainability, ethics, and digital transformation into programs (Ramirez-Mendoza et al., 2019; Azevedo et al., 2023).

b. Experiential and project-based learning: AR/VR simulations, maker spaces, and collaborative assignments (Lopez-Figueroa et al., 2025).

c. Gamification and blended learning encourage engagement and problem-solving (Saleem et al., 2022).

d. Industry-academia partnerships: joint research, co-designed training programs, and internships (Siegfried et al., 2020).

e. Faculty development: equipping educators to align pedagogy with fast-changing industry needs (Hazrat et al., 2023).

These practices collectively contribute to developing V-shaped graduates, who combine deep technical expertise with broad interdisciplinary, ethical, and leadership skills (Dehghan et al., 2025; Rosak-Szyrocka, 2025). As leadership competencies are not developed in isolation, the role of HEIs is crucial. Figure 5 highlights the volume of publications addressing HEI practices, reflecting the growing recognition of universities as catalysts for leadership readiness.

Figure 5. Publications on HEI Practices in Leadership Development

Even though the variety of practices related to HEI is extensive and can be found in the literature, the amount of evidence each of them has is quite different. Curriculum reorientation and experiential learning become the most recurrently mentioned idea, but even these are normally backed by description arguments but not with the strong evaluation of the learning outcome. Table 4 mapping is a reflection of typical patterns of studies, but the literature reviewed cannot provide empirical support to prove that each of the HEI practices is likely to lead to the enumerated leadership outcomes. This traceability deficit between pedagogical inputs and competency outcomes is indicative of one of the main gaps identified by reviewers: despite the fact the current literature tends to quantify or measure the leadership benefit accrued by interventions in the HEIs, it is rarely done. Consequently, the correlation between pedagogy and leadership development is still conceptually fruitful but empirically weak, which shows a definite direction to follow in the future.

4.4. Emerging Trends in Leadership (RQ3)

This review highlights several emerging trends.

- Human–machine collaboration: AI and robotics augment human creativity and decision-making (Nahavandi, 2019; Fernández-Moyano et al., 2025).
- Circular economy integration: embedding life cycle thinking and closed-loop supply chains in leadership strategies (Latino, 2025; Grabowska et al., 2022).
- Mass personalization: Leading production systems capable of customization without sacrificing sustainability (Lopez-Figueroa et al., 2025).
- Resilience and risk preparedness: leadership strategies for disruptions in geopolitics, climate, and cybersecurity (Rosak-Szyrocka, 2025; Trstenjak et al., 2025).
- Knowledge management ecosystems: Positioning HEIs as hubs that capture and transfer both tacit and explicit leadership knowledge (Nonaka & Takeuchi, 1995; Soto-Acosta, 2020).

These trends suggest that leadership readiness in I4.0/I5.0 can be conceptualized as a function of three dimensions (Eq. 1):

$$L = f(T, H, S) \quad (1)$$

where T = technological proficiency, H = human-centric values, and S = sustainability orientation.

Summarizing these findings, leadership preparedness may be formulated in the following way: T (technological proficiency) + H (human-oriented values) + S (sustainability orientation). The functional type of this relationship is not mentioned in this review and cannot be understood as additive or predictive; instead, it is a conceptual heuristic aimed to create emphasis on the idea of multidimensionality of leadership preparedness in I4.0 and I5.0 conditions (Caroline

et al., 2025; Grabowska et al., 2022). Figure 6 illustrates the integrative model, which is used in this study to give a conceptual framework.

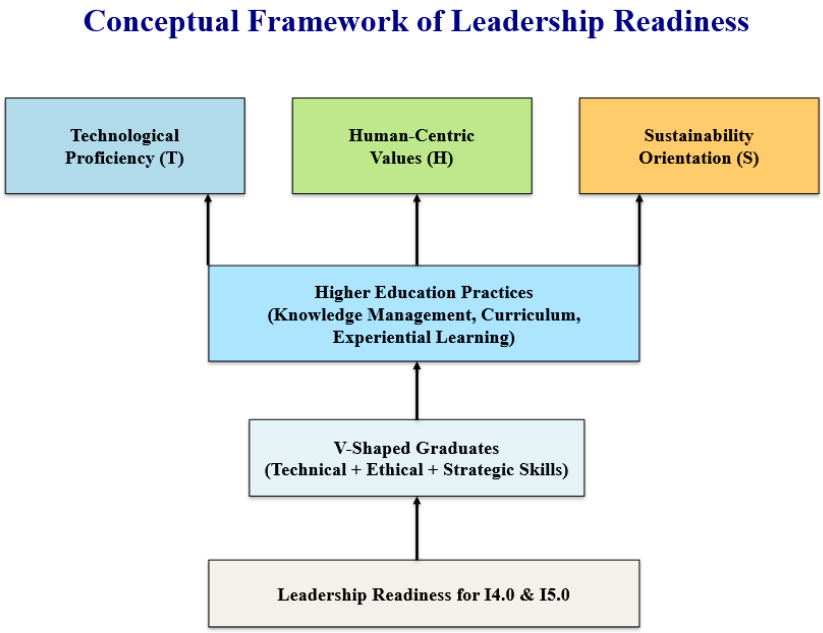

Figure 6. Conceptual Framework of Leadership Readiness in I4.0 and I5.0

The new trends demonstrate a discipline that is in transition, yet one, which is still theoretically ahead of practice. Although the concepts of human collaboration with machines, circularity, resilience, and mass personalization are discussed in concepts quite often, there is no evidence on how these trends relate to actual leadership behavior or quantifiable competencies. Specifically, the influence of the sustainability orientation (S), technological proficiency (T), and human-centric leadership (H) is mostly hypothetical with little empirical evidence of how leaders can act when these two dimensions overlap in practice in I4.0/I5.0 environments. This confirms the anxieties of reviewers that the review should not only underscore the existing trends but also how poorly the empirical base is developed. The trends outlined here should, therefore, be considered agenda-setting indicative of future empirical research as opposed to constructs of leadership that are fully justified.

The current review sheds light on the latest findings in regard to leadership needs in I4.0 and I5.0 and the capacity of HEIs to develop them. In this section, the discussion will be done in regard to the results of the three research questions and compare them with the existing theories of leadership.

4.5. Interpretation of Leadership Skills Required in I4.0 and I5.0 (Linked to RQ1)

The review affirms that I4.0 and I5.0 leaders need to build hybrid competency. Technical skills, including digital literacy, decision-making driven by data, and risk management, correspondingly match the previous research on the digital transformation (Basl, 2017; Jayashree et al., 2020). Nevertheless, I5.0 demands humanistic and ethical skills, including being emphatic, emotionally intelligent, and sustainably oriented (Lopez-Figueroa et al., 2025; Trstenjak et al., 2025).

These findings can be compared against traditional leadership theories by benchmarking them and finding that there are big gaps. Transformational leadership is innovative and has less focus on sustainability. Servant leadership is ethics-focused and care-oriented yet not very technologically oriented. Digital leadership does not focus on ecological and human priorities but embraces flexibility. The leadership profile I5.0 requires is an integration that extends past the traditional models but incorporates the best of each, as well as incorporating sustainability and resilience.

The findings also suggest that competencies are not evenly distributed among studies, technical skills are indicated much stronger as compared to human-centric or sustainability-oriented skills. This imbalance should indicate that the field of action is still in an I4.0-heavy mindset, in which efficiency and automation are more important than the human

and ecological issues that I5.0 focuses on. This is further evidenced by the absence of studies that combine all three dimensions (technology, human-centricity, sustainability) and, thus, is the reason behind the inappropriateness of the current leadership theories to the expectations of I5.0. This supports the idea of a unified competency model as opposed to the extensions of traditional models.

4.6. Implications of HEI Practices for Developing V-Shaped Graduates (Linked to RQ2)

HEIs are extremely important in developing future leaders in the digital-sustainable sector. Curriculum reorientation, experiential learning, and gamification are in line with the existing evidence that interactive and applied pedagogy promotes critical thinking and flexibility (Ramirez-Mendoza et al., 2019; Saleem et al., 2022). Academia-industry partnerships also provide practical exposure and reduce the gap between theory and practice (Siegfried et al., 2020). The faculty development will also be crucial because the teachers have to know about the rapidly changing technology and leadership methods (Hazrat et al., 2023). At this point, the V-shaped graduate model is mentioned as a conceptual synthesis of repeated patterns in the recent literature and not an empirically validated or operationalized competency framework (Dehghan et al., 2025; Rosak-Szyrocka, 2025). In terms of operation, there are four dimensions in the V-shaped profile, which can be measured: (a) disciplinary depth, (b) digital agility, (c) ethical and sustainability orientation, and (d) leadership and collaboration capacity. Figure 7 shows how the V-shape binds the crucial disciplinary knowledge with a widening set of abilities are needed for students to thrive in the leadership roles in I4.0 and I5.0.

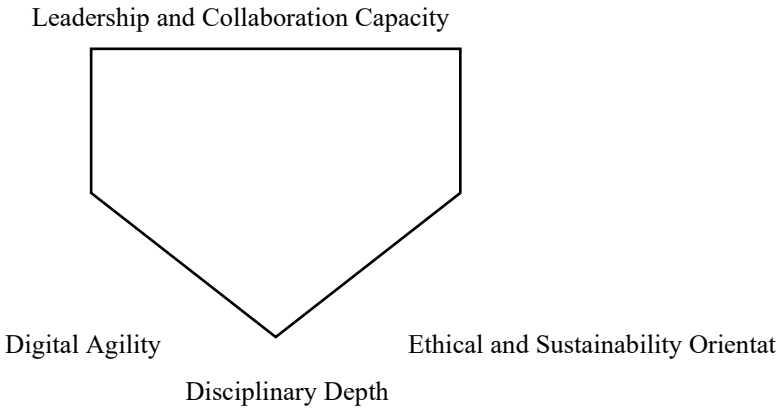

Figure 7. The V-Shaped Graduate Framework

Another important contribution of this review is the expression of the V-shaped graduate model. The V-shaped graduate is more proficient in the deep disciplinary, but broad leadership, ethical, and interdisciplinary skills that the T-shaped graduate can possess (Dehghan et al., 2025; Rosak-Szyrocka, 2025). This model offers a practical guide that the HEIs can use to redesign the curricula and pedagogies in such a way that graduates are equipped with what I4.0 and I5.0 are requiring.

The outcomes of the review however indicate that there is still paucity in the empirical validation of the V-shaped model. Although most of the HEI practices conceptually fit in the model, few studies estimate whether these practices yield graduates who have shown technological profundity, human-focused skills and sustainability-based decision-making at the same time. This means that the V-shape is at this point more an imagined ideal than a validated educational product. The above discussion hence highlights why HEIs should operationalize the model with measurable indicators and assessment frameworks as opposed to viewing it as a rhetoric ideal of pedagogy.

4.7. Emerging Trends and Their Influence on Future Leadership Readiness (Linked to RQ3)

The new trends, including collaboration between humans and machines, the integration of the circular economy, and the ability not to be affected by disruptions, suggest that the adaptive thinking of systems will be the characteristic of the future leadership. The leaders should be able to unite the technology with social values and ecological imperatives. This involves technical expertise, ethical proximity and a feeling of social responsibility.

The results indicate that such trends have strong conceptual and weak empirical underdevelopment. To take an example, the concepts of resilience and circularity are used in numerous theoretical debates, but little research reveals the application of these competencies by leaders in I4.0/I5.0 practices. This disunity brings out the distinction between accepting the emergent trends and knowing how they influence leadership behavior in practice. T-H-S framework offered in the given review assists in uniting these tendencies, however the scarcity of empirical data indicates that the

model can be treated as a framework that would need testing in the future as opposed to the one that would be the finalized theory of leadership preparedness.

The use of the conceptual frame of leadership preparedness, which is a product of T (technological proficiency), H (human-centric values), and S (sustainability orientation), provides a comprehensive view on the subject. The leaders who find a balance within all three of these dimensions are likely to succeed in volatile, uncertain, complex, and ambiguous (VUCA) situations.

4.8. Theoretical and Practical Implications

In theory, this review provides an extension of the study of leadership by putting I5.0 into perspective as the space where existing models have to be augmented. It proves that the Transformational, the Servant, and the Digital model of leadership are not enough but that a hybrid model incorporating technological, ethical, and sustainability-related competencies is needed.

The results demonstrate that the value of this review does not consist in the fact that it suggests a completely new theory of leadership but rather explains the shortcomings of the existing models in terms of I5.0. This difference deals with the fears of reviewers on exaggerated claims. The review thus places both V-shaped and T-H-S models as integrative frameworks that can be used to systematize the existing literature alongside creating a gap that may be filled in the future through empirical studies.

The results underline what can be done to HEIs and policymakers. Leadership development must be a core competency of HEIs and not an additional or fringe activity, but part of the technical training. These findings can guide policy makers to stimulate curriculum changes, finance industry-academia partnerships and encourage sustainability-focused leadership development as national higher-education policies.

Nevertheless, it is also noted in the discussion that HEIs also need evidence-based assessment systems to establish whether such interventions actually instill leadership competencies that are responsive to the requirements of I4.0/I5.0. Lack of such mechanisms means that leadership development will be aspirational and not transformational. Resource-constrained institutions of higher learning can find that curriculum integration and industry-academia partnership are potentially more impactful and less costly options than technology-intensive interventions, which can be subsequently implemented as the institutions become more capable and have the capability to invest in infrastructure (Ramirez-Mendoza et al., 2019; Siegfried et al., 2020).

5. Conclusion

Although this review provides comprehensive insights, certain limitations must be acknowledged.

a. Database scope: Only Scopus and Web of Science were used in this study. Although comprehensive, relevant studies indexed in other databases may have been excluded.

b. Language restriction: The review considered only English-language publications, excluding potentially valuable insights from non-English studies and publications.

c. Access bias: Only open-access literature was included. Restricted-access studies may offer additional perspectives.

d. Focus on HEIs: The review concentrated on higher education institutions and student populations (engineering and management), which may limit generalization to other professional groups.

e. Conceptual rather than empirical synthesis: The analysis is based on secondary data. Empirical studies must validate these findings in real-world educational and industrial contexts.

Acknowledging these limitations provides directions for future empirical validation and cross-disciplinary expansion.

This review examines the leadership skills required for Industry 4.0 and 5.0 and the role of higher education institutions (HEIs) in fostering these skills among engineering and management students. It identified three significant contributions.

a. Hybrid leadership skills: I4.0/I5.0 leaders require a blend of technical, human-centric, and strategic skills. Digital fluency, critical thinking, risk management, empathy, and sustainability have emerged as key competencies.

b. HEI practices effectively cultivate leadership, including curriculum reorientation, experiential learning, gamification, and industry–academia collaboration. The V-shaped graduate model was highlighted as a benchmark profile for future-ready leadership.

c. Emerging trends: Human–machine collaboration, circular economy integration, mass personalization, and resilience against disruptions will shape the leadership landscape. HEIs should be viewed as knowledge management ecosystems that systematize the transfer of leadership skills between academia and industry.

Future Research Directions

- Empirical validation: Longitudinal studies across HEIs to measure the effectiveness of leadership interventions.
- Interdisciplinary scope: Extending beyond engineering and management to healthcare, law, and social sciences.
- Global perspectives: Including non-English studies to capture leadership practices across diverse cultural contexts.
- Policy integration: Research on how national education policies incentivize sustainability-driven leadership development.

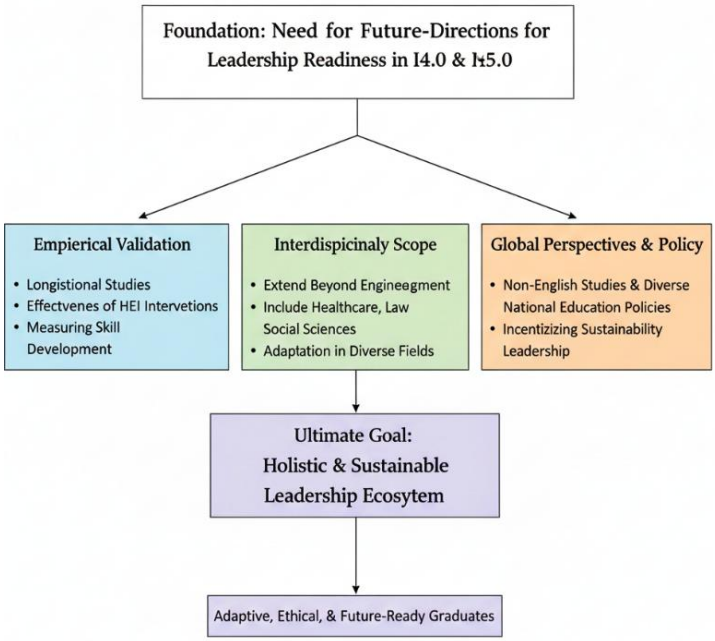

Figure 7. Proposed Future Research Directions for Leadership Readiness in Industry 4.0 & 5.0

In conclusion, leadership in I4.0 and I5.0 is not limited to technological mastery but requires leaders capable of guiding industries toward innovation, resilience, and sustainability. HEIs must reimagine education to produce adaptive, ethical, and future-ready graduate students. By integrating technical expertise with human-centric values, tomorrow's leaders can ensure that industrial transformation aligns with societal and environmental well-being.

Conflicts of Interest: The authors declare that they have no conflicts of interest to report regarding the present study.

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