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IMPACT OF INDUSTRY 4.0 TECHNOLOGIES ON SKILL REQUIREMENTS AND WORKFORCE AVAILABILITY IN KEY SECTORS

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Abstract. The rapid advancement of Industry 4.0 is driving organizations around the world to adopt advanced technologies, generating multiple complex operational and managerial challenges. This article explores the role of human resource management (HRM) in addressing these challenges, emphasizing the alignment of workforce skills with digital transformation goals to promote innovation, adaptability and teamwork. The article aims to highlight those key gaps and essential key competencies that are absolutely necessary for a successful Industry 4.0 transformation, with a focus on both technical skills such as data analytics and artificial intelligence, and non-technical skills such as resilience and creativity. Based on the workforce priorities and competences in this article some strategic visions in human resource management are proposed to support the evolution of the labor market and the impact of Industry 4.0 on workforce resilience, flexibility and collaboration.

The research methodology used in this paper is based on a structured approach that combines literature review and empirical analysis to examine the role of HRM in supporting Industry 4.0 transformations. This mixed methods approach is justified by the complexity of the topic as it allows for both a theoretical perspective and a data-driven analysis of workforce skills needs and organizational challenges in digital transformation.

The research conducted in this article argues that targeted upskilling and reskilling initiatives are key to overcoming the skills gap, enabling organizations to exploit the full potential of Industry 4.0 while paving the way for a sustainable, people-centric Industry 5.0. This article provides insights for HR professionals, policy makers and academics on developing an adaptive, innovation-oriented workforce to sustain competitiveness in a digital economy.

Keywords: *Industry 4.0, digital transformation, workforce skills, skill gaps, employee engagement, sustainable development, organizational competencies.*

JEL code: *O33, J24, M54, Q01*

Introduction

The advancement and intensification of Industry 4.0 have led to a global shift towards adopting advanced technologies, placing organizations under significant pressure to meet new operational and managerial challenges. As digital transformation progresses, businesses face the need to realign their workforce with the demands of an increasingly complex and technologically driven environment. Human resource management has emerged as a key enabler in addressing these challenges, playing a crucial role in aligning workforce capabilities with organizational objectives and fostering behaviors that support innovation, adaptability, and teamwork. Effective HR practices can accelerate digital transformation, promote employee commitment, and benefit stakeholders by emphasizing socially responsible employee welfare, talent retention, and inclusion.

This shift towards Industry 4.0 also necessitates specific competencies across the workforce to manage the emerging technologies effectively. Competencies such as flexibility, agility, collaboration, and technological literacy are essential for a resilient supply chain, where employees must be equipped to leverage digital tools and data for informed decision-making. However, the lack of these skills, as evidenced by recent studies, has become a barrier to successful digital transformation in many industries.

The transition to Industry 4.0 requires a workforce proficient in both technical and non-technical skills. Technical competencies such as data analytics, artificial intelligence, programming, and digital literacy are foundational for handling automation, robotics, and smart systems, which are central to Industry 4.0. At the same time, non-technical skills like analytical thinking, creativity, adaptability, and emotional intelligence are equally important, enabling employees to problem-solve, innovate, and navigate complex work environments. This dual skill set is essential for integrating new technologies effectively, fostering a resilient workforce capable of thriving in a digitalized and interconnected landscape.

Key statistics on workforce skills priorities are indispensable in understanding the evolving demands of the labor market in the context of Industry 4.0. Such data provide valuable insights into the skills employers prioritize, helping organizations and policymakers make informed decisions about workforce development and strategic investments in education and training.

Literature review

As the promotion of Industry 4.0 expands and intensifies, the whole world is polarizing towards the transformation and adoption of advanced technologies, thus organizations are facing multiple managerial challenges in their implementation [1]. The widespread push for Industry 4.0 adoption is not only reshaping global industrial landscapes but also imposing complex managerial challenges on organizations, as they must navigate the integration of advanced technologies while simultaneously restructuring workflows, adapting leadership strategies, and addressing skill gaps within their workforce.

The role of human resources in addressing Industry 4.0 challenges involves aligning HR practices strategically to support digital transformation. HR practices need to foster behaviors that align with the organization’s objectives, including teamwork, and employee engagement, which encourage innovation and adaptability [2].

Digitalization, particularly through artificial intelligence, has disrupted many aspects of society, altering how we live, work, and learn, while also offering pathways to achieve sustainable development goals. Understanding the skills needed for sustainable digitalization significantly impacts the labor market, sparking debates about future job structures [3].

The study identifies key people-related challenges and barriers to the sustainable development of Industry 4.0 and proposes HR tools and practices to overcome these barriers while ensuring socially responsible employee welfare and decent work. By applying specific HR practices, firms and HR professionals can accelerate the pace of digital manufacturing development, fostering employee commitment and benefiting multiple stakeholders. The HRM role is an enabler for sustainable Industry 4.0 development through socially responsible HR programs, ultimately supporting aspirations of equality, diversity, inclusion, talent retention, and socio-economic protection [4].

The impact of Industry 4.0 on resilience elements such as flexibility, redundancy, visibility, agility, collaboration, robustness, security, and information sharing within the supply chain is connected to human resource competencies through the need for employees to adapt to and utilize these advanced technologies effectively. This requires a workforce that is skilled in handling digital tools, analyzing data, and collaborating across different functions to ensure the successful implementation of Industry 4.0 technologies in the supply chain [5]. The successful implementation of Industry 4.0 technologies in the supply chain is intrinsically linked to human resource competencies, as it necessitates a workforce adept in digital tools, data analysis, and cross-functional collaboration, thereby enhancing resilience elements such as flexibility, agility, and security critical to modern supply chain operations.

The findings from a sample of manufacturing companies in Spain reveal that HR practices play a mediating role in connecting strategic alignment to digital transformation. This alignment helps organizations achieve superior performance by supporting innovative behaviors essential in a digitalized environment [2]. The experience of Spanish manufacturing companies reflects a broader global trend: when HR practices are aligned with digital transformation goals, they can play a fundamental role in helping organizations everywhere foster innovation and reach new levels of success in today’s digital-driven world.

The importance of workforce engagement and job satisfaction in the context of Industry 4.0 has become imperative. Today, digital tools are enabling the promotion and monitoring of work engagement, with the ultimate goal of contributing to the development of Industry 5.0 by integrating sustainable HRM practices [6].

The shift toward Industry 4.0 requires a multifaceted skill set from today's workforce, encompassing both technical and non-technical competencies (Figure 1).

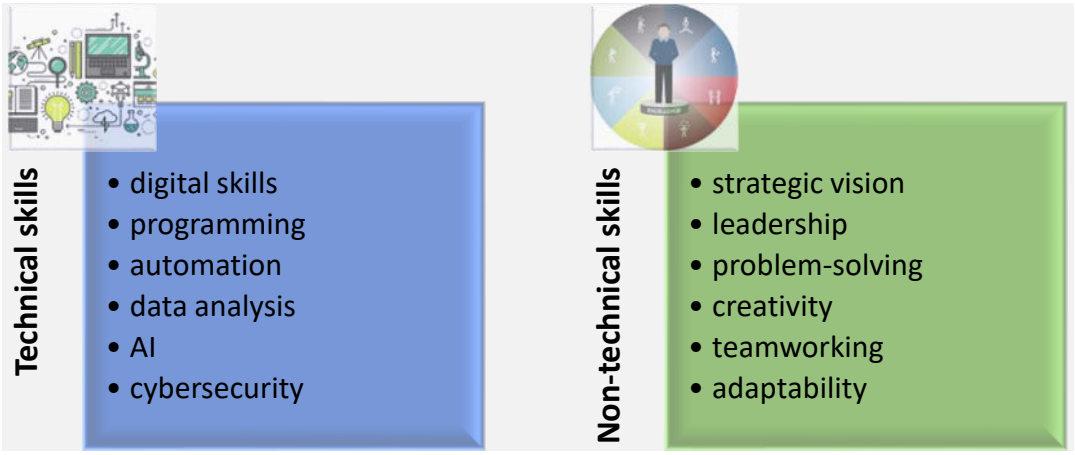

Figure 1. Essential technical and non-technical skills for workforce adaptation in industry 4.0

Source: Elaborate by authors

On the technical side, employees must be proficient in areas like data analytics, programming, artificial intelligence, and advanced digital literacy to effectively work with and manage automation, robotics, and smart systems. Knowledge in areas such as IoT, Big Data Analytics and Cloud Computing are essential for building and managing cyber-physical systems [7], [8], [9].

Equally important are non-technical skills, such as analytical thinking, creativity, adaptability, and emotional intelligence, which enable workers to problem-solve, innovate, and navigate complex, rapidly changing environments [8], [9].

This blend of skills not only ensures effective integration of new technologies but also fosters a resilient and agile workforce capable of thriving in an increasingly digital and interconnected landscape.

Effective implementation of Industry 4.0 technologies hinges on a workforce skilled in both technical and non-technical competencies ranging from digital literacy and data analytics to resilience and creativity enabling organizations to enhance supply chain resilience and achieve superior performance.

Key statistics on workforce skills priorities

Key statistics on workforce skills priorities are absolutely necesary for understanding and adapting to the rapidly evolving demands of the modern labor market, especially in the context of Industry 4.0 and digital transformation. Analyzing these statistics provides critical insights into the skills that employers prioritize, helping both organizations and policymakers to make informed decisions about workforce development and strategic investment in education and training programs.

The following figure shows the core skills prioritized by businesses for the 2023 workforce, alongside the the estimated distribution of these skills across different skill categories, highlighting strong demand for some skills and resistance for others.

The skills landscape for workers in 2023 reveals significant alignment between the priorities of companies and the competencies present in the workforce, critical for success in the context of Industry 4.0. Based on the data, analytical thinking ranks as the highest-priority skill, with nearly 100% of companies emphasizing it as essential, while around 11% of the average workforce possesses this skill. This strong correlation suggests that both educational institutions and professional development programs have effectively prioritized this cognitive skill, which is foundational for problem-solving, innovation, and technological adaptability.

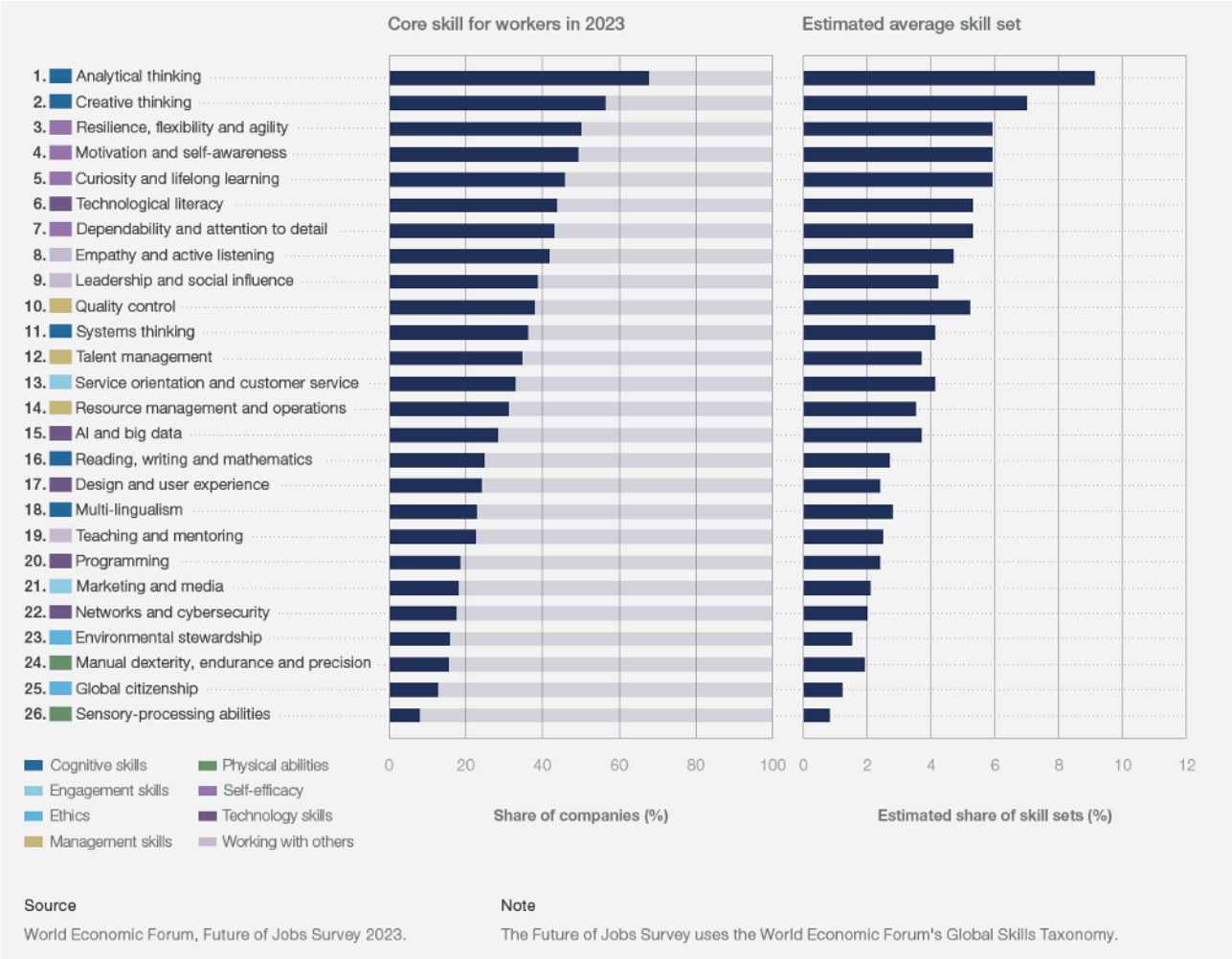

Figure 2. Core skills for 2023 workforce and projected competency distribution by skill category

Surse:[10], p.38

Creative thinking follows closely, also prioritized by nearly 100% of companies, with a similar workforce representation of approximately 11%. This alignment highlights the importance placed on innovative and outside-the-box problem-solving capabilities in modern workplaces, especially those navigating Industry 4.0’s complex technological demands.

Resilience, flexibility, and agility rank third in demand, with roughly 90% of companies identifying these attributes as essential for handling dynamic and uncertain work environments. Workforce representation for these skills is around 10%, indicating a favorable match between demand and availability. This alignment suggests a focus on soft skills training that equips employees to handle frequent shifts in work modalities, such as remote or hybrid setups.

Technological literacy, another critical skill in digital transformation, is emphasized by about 80% of companies. However, only about 8% of the workforce possesses this skill, revealing a smaller but meaningful gap. The moderate presence of this skill reflects that, while general digital skills are widely adopted, more specialized competencies in technology are still developing. This indicates an area where further emphasis on digital upskilling may be required to meet the full scope of Industry 4.0’s requirements.

Curiosity and lifelong learning, prioritized by about 85% of companies and represented by around 9% of the workforce, reflect the ongoing need for adaptability in a rapidly evolving digital landscape. The alignment here suggests that employees are relatively prepared for continuous learning, yet ongoing investment in professional development remains crucial as technology continues to advance.

Programming and AI/big data skills, while essential in some technical roles, have relatively lower priority across companies, with programming being emphasized by only about 20% of organizations. This is mirrored by a low workforce availability, as only 1-2% possess these specialized skills. The data indicates that companies are likely to rely on a select group of highly trained technical staff for these competencies, rather than expecting them from the general workforce. However, as automation and AI become more integral to operations, the demand for these technical skills may increase, underscoring a need for future-focused training.

Ethics and environmental stewardship are moderately prioritized, with roughly 50% of companies valuing these skills. Yet, only about 3-4% of the workforce possesses these competencies. This gap highlights an opportunity for HR departments and training programs to increase focus on these areas, especially as sustainability and corporate responsibility gain importance globally. The lack of alignment here suggests that, while companies recognize the significance of these values, they may not yet be seen as immediate priorities for all roles. Leadership and social influence, with about 70% of companies identifying it as important, is underrepresented in the workforce at around 6%. This gap suggests that employees may not possess the leadership skills necessary for guiding digital transformation efforts, indicating a need for targeted leadership development programs. The relatively low availability of these skills could impact the effectiveness of digital initiatives, as cross-functional collaboration and influence become increasingly critical in Industry 4.0 environments.

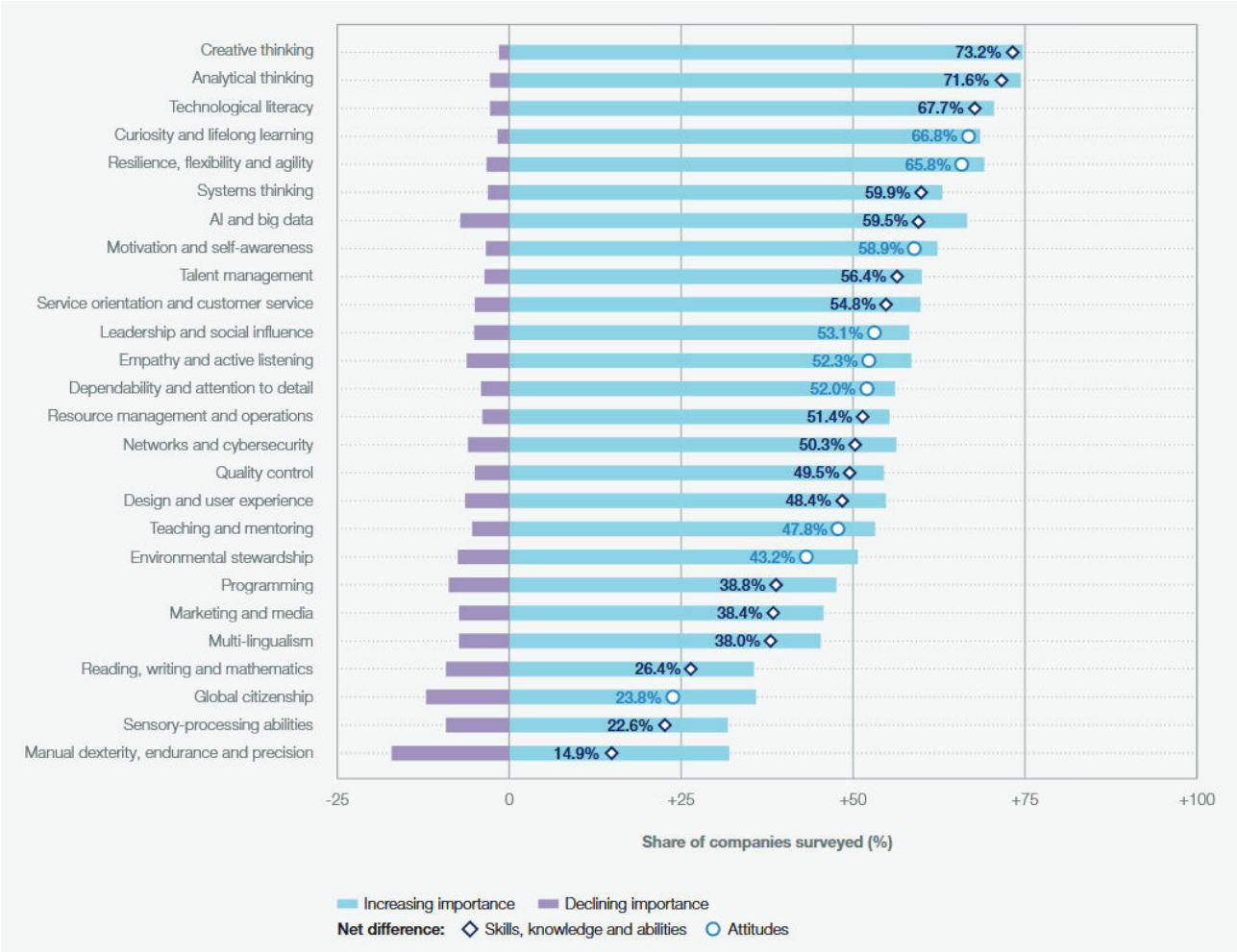

Figure 3. Evolving workforce skill priorities for 2023 to 2027 in the digital economy

Surse:[10], p.39

The analysis suggests that the labor market is well-aligned with cognitive and adaptability skills like analytical and creative thinking, which are in high demand and readily available within the workforce. However, gaps in specialized technical skills (e.g., programming, AI expertise) and soft skills like leadership and ethics reveal areas for strategic HR interventions. As concepts like Industry

5.0 – focused on sustainability, human-centered values, and ethical considerations emerge, the demand for underrepresented skills like environmental stewardship and global citizenship may increase.

Figure 3 illustrates the projected changes in workforce skill importance from 2023 to 2027, highlighting which skills are expected to increase or decrease in relevance according to surveyed companies.

This figure depicts the projected changes in the importance of various workforce skills from 2023 to 2027. Top skills with increasing importance are following:

- Creative thinking and analytical thinking rank highest, with 73.2% and 71.6% of companies, respectively, predicting an increase in their importance. This trend underscores the growing value placed on cognitive skills essential for problem-solving, innovation, and adaptability in a technology-driven work environment.
- Technological literacy and curiosity and lifelong learning follow closely, with 67.7% and 65.9% of companies, respectively, indicating their rising significance. These skills are critical as industries adopt new technologies, requiring workers to continually update their knowledge and adapt to emerging tools and methodologies.
- Resilience, flexibility, and agility and systems thinking are also highlighted, reflecting the demand for employees who can handle the fast-paced, complex environments typical of Industry 4.0.

Skills such as resource management and operations (51.4%) and quality control (49.5%) see moderate increases, suggesting they remain relevant but are not as prioritized as cognitive and adaptive skills. Technical skills like programming (38.8%) and networks and cybersecurity (51.2%) are moderately emphasized, likely reflecting a targeted rather than universal need for these specialized skills across roles.

The chart also reveals a decline in the importance of certain physical and manual skills, such as manual dexterity, endurance, and precision (14.9%) and sensory-processing abilities (22.6%). These declines reflect the impact of automation and digital transformation, which reduce the need for human involvement in repetitive, manual tasks. Additionally, reading, writing, and mathematics (26.4%) sees a relatively low increase, indicating that traditional foundational skills are not as prioritized in a workforce increasingly focused on higher-order cognitive skills. Based on the data it can be concluded that more traditional or manual skills are experiencing a decline, suggesting that companies are focusing on building a workforce that can thrive in a digital, knowledge-based economy.

By understanding which skills are growing in importance, organizations can allocate resources more effectively for reskilling and upskilling programs. This data-driven approach to workforce planning is more efficient and cost-effective than a reactive or generalized training strategy.

Figure 4 illustrates the core skills deemed essential for the 2023 workforce alongside the reskilling focus for these skills projected from 2023 to 2027. This figure compares the core skills currently prioritized for the workforce in 2023 with the projected reskilling focus from 2023 to 2027, segmented by various competency categories. The data indicates a strong emphasis on cognitive skills, particularly analytical thinking and creative thinking, which stand out with both high current importance (over 60%) and high reskilling focus (over 50%). This trend highlights the need for problem-solving and innovation capabilities, which are crucial in an increasingly digital and complex work environment. Similarly, adaptive skills like resilience, flexibility, and agility, as well as curiosity and lifelong learning, are also prioritized, reflecting the value of adaptability in a dynamic labor market influenced by Industry 4.0.

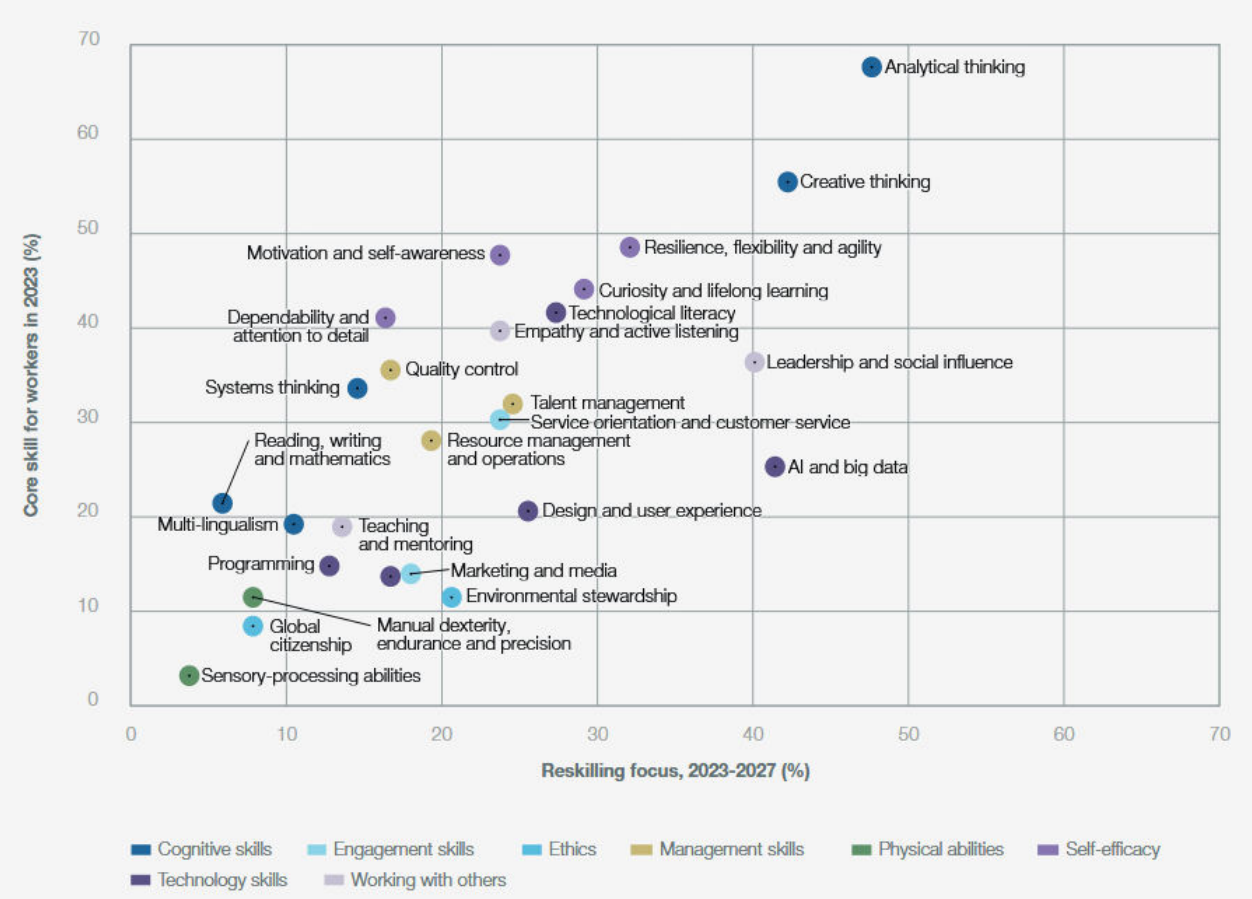

Figure 4. Correlation between core skills in 2023 and reskilling priorities for 2023-2027 by competency category

Surse: [10], p.43

Conversely, skills related to manual dexterity, endurance, and precision, as well as sensory-processing abilities, have low current importance and low reskilling focus. This is consistent with the impact of automation, which reduces the demand for manual labor and physical abilities, especially in industries increasingly reliant on digital processes. Additionally, technology skills like AI and big data have a moderate current importance but show significant reskilling focus, indicating that while these skills are essential for specific roles, they are expected to become even more critical in the near future.

The following figure illustrates the relationship between the probability of organizations prioritizing skills training in AI and big data, their likelihood of adopting artificial intelligence technologies, and their inclination to pursue automation as a business strategy.

This figure provides a comparative view of various industries' tendencies to prioritize skills training in AI and big data, adopt AI technologies, and accelerate automation. Industries such as electronics and information and technology services exhibit high levels of AI adoption (close to 100%) and prioritize AI and big data skills training (over 80%), reflecting their advanced digital maturity and reliance on cutting-edge technology. Employment services and insurance and pensions management also display a high adoption rate for AI technologies but with a slightly lower focus on skills training, suggesting reliance on AI while possibly facing a lag in workforce upskilling.

On the lower end, industries like agriculture, forestry and fishing and mining and metals have lower percentages in both AI adoption and skills training, highlighting a slower digital transformation process in sectors that traditionally rely on manual or less technologically driven processes. Accommodation, food and leisure also ranks low on both dimensions, suggesting minimal prioritization of AI skills or technologies in these sectors.

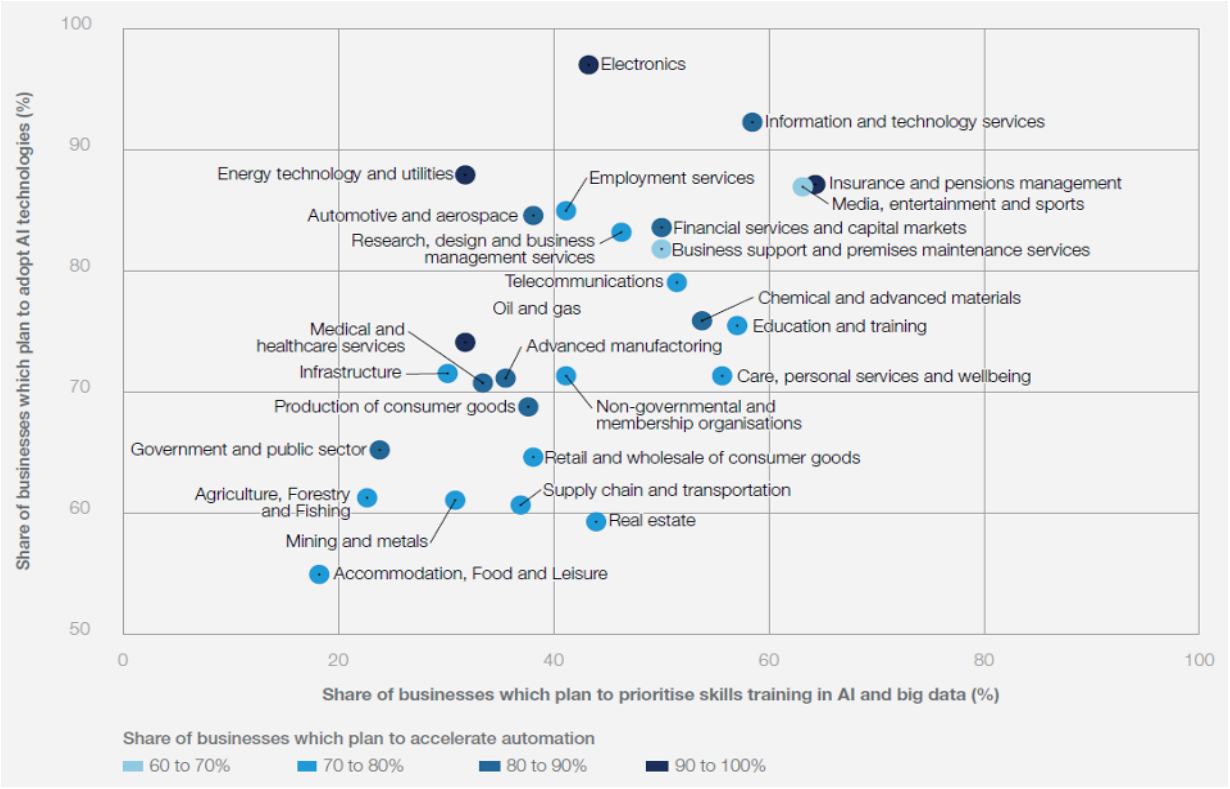

Figure 5. Correlation between AI skills training prioritization, AI technology adoption, and automation strategies across industries

Surse:[10], p.46

The size and colour of each data point further indicate the share of businesses within each industry that plan to accelerate automation. In this way, the indutsries like electronics and IT services are showing a higher commitment to automation. This layered information suggests that industries heavily investing in AI skills and technologies are also more likely to pursue automation as a core strategy.

As organizations navigate the demands of Industry 4.0 and digital transformation, they encounter a variety of obstacles that hinder progress and competitiveness. One of the most pressing challenges is the persistent gap between the skills required for these new technologies and the competencies available in the workforce. Figure 6 illustrates the primary barriers to business transformation projected for 2023-2027, with skill shortages in the labor market and organizational leadership standing out as critical concerns. These findings underscore the urgency for targeted workforce development and leadership training to support successful adaptation to rapidly evolving industry requirements.

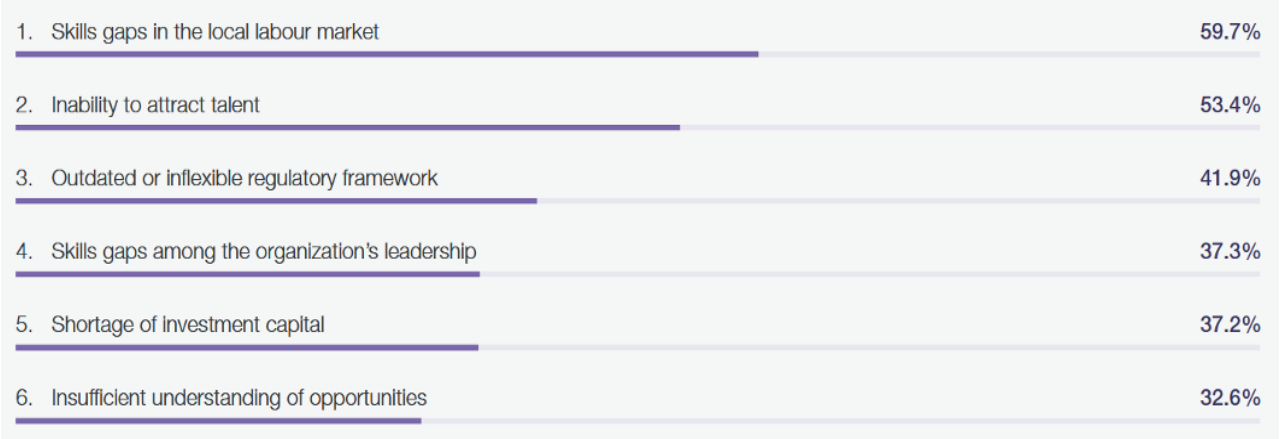

Figure 6. Barriers to business transformation, 2023-2027

Surse:[10], p.49

The figure shown above highlights key obstacles that organizations anticipate facing in their transformation efforts over the coming years. The data, sourced from the World Economic Forum's Future of Jobs Survey 2023, underscores that skill gaps in the labor market are the most significant barrier, with 59.7% of surveyed organizations identifying this as a critical limitation to transformation. It indicates a widespread lack of necessary competencies within the local workforce to meet the demands of emerging technologies and business models, particularly those driven by Industry 4.0. Such gaps include technical skills (data analysis, AI, automation, etc.) and soft skills (problem-solving, adaptability, etc.).

Skill gaps in organizational leadership show that 37.3% of organizations concerned about leadership skill shortages, this barrier points to challenges within management teams. Effective transformation requires leaders who not only understand new technologies but also have the strategic vision, adaptability, and leadership capabilities to guide their organizations through complex changes. This gap suggests a need for leadership development programs focused on digital skills, change management, and innovation.

Alongside skill shortages, inability to attract talent is highlighted by 53.4% of organizations as a critical barrier. This challenge is intertwined with skill gaps, as organizations struggle to find candidates who possess the required competencies, potentially exacerbating the shortage of skilled labor. Outdated or inflexible regulatory frameworks (41.9%) and shortage of investment capital (37.2%) are also notable barriers, as they limit organizations' ability to innovate and adapt to new technologies. Additionally, insufficient understanding of opportunities (32.6%) suggests a gap in awareness or knowledge about leveraging digital advancements, further hindering transformation efforts.

Conclusions and suggestions

The data shows a strong alignment between company priorities and workforce competencies in core cognitive and adaptability skills, with close to 100% alignment in areas like analytical and creative thinking. However, the lower presence of technical and leadership skills highlights future areas of development. Organizations that proactively bridge these skill gaps are likely to maintain a competitive edge in the rapidly evolving global economy, staying prepared not only for Industry 4.0 but also for the human-centered focus of Industry 5.0. Skill gaps are the most significant barrier to business transformation, indicating an urgent need for workforce development programs, talent acquisition strategies, and leadership training that emphasize both technical and adaptive skills. Organizations may benefit from investing in upskilling and reskilling initiatives to address local labor shortages, while also equipping their leaders with the strategic competencies required to navigate and drive digital transformation successfully. The data analyzed in this article highlights the strong correlation between industries prioritizing AI skills development, adopting AI technologies and embedding automation strategies, revealing how these elements are intertwined in shaping the Industry 4.0 transformation across sectors

Evolving workforce skill priorities underscores the critical need for training programs and educational initiatives that emphasize creativity, analytical thinking, and technological literacy to equip the workforce for future challenges and opportunities. Companies are increasingly investing in developing these skills to prepare their workforce for the evolving demands of Industry 4.0, indicating a strategic move towards building a resilient, flexible, and innovation-driven labour force.

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