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5G Competencies in Consideration of Industry 4.0 and Beyond: A Review of the Propositions

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Abstract

The emergence of 5G technology heralds a transformational era for the workforce, indicating changes in job creation, skillsets, and economic expansion. The features of 5G technology will play a pivotal role in shaping the future of industries. 5G's critical role in refining industrial practices becomes particularly salient as we shift from Industry 4.0 to Industry 5.0. For industries to successfully implement 5G, there must be a clear overview of the current proceedings and a strategic plan for future development. This necessitates an assessment of the various prospects that may arise during the implementation of 5G. The present study utilized a narrative review, which entailed an exploration of pertinent material using distinct search phrases and multiple databases, and synthesizing the findings into categories to provide a summary and interpretation of the results. In this analysis, a collection of multidisciplinary studies has been gathered, analyzed, and integrated to form a holistic view of the requirements for the 5G workforce to perform efficiently in their respective fields. Additionally, this research delineates original insights with respect to existing works and sets a perspective that combines viewpoints from information and communication technologies (ICT), human resources management (HRM), and management into one whole frame. Moreover, this paper provides an outline of the propositions surrounding 5G, competencies, and the status of Industry 4.0 and Industry 5.0. Future research should concentrate on developing robust frameworks and guidelines for successful collaboration between industry and academia in the context of technological transitions. Furthermore, studies could explore the impact of effective partnerships on innovation, productivity, and skill development within the workforce to better understand the long-term benefits of such collaborations.

Keywords: 5G, Competencies, Human Resources Management (HRM), Industry 4.0, Industry 5.0

Introduction

It is forecasted that the fifth-generation technology standard (5G) will upsurge the global GDP by $1.3 trillion by the year 2030, contribute to a $13.2 trillion economic output by 2035, and facilitate the creation of 22.3 million jobs in the process (pwc.com, 2020). The significance of 5G for the global economy becomes evident when considering these figures, which also highlight the burgeoning demand for skilled labor in industries that are poised to leverage 5G. In the wake of 4G wireless mobile technology advancements, the need for further technical progression to 5G communication technology was recognized due to several critical necessities such as heightened data transfer rates, increased network capacity, reduced latency, and enhanced quality of service (Element14, 2022). Consequently, the deployment of 5G commenced in 2020, with nations around the world beginning to adopt 5G applications at diverse paces and with different emphases. The 5G ecosystem is anticipated to encounter considerable challenges in aligning communication technology, infrastructure, human capital, and financial investments (Asean, 2022). Specialized skills are imperative throughout this transition to oversee, sustain, and engage with 5G infrastructure and services. Thus, to leverage 5G technology effectively and to its full potential, a workforce equipped with the requisite qualifications is essential. The pace of technological disruption is so rapid that it necessitates adaptability across all sectors, especially in the realms of education and policy-making (Muktiarni et al., 2019).

The advent of 5G technology is poised to have a significant impact on the labor force, with implications for job creation, skill requirements, and economic growth. Research by Rao and Prasad suggests that the features of 5G technology will play a pivotal role in shaping the future of industries, potentially leading to increased efficiency and the creation of new types of jobs (Rao & Prasad, 2018). Moreover, a report by Mandel and Long delves into the labor market impact of wireless technologies, including 5G. They propose that 5G will drive job growth by creating demand for new skills and positions, particularly as industries adapt to and integrate these new technologies (Mandel & Long, 2020). Prieger's economic analysis on 5G wireless deployment discusses how the labor required to build out 5G networks will immediately demand new job opportunities. This analysis underscores the positive influence 5G could have on the labor market in terms of both immediate and long-term employment prospects (Prieger, 2020). Additionally, Fahn and Yan's analysis emphasizes the need for re-training and re-education of the workforce to align with the demands of 5G technology. This shift suggests that while 5G may create new opportunities, it also presents challenges in terms of workforce adaptation and skill development (Fahn & Yan, 2021). In the context of vocational education, research by Li, Xu, and Ling indicates that 5G technology will not only promote the development of products and services but will also expand innovation space and potentially mitigate adverse effects on the employment market. This could mean that the implementation of 5G technology may lead to a more dynamic and resilient labor market (Li, Xu, & Ling, 2021). Ultimately, the impact of 5G technology on the labor force is multifaceted, with potential for both positive job growth and economic development, as well as significant challenges in workforce transition and skill acquisition.

Background

The arrival of 5G technology plays a crucial role in the evolution of industrial practices, particularly as we transition from Industry 4.0 to Industry 5.0. Industry 4.0 is marked by the integration of smart technologies into manufacturing, leveraging data and automation to create smart factories. In contrast, Industry 5.0 aims to bring a more collaborative approach

where humans and machines work together to achieve more personalized and sustainable industrial outcomes. According to a study, the primary principle behind Industry 4.0 is to transform the manufacturing industry into a “smart” environment through the use of cyber-physical systems, the Internet of Things (IoT), and cloud computing (Maddikunta et al., 2022). The integration of 5G technology is expected to further enhance these capabilities by providing ultra-reliable, low-latency communication that is essential for real-time data processing and the operation of autonomous systems. Another study highlights how 5G and beyond 5G technologies can enable the development of Industry 5.0 by targeting sectors like logistics, healthcare, and Industry 4.0 itself (Lessi et al., 2024). The capabilities of 5G-powered robotic applications, for example, could be leveraged to improve efficiency and adaptability in these sectors, facilitating the shift towards a more advanced industrial paradigm. Furthermore, the transition from Industry 4.0 to Industry 5.0 aligns with the networking trend moving from 5G to 6G. This suggests that the innovations in networking technology will continue to be a driving force for industrial advancements, with Industry 4.0 and 5.0 being key use cases for these upcoming generations of wireless technology (Chi et al., 2022). In the context of Industry 5.0, 5G technology not only supports communication among people but also facilitates communication between machines, enabling more complex and autonomous systems. This allows for greater sustainability and resilience within the industry, as detailed in a paper from the journal Processes (Alojaiman, 2023). 5G technology significantly impacts Industry 4.0 by enhancing its smart capabilities and is anticipated to continue this influence as we progress into Industry 5.0, fostering a more collaborative industrial environment where human ingenuity and machine efficiency coalesce to create a sustainable and resilient future. For industries to successfully implement 5G, there has to be a clear overview of the current state of technology and a strategic plan for future development. This involves understanding the potential roadblocks and opportunities that the industry may encounter during the implementation of this technology (Peraković et al., 2020).

Search Strategy

The initial phase involved an extensive search of concepts related to 5G in order to acquire a broad understanding of the topic. The subsequent database searches were carried out using the following terms in Web of Science, Scopus, and ProQuest:

"5G" OR "Fifth-Generation Technology Standard"
"Digital Competencies" OR "IT Competencies"
"Competencies" OR "Talent" OR "Skills"
"5G" AND "Human Resources" OR "Human Resource Management"
"Human Resources" OR "Human Resource Management"
"Human Resources" OR "Human Resource Management" AND "Industry 4.0" OR "Industry 5.0"
"Human Resources" OR "Human Resource Management" AND "Industry 5.0"
"5G" OR "Fifth-Generation Technology Standard" AND "Industry 5.0"

These terms were applied to filter through the "Title/Abstract/Keywords" sections. Subsequently, to identify relevant literature, the reference lists of the selected articles were meticulously reviewed. Despite this methodical approach, the search yielded only a handful of papers deemed significant. Consequently, an additional search was conducted using Google Scholar to find supplementary materials, and references that had not been peer-

reviewed were also considered. Ultimately, a total of 40 pertinent papers, using the aforementioned search terms, were identified as the most significant.

Table 1
List of Documents Attained Using the Search Strategy

No.	Article Title	Year Published
1	Information Technology Competencies, Organizational Agility, and Firm Performance: Enabling and Facilitating Roles	2013
2	A Brief Overview of 5G Research Activities	2014
3	Digital competence – an emergent boundary concept for policy and educational research	2016
4	Holistic approach for human resource management in Industry 4.0	2016
5	5G: A Tutorial Overview of Standards, Trials, Challenges, Deployment, and Practice	2017
6	Human Resources Management: Meta-Study - Analysis of Future Competences in Industry 4.0	2017
7	On the issues of digital competence in educational contexts – a review of literature	2017
8	On the way from industry 4.0 to industry 5.0: from digital manufacturing to digital society	2017
9	A Review of Literature on Industry 4.0	2018
10	Business Models for Local 5G Micro Operators	2018
11	Impact of 5G Technologies on Industry 4.0	2018
12	Digitalisation trend in education during industry 4.0	2019
13	Fostering the Digital Competencies for the 5G Era	2019
14	Information Technology as the Basis for Transformation into a Digital Society and Industry 5.0	2019
15	A Review of Talent Adaptive Concept and Conceptual Framework of Accelerated Industry4WRD Talent Adaptation in Malaysia	2020
16	Competency Definitions, Development and Assessment: A Brief Review	2020
17	Digital competencies: A review of the literature and applications in the workplace	2020
18	Digital Transformation and Economic Contributions of 5G Networks	2020
19	The Intricacies of 5G Development in Southeast Asia	2020
20	The Transition from Industry 4.0 to Industry 5.0. The 4Cs of the Global Economic Change	2020
21	Acceptance determinants of 5G services	2021
22	Analysing workforce development challenges in the Industry 4.0	2021
23	Design of Personal Trajectories for Employees' Professional Development in the Knowledge Society under Industry 5.0	2021
24	Industry 4.0 and Industry 5.0—Inception, conception and perception	2021
25	Knowledge and Skills of Industrial Employees and Managerial Staff for the Industry 4.0 Implementation	2021

26	Technological competitiveness and emerging technologies in industry 4.0 and industry 5.0	2021
27	5G Technology Readiness in Education among Malay Bumiputera Students in Shah Alam	2022
28	A Literature Review of the Challenges and Opportunities of the Transition from Industry 4.0 to Society 5.0	2022
29	Analysis of Employees' Competencies in the Context of Industry 4.0	2022
30	Analytical study of HRM practices in industry 5.0	2022
31	Development of Best Practice Guides for 5G Ecosystem Development in ASEAN (Study Report)	2022
32	Emerging Enabling Technologies for Industry 4.0 and Beyond	2022
33	Employee competencies in line with Industry 4.0	2022
34	From Industry 4.0 towards Industry 5.0: A Review and Analysis of Paradigm Shift for the People, Organization and Technology	2022
35	Industry 5.0: A survey on enabling technologies and potential applications	2022
36	Industry 5.0: improving humanization and sustainability of Industry 4.0	2022
37	Industry 5.0 is Coming: A Survey on Intelligent NextG Wireless Networks as Technological Enablers	2022
38	Role of Industry 5.0 in leveraging the Business Performance: Investigating Impact of Shared-Economy on Firms' Performance with Intervening Role of i5.0 Technologies	2022
39	State of Industry 5.0—Analysis and Identification of Current Research Trends	2022
40	Use cases for 5G and beyond	2022

Propositions

An Overview of 5G

5G technology, often referred to as "the network of networks," is poised to serve as a cornerstone for Industry 4.0 and beyond. It is anticipated to integrate numerous existing standards and span a wide array of industries and technologies. According to TWI Global (2023), a diverse range of products, services, and industries are on the cusp of transformation due to the advent of 5G. Furthermore, the evolution of 5G technology, in conjunction with advancements in artificial intelligence (AI), the Internet of Things (IoT), 3D printing, and other innovations, is set to revolutionize how consumers live and engage within businesses and communities (Reply, 2022). When compared to 4G networks, 5G networks promise to offer increased bandwidth capacities, accelerated data transfer rates, reduced latency, expansive coverage, lower costs, and enhanced quality of service (QoS). The capabilities of 5G networks will be instrumental in establishing seamless connections among a multitude of IoT devices (Sigov et al., 2022). Specifically, 5G is expected to leverage key technological frameworks such as Software Defined Networking (SDN), Network Function Virtualization (NFV), and Mobile Edge Computing (MEC) to support its infrastructure (Blanco et al., 2017).

Table 2
5G Technology Key Features (Eswaran & Honnavalli, 2023; Qi et al., 2016; Kotulski et al., 2020; Yu et al., 2017; Chen et al., 2020; Feng et al., 2017; Abdulghaffar et al., 2021)

Feature	Key Points
Deployment	Private 5G networks bring enhanced data rates and lower latencies tailored to specific applications and environments.
Data Bandwidth	Offers over 100Mbps data rates even in high-demand areas due to expanded spectrum resources, enabling high-speed connectivity.
Network Types	Network slicing allows for customized logical networks, optimizing resources and services for specific user needs and applications.
Services	Supports a wide array of services from enhanced mobile broadband (eMBB) to massive IoT deployments (mMTC), catering to diverse use cases.
Multiplexing	Beam-space and space division multiplexing techniques significantly increase the capacity and efficiency of wireless communications.
Switching	Dynamic base station ON-OFF switching contributes to energy efficiency and sustainability of network operations.
Core Network	Incorporation of SDN and NFV leads to a flexible, scalable core network that can efficiently manage and orchestrate network resources for various services.

The key features of 5G technology are designed to significantly enhance communication systems. A survey on 5G technology by Gohil et al. (2013) indicates that 5G is expected to offer higher bandwidth, lower latency, and increased connectivity for a multitude of devices. This new generation of mobile communication is engineered to support a vast ecosystem of applications ranging from high-speed mobile internet to autonomous vehicles, smart cities, and Internet of Things (IoT) devices. 5G's network capacity is crucial in accommodating the burgeoning number of connected devices and the voluminous data they produce. Research by Li et al (2014) on 5G network capacity highlights key technologies such as advanced antenna systems, spectrum efficiency techniques, and network slicing. These technologies allow for a more efficient use of the radio spectrum and the ability to tailor network capabilities to specific applications and services. Additionally, a systematic review of 5G technology by Dangi et al (2021) collected key information about its features, which include enhanced mobile broadband (eMBB), ultra-reliable and low-latency communications (URLLC), and massive machine type communications (mMTC). These features are essential for a wide range of applications and services that require high data rates, reliable connections with minimal delay, and connectivity for numerous devices. Moreover, Felita and Suryanegara (2013) identify innovation opportunities in 5G technology through the proposal of a universal terminal, which integrates all previous radio features into a single device. This convergence in terminal technology is expected to improve user experience by providing more versatile and capable communication devices. The key features of 5G technology, including high-capacity networks, improved spectrum efficiency, low latency, and the ability to support an expansive number of devices and applications, are set to bring transformative changes across various industries, with a notable impact on healthcare, and pave the way for future innovations in mobile communication. The technical features collectively establish 5G as a pivotal technology in the evolution of mobile communications and its influence extends beyond, shaping the digital connectivity and service landscape of the future.

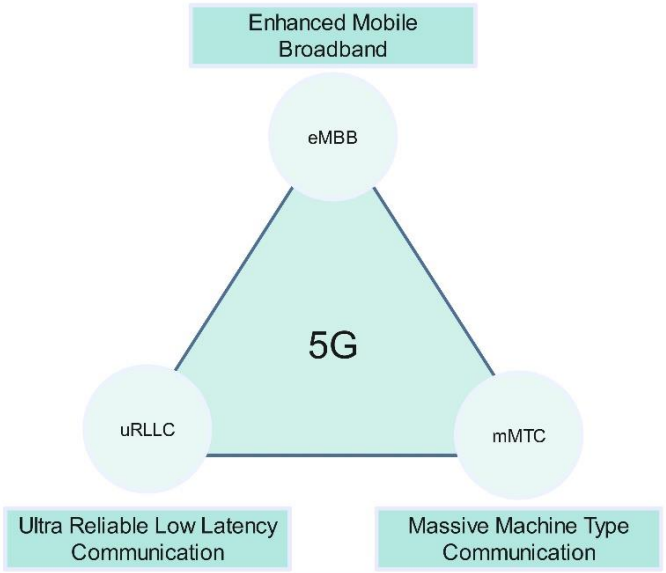

Figure 1. The Triangular Classification Structure of 5G Applications

An Overview of Competencies

Several factors can be employed to categorize competencies, such as the origin of skill development, the breadth of knowledge, accessibility within an organization, and the precision of definition (Kowal et al., 2022). The term 'competency' fundamentally denotes the ability to perform a task successfully or efficiently (Oxford Languages, 2022). It encompasses a spectrum of discernible characteristics and skills that contribute to, and bolster, the efficient completion of a job (Darwinbox, 2022). While "competencies" refer to the demonstration of behaviors essential for effective performance, "being competent" implies fulfilling the job's requirements or functions (Wong, 2020). Competencies can be divided into various types, such as organizational and technical competencies. Organizational competency pertains to the combination of knowledge, skills, attitudes, and behaviors that an individual possesses, which are crucial for professional excellence (Boyatzis, 1982). On the other hand, technical competencies relate to the expertise and understanding required to apply specific technical concepts and information, typically acquired through formal education, to a professional task or position (CCSA, 2022).

It is predicted that the initiation of widespread automation will lead to the displacement of both new and existing jobs. Jobs that involve repetitive, manual tasks or require only basic cognitive skills are the most susceptible to becoming redundant. Consequently, incorporating reskilling into future strategic planning is imperative. Skills that are less likely to be supplanted by automation and, thus, will be in greater demand, include advanced problem-solving, sophisticated cognitive functions, as well as quantitative, statistical, and technical aptitudes. Additionally, the capacity to forge and nurture relationships with various stakeholders will gain importance. Despite the daunting prospect of reskilling millions, history has shown that similar transformative efforts have yielded positive outcomes (McKinsey & Company, 2021).

The competencies essential for the 5G era align closely with the concept of digital competencies, yet they also call for unique skill sets beyond the basic digital skills. When

discussing competencies related to 5G, it is necessary to consider both organizational and technological skills.

Digital competencies act as a cross-disciplinary boundary concept, engaged across various fields to scrutinize competencies intersecting with digital technology. Given the rapid evolution of digital technology and the dynamic nature of political aims and societal expectations in a knowledge-driven society, our understanding of digital competencies is ever-changing. This is highlighted by Ilomäki et al (2016), who note that the concept's definition is expected to evolve.

The terminology related to competencies for using digital technology is diverse, often lacking a uniform, evidence-based consensus. In an attempt to clarify, Oberländer et al (2020) describe digital competencies as the adeptness in using digital technologies for a range of purposes, including locating, managing, integrating, evaluating, and synthesizing digital information. It embodies knowledge, skills, and attitudes, spanning from fundamental tasks such as online searching to complex activities like data analysis and interpretation, and its subsequent application to real-life situations. Nonetheless, the existing literature has yet to fully encapsulate the depth and breadth of digital competency.

Transitioning to the significance of these competencies, Săvulescu and Antonovici (2019) underscore their importance in today's digital era, postulating that it is through adequate digital skills and constant learning that individuals can reap the full benefits of the digital world. Hecklau et al (2016) discuss the goal of competency development, which is to pinpoint and bridge critical skill gaps, asserting that adopting a competency model can enhance the transparency of this process. Furthermore, Zizic et al (2022) champion the use of innovative technologies to augment human performance in closing these competency gaps.

Taking a broader view, Saniuk et al (2021) identify several catalysts driving the necessity for new competencies. These include comprehensive integration, increased information transparency, automated production systems, autonomous management, digital communication, interactive management functions, and workforce flexibility. Similarly, Chakravarty et al. (2013) posit that IT competencies are pivotal for a company to enhance its agility and, by extension, its overall performance, with benefits permeating various operational and strategic levels.

Furthermore, Pettersson (2018) contends that a high level of digital proficiency can lead to more frequent and critical interaction with digital technologies. In the milieu of Industry 4.0, Rao et al (2018) delve into the challenges presented by 5G technologies, which encompass security, privacy, and scalability, as well as the collaboration between humans and robots in production, emphasizing the imperative of a skilled workforce. Ungureanu (2020) remarks that despite ongoing debates concerning the role of human capital in the labor market, there is a shared agreement on the need for it to be adaptable to a fluid and unpredictable environment.

Praj et al (2022) bring to light that according to Industry 4.0 standards, key employee competencies include IT expertise, the capability to employ modern technologies, data processing, and analysis, along with an understanding of organizational and process-related complexities. These employees must also be proficient in IT security, data protection, possess a multidisciplinary knowledge base of production, and be aware of legal regulations. In this evolving digital terrain, jobs may not necessarily be lost but are likely to transform.

Key competencies for thriving in the digital economy include areas such as data analysis, management, software development, computer programming, and digital security and privacy, as identified by (Burning Glass, 2018). The exploration of future competencies in

digitization entails the identification and structuring of the necessary skills for firms adjusting to Industry 4.0 transformations. These competencies can be categorized into personal, domain-specific, social, and methodological components, with the core competencies at the strategic level serving to unify the organization, as per (Hecklau et al., 2017).
The concept of digital competencies is a multifaceted and evolving construct, vital for personal and organizational success in the modern, digitally-driven landscape. As technologies advance, the competencies required to engage effectively with digital tools also progress. Therefore, continuous learning and adaptability are essential for individuals and organizations alike to ensure that they remain competitive and capable in harnessing the full potential of digital advancement.
These following knowledge and competencies cover the technological, regulatory, and infrastructural aspects of 5G technology, as identified by this study.

1. **5G Specific Concepts**
    - Cellular Networks Fundamentals
    - Telecom Regulation Basics (as it applies to the spectrum and operation of 5G networks)
    - Traffic engineering principles (which can be related to managing 5G network traffic)
    - Spectrum Regulation Basics (5G requires regulation of new spectrum bands)
    - 5G concepts, elements, 5G Security (direct references)

2. **Networking and Protocols**
    - Network layer and IP protocol (5G uses an evolved packet core for IP connectivity)
    - LAN Protocols (for integration with existing networks, e.g., 5G LANs)
    - Application layer protocols and concepts (5G supports a wide variety of applications)
    - Interior Routing Protocols and Exterior Routing Protocols (for routing within 5G networks and between other networks)
    -
3. **Signal and Transmission**
    - Digital Transmission Fundamentals (5G uses advanced digital transmission techniques)
    - Basic Digital Modulation Techniques (5G employs advanced modulation schemes)
    - Signal Multiplexing (5G uses sophisticated multiplexing for efficient spectrum usage)
    - Data Multiplexing and Switching (essential for 5G data handling)
    - Wireless Transmission Systems (5G is the latest generation of wireless systems)

4. **Infrastructure and Technologies**
    - Mobile Networking (3G, 4G, LTE, 5G): Technology, architecture, and protocol
    - Network Functional Virtualization (NFV) and Software-Defined Networking (SDN) (both are important for the flexible network architecture of 5G)

- CRAN, Massive MIMO, Dual connectivity (specific technologies that are crucial for enhancing 5G network capacity and performance)

5. **Security and Regulation**
   - Network Security Basics (security is a major consideration for 5G networks)
   - Global Regulatory Issues (applicable to international 5G standards and deployment)
   -
6. **Emerging Technologies**
   - Edge computing (5G enhances the capabilities of edge computing by reducing latency)
   - AI/ML (Artificial Intelligence and Machine Learning) (for network optimization and automation in 5G)
   - Blockchain (potential use cases in 5G for security and transactions)
   -
7. **Management and Planning**
   - Project Planning and Management (for 5G network rollouts)
   - Advanced Regulatory Issues (regarding the deployment and management of 5G networks)

An Overview of Industry 4.0

The rapid transformation in technology, industry, and societal norms and processes over the recent decade is epitomized by the Fourth Industrial Revolution, or Industry 4.0. The aim of Industry 4.0 is to integrate advancements in information and communication technology, spurred by the internet and telecommunications revolution, with developments in machinery, networks, and infrastructure from the industrial revolution (Rao and Prasad, 2018). Industry 4.0 is characterized by the smart interconnection of machines and processes using CPS (cyber-physical systems), a technology that facilitates sophisticated control via embedded networking systems (Xu et al., 2021). By enhancing operational efficiency and innovating new business models, services, and products, Industry 4.0 has transformed manufacturing and production systems. As a result, the focus has shifted to the digitization and digitalization of systems. At the core of Industry 4.0 are 'smart factories' (Zizic et al., 2022); therefore, engineers involved in Industry 4.0 have largely put emphasis on the technological improvements of production and manufacturing systems and networks, prioritizing industrial agility and efficiency over environmental sustainability and employee well-being (Mourtzis et al., 2022).

Ozkan-Ozen and Kazancoglu (2022) argue that the full potential of Industry 4.0 can only be realized when it is combined with appropriate human resource practices. Their research indicates that workforce development is significantly hindered by a deficiency in IT and digital competencies. Management should cultivate a digital culture and establish an organizational structure that is adaptable to the transformations induced by Industry 4.0. Moreover, there is a systemic imperative for workforce advancement that includes the need for systems thinking and the encouragement of human-machine collaboration. Kowal et al (2022) highlight that the expectations of employers and the integration of Industrial 4.0 technologies pose novel challenges for workers, especially in the realms of knowledge and skill requirements. The primary assets of a company are the skills and competencies of its workforce, which not only contribute to its added value but also furnish a competitive edge.

As per the identification of this study, the following skills reflect a combination of hard and soft skills that are increasingly important as automation, artificial intelligence, and machine learning become more prevalent in the workplace. Employees who cultivate these skills are likely to be better prepared for the challenges and opportunities of the fourth industrial revolution.

Table 3
Top Industry 4.0 Skills (Rotatori et al., 2021; Schwab, 2017; Venter et al., 2019; Eberhard et al., 2017)

No.	Skill	Description
1	Technological Literacy	Ability to understand and leverage new technologies for better productivity and innovation.
2	Adaptability and Flexibility	Being open to change and able to pivot, when necessary, in response to the rapidly changing work environment.
3	Critical Thinking	Evaluating problems and scenarios critically to find solutions and make decisions.
4	Creativity and Innovation	Generating new ideas and approaches to improve processes and solutions.
5	Emotional Intelligence	Understanding and managing your own emotions, and recognizing and influencing the emotions of others.
6	Interpersonal Communication Skills	Effectively communicating, negotiating, and influencing others.
7	Data Analysis	Interpreting data to make informed decisions and drive strategies.
8	Leadership Skills	Guiding teams and projects to success with a clear vision and effective management.
9	Continuous Learning	Commitment to ongoing personal and professional development.
10	Problem-Solving Skills	Identifying complex problems and reviewing related information to develop and evaluate options and implement solutions.

Industry 4.0 heralds a transformative era marked by unprecedented advancements in digital technologies, automation, and interconnectedness in manufacturing and industry. This revolution is characterized by the integration of cyber-physical systems, the Internet of Things (IoT), and big data analytics into the very fabric of production and management, fundamentally altering how industries operate.

Building on the findings of Muktiarni et al (2019), who suggest that the commencement of the Industry 4.0 era necessitates a novel strategy for developing human resources adept at meeting diverse and evolving requirements, we see the need for a clear action plan. To thrive in this new landscape, there is an imperative to cultivate a workforce equipped with advanced skills in planning, management, and IT-related tasks. Their research underscores the predicted decline in low-skilled jobs against a backdrop of an escalating demand for high-skilled roles. This paradigm shift anticipates that employees will need to acquire new or modified skills to remain competitive. The fourth industrial revolution, particularly impactful in the realms of big data and artificial intelligence, is already reshaping education to prioritize skills and technological fluency. In this transition, it is crucial for education systems to evolve,

fostering competencies and knowledge that cannot be replicated by the burgeoning presence of machines.

Echoing these sentiments, Rao and Prasad (2018) also acknowledge the onset of Industry 4.0 as a period defined by increased automation and its inevitable consequence: the displacement of jobs in traditional sectors. Anticipating a shift, they predict a surge in demand for knowledge-intensive positions in technical operations, automation, research, and innovation. Conversely, roles traditionally centered around production, office support, and routine tasks face a decline as these become automated. To illustrate, companies might adopt a "novel strategy" that integrates continuous professional development programs, focusing on emergent technologies like machine learning and robotics, thereby equipping their workforce for the high-skilled roles that are becoming increasingly pivotal.

Furthering the discourse, Saniuk et al. (2021) raise concerns that while there is a significant prominence on technological enhancements in businesses, the development of human resources is not receiving equivalent attention. This gap presents a challenge as the human element remains central to the successful implementation of Industry 4.0 innovations. Thereof, their insights suggest that Industry 4.0 might serve as the catalyst for the emergence of Society 5.0 – a concept representing a harmonious integration of advanced technological systems with human needs and values. Society 5.0 envisions a future where the subjective ontologies of various stakeholders are synthesized, creating a more inclusive and interconnected societal framework.

An Overview of Industry 5.0

Foremost, it is essential to introduce the terms “Society 5.0,” “Digital Transformation,” and “Industry 5.0” to facilitate an understanding of the Industry 5.0 concept.

The Fifth Industrial Revolution, or Industry 5.0, represents an emerging phase in industrial evolution where human collaboration with advanced machines and robots equipped with artificial intelligence enhances business processes. It places a greater focus on human needs, resilience, and a deeper commitment to sustainability [twi-global, 2023]. The ambition of Industry 5.0 is to merge highly efficient, intelligent, and precise technology with the creative capacity of human experts (Maddikunta et al., 2022). Industry 5.0 recognizes the potential of industrial activity to contribute to societal objectives beyond job creation and economic growth by insisting on production practices that respect the Earth's boundaries and prioritize the well-being of workers, positioning industry as a robust source of prosperity (Xu et al., 2021). The foundational elements of Industry 5.0 include a focus on human-centricity, sustainability, and resilience, with big data, AI, 6G, the Internet of Everything (IoE), and cloud/edge computing identified as the primary technologies that will facilitate this transformation (Sucia and Vochin, 2022). A key trend in Industry 5.0 is the development of a smart society and the establishment of collaborative workspaces for humans and robots (Akundi et al., 2022).

Table 4
The Key Enabling Technologies of Industry 5.0 (Xiang et al., 2023; Tallat et al., 2023; Sigov et al., 2022; Leng et al., 2022)

Key Enabling Technologies	**Description**
Artificial Intelligence (AI)	AI enables machines to learn from experience, adjust to new inputs, and perform human-like tasks.
Machine Learning (ML)	ML is a subset of AI that provides systems the ability to automatically learn and improve from experience without being explicitly programmed.
Robotics	Robotics involves the design, construction, operation, and use of robots for automation and enhanced efficiency in various tasks.
Internet of Things (IoT)	IoT connects physical devices, vehicles, home appliances, and other items embedded with electronics, software, sensors, and connectivity to exchange data.
Advanced Materials	Materials which possess properties superior to conventional materials, enabling new capabilities in manufacturing and product design.
Cyber-Physical Systems (CPS)	CPS are integrations of computation, networking, and physical processes, where embedded computers and networks monitor and control the physical processes.
Smart Sensors	Smart sensors are advanced platforms with onboard technologies such as microprocessors, storage, diagnostics, and connectivity tools for better data collection and analysis.
Big Data Analytics	Big data analytics is the process of examining large and varied data sets to uncover hidden patterns, unknown correlations, market trends, customer preferences, and other useful business information.

These technologies are interconnected and when combined, they create a powerful ecosystem for Industry 5.0, supporting smarter, more efficient, and more human-centric industrial processes. Industry 5.0 represents the evolution of Industry 4.0, with a focus on digitalization and AI-driven technologies to enhance manufacturing efficiency and flexibility. It prioritizes environmental sustainability and the welfare of workers, embedding societal objectives such as job creation and economic growth into technological advancements. Industry 5.0 is characterized by a value-oriented movement, known as the Techno-Social Revolution, emphasizing the integration of technology with societal goals (Xu et al., 2021).

Society 5.0 aims to harmonize economic advancement with the resolution of social challenges, creating a human-centered society that integrates cyberspace and physical space effectively. This era follows historical societal progressions and seeks to address societal challenges by converging the internet with physical spaces (Cabinet Office, Government of Japan, n.d.).

Digital transformation is crucial for companies to integrate technology into their business models, enhancing operational efficiency and creating new value for stakeholders. Industry 5.0 merges scientific and technological domains to establish a unified information environment, aiding in real-time resource planning and management (Akundi et al., 2022).

Mourtzis et al (2022) highlight that autonomous manufacturing, supported by human intelligence and AI, will be central to Industry 5.0. This new industrial phase will utilize technologies such as edge computing, digital twins, collaborative robots, and the Internet of

Everything to enhance manufacturing processes. It will also challenge professionals to prioritize human-centered approaches when integrating technology into industries.
Personalization is a key component of Industry 5.0, focusing on delivering custom products and fostering individualized relationships. Training the workforce to collaborate with intelligent systems is vital to support human labor and manage the transition from Industry 4.0 (Orlova, 2021). Industry 5.0 should be seen as an expansion of Industry 4.0, emphasizing technology as a support to human ingenuity (Zizic et al., 2022).
Guided by the 6R principles—Recognize, Reconsider, Realize, Reduce, Reuse, and Recycle—which advocate for waste minimization, industrial upcycling, and optimized logistics design, Industry 5.0 is human-centric. It underscores the importance of intelligent manufacturing, reintegrating human insight on the factory floor, and fostering collaboration between robots and humans. Industry 5.0 represents an asymmetrical innovation and a progressive enhancement of Industry 4.0. It bolsters the existing Industry 4.0 framework by providing a natural evolution that enhances its strengths (Zeb et al., 2022). Robots are employed for tedious, repetitive tasks, while humans oversee customization and engage in critical thinking roles. Crucially, Industry 5.0 restores the role of human labor in manufacturing processes (Maddikunta et al., 2022). The concept of Industry 5.0 fuses automation with information technology, facilitates data exchange, advances cyber-physical systems using AI and quantum computing, and pioneers novel manufacturing methodologies (Grabowska et al., 2022). In this synergy, humans and robots collaborate to forge an intelligent society. We stand at the threshold of the personification revolution, where human intelligence and artificial intelligence will work in unison (Ungureanu, 2020). Future industries are expected to play a pivotal role in devising solutions for societal challenges, such as pandemics and climate change. Through the integration of innovative and existing technologies, Industry 5.0 is poised to offer inventive solutions (Zeb et al., 2022).

Conclusion

In contemplating the future landscape of industry, it is imperative to recognize that the emergent Industry 5.0 paradigm is not just a successor to Industry 4.0; rather, it serves as a complementary and enhancing force. The symbiotic relationship between these industrial revolutions suggests a continuum where each phase builds upon the innovations of its predecessor, preparing the groundwork for the successive era. As scholars like Xu et al (2021) have noted, we stand on the cusp of a rapid evolution where terms such as "Industry 4.0," "Industry 5.0," and even the nascent "Industry 6.0" will permeate the lexicon of the global economy, signaling transformative shifts in the way we conceive and execute industrial processes.
The transition between industrial models is marked by an increasingly intricate interplay between technology and human ingenuity. In this dynamic, every individual—whether an industry employee or a consumer seeking specialized products—plays a pivotal role in shaping the industrial narrative (Zizic et al., 2022). Recognizing the centrality of human capital in this equation is essential for strategic maneuvering within the emerging industrial landscape. Human capital, as defined by the World Bank (2022), encompasses the cumulative investments in knowledge, skills, and health made by individuals over their lifetimes, enabling them to contribute effectively to societal advancement. It embodies not only the capacity for critical thought and societal participation but also the cultivation of cognitive abilities and self-awareness, which Orlova (2021) identifies as fundamental elements of human capital.

This study recognizes that the absence of a robust framework for the anticipated collaboration between industrial entities and the academic sector poses a significant barrier to effectively harnessing the full potential of human capital in the context of Industry 4.0 and 5.0 transitions. Without clear guidelines and models for partnership, there is a risk of disjointed efforts, underutilization of academic research in practical applications, and a potential skills mismatch in the workforce as industrial demands evolve.

The interdependence between an organization's success and the way it nurtures its workforce cannot be overstated. Hecklau et al (2016) emphasize that an organization's competitive advantage is deeply influenced by its workforce management strategies. To navigate this terrain effectively, a more robust collaboration between industrial entities and the academic sphere is imperative (Saniuk et al., 2021). Such partnerships are critical in ensuring that the workforce is adeptly prepared to meet the challenges and leverage the opportunities presented by the convergence of Industry 4.0 and 5.0.

As we look towards the horizon of an interconnected industrial ecosystem, it is clear that the integration of advanced technologies with a skilled, aware, and adaptable human workforce will be the cornerstone of sustainable growth and competitive superiority. The alignment of strategic planning with the enhancement of human capital represents a clear-sighted approach to thriving in the forthcoming industrial renaissance. It is through such an integrated, human-centric model that the full potential of Industry 5.0 will be realized, setting the stage for a future where technological progress and human flourishing are inextricably linked.

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