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# Bridging digital skill gaps in the global workforce: A synthesis and conceptual framework building☆

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ABSTRACT

Industries undergoing rapid digital transformation are facing a significant global challenge: a widening gap between required and available workforce digital skills. This study identifies key determinants of this gap and develops a comprehensive conceptual framework for mitigation. The research adopted a mixed-methods strategy, integrating expert insights through interviews and a PRISMA-informed systematic review of existing literature. The findings identify critical enablers, including accessible digital infrastructure, targeted investments in skilling, inclusive policies, government-led digital literacy initiatives, industry-aligned curricula, and organizational digital maturity. In contrast, key barriers include limited access to quality educational resources, outdated curricula, high infrastructure costs, and inadequate regulatory support. Further, integrating the Resource-Based View and Technology Acceptance Model, Technology–Organization–Environment frameworks, we propose a novel conceptual model capturing organizational and individual factors influencing skill acquisition. This framework elucidates the complex dynamics driving digital skill gaps and provides actionable guidance for designing inclusive, future-ready upskilling strategies. Our findings offer vital insights for researchers, HR leaders, educators, and policymakers building resilient, digitally competent workforces for Industry 4.0 and beyond.

## Introduction

The work environment has changed considerably over the past few decades, driven by advances in information and communications technology (ICT) resulting in the democratization of remote and hybrid work (Cherbonnier et al. 2025). This transformation demands digital skills (Van Deursen et al. 2014). The Fourth Industrial Revolution, or Industry 4.0, is rapidly advancing and transforming the industrial paradigm, reshaping social, economic, and political landscapes (French et al., 2021). Industry 4.0 signifies a dramatic change in how sectors function and develop. Artificial Intelligence (AI), the Internet of Things (IoT), machine learning, programming, data analytics, and augmented and virtual reality (AR/VR) are some of the cutting-edge technologies that are driving this change (Huber et al., 2022; Bag & Wood, 2022; Hernandez-de-Menendez et al., 2020). Amid this wave of digital transformation, the pace of technological advancement continues to accelerate, with new digital capabilities emerging each year (Nadkarni & Prügl, 2021). Industries are changing and the way work is done is being redefined by this quick evolution. Since Industry 4.0 and rapid digitalization put more demands on the workforce, navigating this dynamic environment requires proficiency with advanced digital technologies (Alam & Dhamija, 2022; Giwa & Ngepah, 2024; Kinkel et al., 2022). This in turn has prompted workers to upskill and acquire new digital competencies to aligned to the new technologies embraced under the umbrella of Industry 4.0(Pacheco & Coello-Montecel, 2023). In this context, addressing digital skill gaps is crucial to ensure inclusive participation in the digital economy. This enables both individuals and nations to thrive in an increasingly interconnected and technologically driven world. (Kraiwanit et al. 2023; Maji & Laha 2022; Tran et al. 2023). Lack of digital skills can lead to greater socioeconomic divides across industries and geographical areas (Ho et al. 2025; Maji & Laha 2022; van Laar et al. 2020).

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For organizations to remain competitive, efficient, and productive, workforce skill development is crucial (Wesche & Handke, 2024). To thrive in the modern digital economy, employees must possess twenty-first-century competencies (Bejinaru, 2016; Sokół & Figurska, 2017). Digital skills, encompassing the ability to utilize digital technologies, communication tools, and online networks to retrieve and manage data, are part of this category (Feijao et al., 2021). In today's information-driven, digital society, varying levels of digital proficiency are crucial for all individuals (Feijao et al., 2021). Such skills not only enhance job performance but also help mitigate technostress among workers (Xie & Yang, 2025). As Deursen et al. (2025) aptly note, "Smart devices require skilled users. These skills are essential for businesses sustainability, workforce development, secured employment, and economic growth (Ozkan-Ozen & Kazancoglu 2022; Reddy et al. 2023) and for enhancing workforce productivity, efficiency, motivation, confidence and overall experience in the organization (Carlisle et al. 2023; Joshi et al. 2024; Shanthi & Sharma 2019), thereby driving organizational competitiveness and innovation (McGuinness & Ortiz 2016; van Laar et al. 2017). Digital skill development contributes to long-term digital resilience, playing a key role in helping businesses align with and advance sustainable development objectives (Tran et al. 2023; Várallyai & Herdon 2013; Wang et al. 2025).

The rapid shift to remote work, online learning, and digital services during and after COVID-19 has amplified the importance of human–computer interaction. The pandemic accelerated digital transformation across various sectors (Feijao et al., 2021; OECD, 2020), leading to a rapid surge in demand for digital skills and, consequently, widening digital skill gaps. Companies are focusing on enhancing digital competencies to help their employees thrive in dynamically evolving remote and hybrid work settings (Gao et al. 2024). The term skill gaps describes a misalignment between the abilities individuals currently hold and those demanded by the prospective roles in the industry (McGuinness & Ortiz, 2016), or more specifically, the disparity between the skills acquired by the workforce and those actually needed by firms (Shanthi & Sharma, 2019). Workers with lower skills, especially those engaged in routine activities, often encounter difficulties in adapting to evolving skill requirements and have a risk of losing their job (Frey & Osborne 2017; Guliyev 2023). Identifying skills gaps and their determinants is crucial, as they can have detrimental impacts on the economy (Bag et al. 2021), organizations (McGuinness & Ortiz 2016; Sokół & Figurska 2017), and individuals (Shanthi & Sharma 2019; Reddy et al. 2023). Lack of digital skills can result in increased training and labor costs (Goulart et al. 2021), decreased productivity and profitability (McGuinness & Ortiz 2016), challenges in hiring (Mikalef & Krogstie 2019; James 2021; Saniuk et al. 2023), and mass unemployment (Bag et al. 2021). Persistent skills gaps can threaten the adoption of emerging technologies (Schneider 2018); and impede employee motivation, confidence and behavior (Shanthi & Sharma 2019). Analyzing digital skills gaps is crucial for organizations to ensure a well-trained workforce for new technologies (Li 2024). Hence, the success of Industry 4.0 relies on the overall skills of the workforce, making it imperative to address and bridge these digital skills gaps (Bughin et al. 2018; Hernandez-de-Menendez et al. 2020). However, the digital skilling of the workforce remains a significantly under-researched area, as also emphasized by Nadkarni and Prügl (2021). Therefore, studying the future of digital skills and digital skills gaps becomes particularly important.

Previous SLRs have identified the various facets of (digital) skill gaps across sectors. However, they have predominantly focused on the relationships between digital skills and 21st century skills (van Laar et al. 2017), determinants of 21st-century skills (van Laar et al. 2020; Koehorst et al. 2021) and skills demand for Industry 4.0 (Li 2022; Hernandez-de-Menendez et al. 2020). Unlike prior work, our research examines the uncharted dynamics (enablers and barriers) that influence digital skill gaps in Industry 4.0 environments.

The term "digital globalization" describes the more interconnected cross-border movement of data, technologies, digital services, and workers with digital skills that is changing social and economic systems all over the world (Luo 2021). Digital globalization places greater emphasis on the dissemination of innovation, knowledge, and technology, contrasting with traditional globalization, which primarily focused on trade in goods and the movement of capital (Burlacu et al. 2021; Luo 2021; Schilirò 2020). Due to the increased demand for digital capabilities worldwide, having digital skills is essential for engaging in the rapidly changing digital economy (Adeyinka-Ojo et al. 2020; Guitert et al. 2020; Martínez-Cantos 2017; Maji & Laha 2022). However, this rapid spread of technology has also exposed and widened disparities in digital preparedness between countries, regions, and socio-economic groups. In addition to impeding inclusive growth, the resulting digital skill gaps run the risk of marginalizing communities and industries that face challenges in keeping pace with the rapidly evolving technological advancements (Feijao et al. 2021; OECD 2020; Turner 2016; Van Dijk 2020). The digital skills gap has become a global policy priority because it necessitates concerted efforts from governments, corporations, and educational institutions. (Feijao et al., 2021; Guitert et al., 2020; James, 2021). This research enhances current academic understanding by systematically uncovering the key factors behind digital skill gaps through an SLR. The findings derive a theory-driven framework that can augment digital skills development efforts on both national and global scales. These insights aim to aid workforce policy formulation, HR professionals in strategic talent management, and recruitment teams adapt to evolving employer expectations. By addressing the concerns of industry leaders, academic bodies, and policy developers, this SLR offers relevant and actionable strategies for bridging digital skill gaps. The review also provides capacity building trainers and academicians with actionable guidance to better bridge learners' digital skillsets with the needs of today's job market.. The study is guided by two research objectives:

RO1: To identify the significant determinants, both enablers and barriers, of digital skill gaps.

RO2: To propose a practical framework for addressing and mitigating digital skill gaps across sectors.

To conceptually anchor the study, this research draws upon three complementary theoretical perspectives: the Technology Acceptance Model (TAM) (Davis, 1989a, 1989b), Technology-Organization-Environment (TOE) framework (Tornatzky & Fleischer 1990), and Resource Based View (RBV) (Barney 1991). These theoretical models support understanding of the behavioral, structural, and strategic elements that influence digital skill gaps through a multi-dimensional lens. A detailed exploration of these theoretical frameworks and their applicability to the study's context is presented in Section 2 (Background).

Section 2 presents the background and contextual foundations of the study. Section 3 outlines the research design and methodological approach. Section 4 provides the main findings, serving as the basis for the theoretical framework proposed in Section 5. Section 6 explores the wider implications of the study, covering theoretical, practical, and societal implications, while also acknowledging the current study's limitations. Finally, Section 7 summarizes the principal insights and offers directions for future research.

## Background

Digital skills can be categorized into basic, intermediate (or moderate), and advanced levels, depending on their complexity and usage (Beblavý et al. 2016; Behrend et al. 2022; Bughin et al. 2018). The basic skills include the ability to use simple computer functions, such as operating systems; and ability to operate digital instruments for communication, information gathering, and social media (James 2021). The digital economy requires advanced digital skills to effectively create, share, communicate, collaborate, and solve problems. These skills, including AI, programming, IoT, machine learning, blockchain are integral to the current digital landscape (Pirzada & Khan 2013; Mikalef & Krogstie 2019; Alam & Dhamija 2022; Carlisle et al. 2023).

While terms such as "digital competence", "digital skills", "technological literacy" and ICT skills, are frequently treated as synonyms in academic literature, this research applies a fresh perspective of digital skills to enhance analytical precision, defining them as the abilities essential for navigating digital technologies within workplace environments and broader societal contexts. These include both foundational abilities, such as operating digital tools and applications, and more advanced competencies, including data analysis, digital collaboration, and cybersecurity awareness.

In contrast to ICT skills, encompassing technical expertise with hardware and software, and technological literacy, which involves the ability to understand and assess technology, digital skills in this context are defined as practical, task-driven competencies tailored to the dynamic requirements of contemporary work environments. While digital competence represents a broader construct encompassing knowledge, attitudes, and ethical technology use, digital skills in this study are used as the core operational construct guiding the methodology and framework development. This delineation ensures that the study remains anchored to the specific workforce-oriented dimensions of digital capability that are most relevant to bridging the skill gap amid ongoing digital transformation.

The classification of digital skills into *"Basic or General," "Intermediate or Moderate," and "Advanced"* was systematically derived through a rigorous synthesis of existing literature as part of this systematic review. The tiered framework offers a comprehensive and nuanced understanding on the diverse digital competencies needed within the global workforce. It helps to more accurately assess existing skill gaps and formulate targeted strategies for effective intervention.

Based on thematic analysis and cross-referencing across studies, the study established criteria for each tier. The PRISMA-driven thematic analytical methodology is explained in detail in Section 3.2:

i. *Basic or General:* This category covers fundamental digital skills, such as word processing, email, and internet browsing, which are essential for routine tasks and entry-level roles (Allmann & Blank 2021; Carlisle et al. 2023; James 2021; Sailer et al. 2021). Typically acquired through basic training or everyday use, these competencies are now standard for active participation in the digital world.
ii. *Intermediate or Moderate:* Expanding on basic competencies, this tier encompasses intermediate digital skills that enable more strategic and efficient use of digital tools. Key abilities include professional communication via productivity software, file management, basic data handling, and adherence to core cybersecurity practices (Allmann & Blank 2021; James 2021). These skills are generally acquired through formal training or hands-on workplace experience.
iii. *Advanced:* This category represents advanced digital expertise and deep conceptual understanding, essential for roles in high-tech and innovation-driven fields such as data science, software engineering, cybersecurity architecture, machine learning, and emerging technology development (Arcelay et al. 2021; Feijao et al. 2021; Li 2024; Pessot et al. 2021). Proficiency at this level usually demands formal education, professional industry certifications, or extensive on-job practical training.

This tiered classification serves as a foundational tool for assessing digital proficiency levels, designing skill development pathways, and aligning workforce capabilities with current and future technological demands. Fig. 1 illustrates the digital skills tiered classification. This paper primarily focuses on discovering the determinants of the 'Professional' digital skills that help gain employment.

To gain a well-rounded perspective on the determinants of digital skill gaps, this study integrates three established theoretical frameworks: the TOE (Tornatzky & Fleischer 1990), TAM (Davis, 1989a, 1989b), and RBV (Barney 1991). TOE offers a holistic lens for analyzing external and internal organizational factors (Tornatzky & Fleischer 1990)—technological infrastructure, organizational readiness, and environmental influences—that shape digital skill development ecosystems. TAM helps capture user-level attitudes and behaviors toward adopting digital technologies (Davis, 1989a, 1989b) and training initiatives, which are critical in understanding motivation and resistance to digital upskilling. RBV provides a strategic perspective (Barney 1991) by positioning digital skills as key intangible assets that can enhance an organization's competitive advantage. The integration of these theories ensures that the study not only maps the external and internal enablers and barriers to digital skills development but also aligns them with organizational strategy and individual adoption behavior—thereby supporting the dual objectives of identifying determinants and proposing a contextually relevant intervention framework.

## Methodology

### *Expert Interviews for themes and keyword identification*

To ensure the relevance and comprehensiveness of the search process

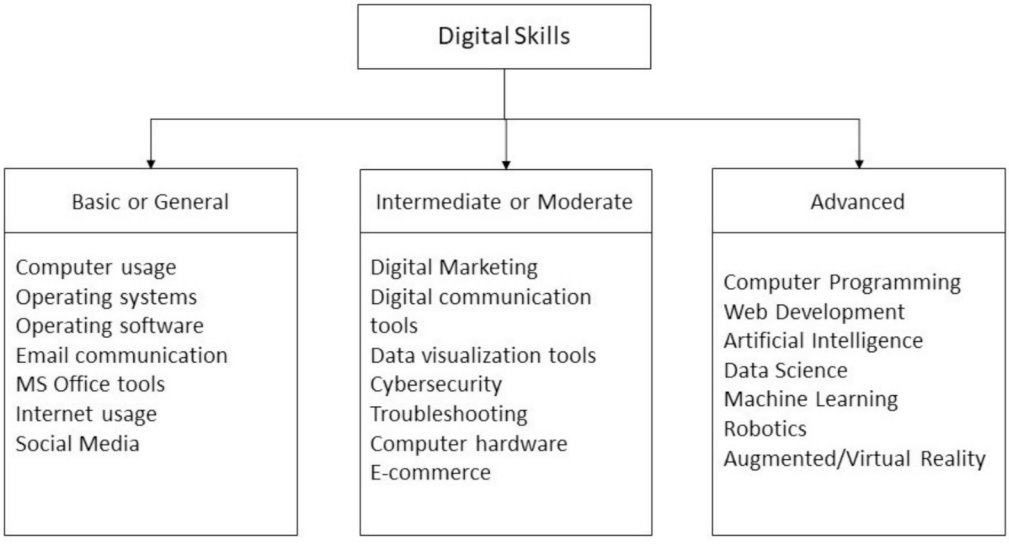


**Fig. 1.** Digital skills tiered classification (Synthesized from literature).

in this systematic literature review (SLR), an exploratory phase involving expert interviews was conducted prior to finalizing the search strategy. This preliminary step helped refine the themes and keywords to be used in the SLR.

Five experts with substantial experience in digital skilling and workforce development were interviewed after obtaining prior consent. These experts were selected through purposive convenience sampling, ensuring relevance and diversity across domains such as capacity building, industry, academia, and public policy. The interviews were conducted using a semi-structured format over virtual platforms (MS Teams), and each session lasted between 45 and 60 min. To enhance transparency and methodological clarity, a summary of the expert profiles is provided in Table 1.

To refine the search strategy and ensure the robustness of our systematic literature review, we conducted semi-structured interviews guided by the following core questions:

(i) What are the major areas of digital skills that you consider vital for modern industries operating within the Industry 4.0 paradigm? *(This question aims to identify key domains of digital competency relevant to current and emerging industrial needs.)*
(ii) What specific "terms" or "phrases" do you frequently encounter in research, policy, or industry practice related to digital skills? *(This helps surface commonly used keywords and constructs for inclusion in the literature search strategy.)*
(iii) Are there any specific competencies or skills you have observed to be frequently lacking among staff during digital transformation efforts? Additionally, are there any emerging concepts, frameworks, or buzzwords in the digital skills domain that you believe should be included in a comprehensive literature review? *(This double-barreled question seeks both skill gap insights and evolving trends or language in the field.)*

The primary focus of these interviews was to identify emerging trends, key terminologies, and sector-specific nuances within the digital skilling landscape. Through thematic analysis of the interview transcripts, several core concepts surfaced, including *"digital competency," "workforce digitalization," "digital training,"* and *"21st-century skills."*.

Additionally, the analysis revealed specific digital skill areas frequently associated with gaps in industry. These included high-demand technical competencies such as *"Analytics," "Data Science," "Machine Learning," "Business Intelligence," "Artificial Intelligence," "Big Data," "Cloud Computing," and "Robotics."*.

These insights informed both the refinement of search keywords and the conceptual framing of the systematic literature review, ensuring its alignment with real-world demands and emerging discourse.

### *PRISMA driven systematic literature review*

We employed the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) methodology (Moher et al. 2015) of SLR. Three databases, Scopus, EBSCO Business Source Ultimate, and Science Direct were searched. These databases were chosen as they included the most relevant and reputable peer-reviewed journals, established by publishers as Elsevier, Emerald, Springer, IEEE, and Taylor and Francis. These databases traditionally host research on digital skills demand and digital skills gaps. Also, several existing SLRs on digital skills gaps analysis (van Laar et al. 2017; Hernandez-de-Menendez et al. 2020; van Laar et al. 2020; Koehorst et al. 2021; Li 2024) and other recent systematic literature review studies (Schneider et al. 2018; Calderon-Monge & Ribeiro-Soriano 2024; Pütz & Werner 2024; Baltazar et al. 2023) have used these databases to source their articles.

**Table 1**
Demographic Summary of expert profiles.

| Expert Code | Role/Designation | Industry/ Domain | Region of Operations |
|---|---|---|---|
| E1 | Senior Professional, Skilling Sector, Government of India | Government/ Policy | India |
| E2 | Senior Manager, Corporate L&D | ITES Sector | MNC |
| E3 | Consultant, Skills & Innovation | International Development | Southeast Asia |
| E4 | Professor, Digital Education | Academia | Australia |
| E5 | Consultant, Digital Skilling and Capacity Building | Freelance professional | South Asia |

The literature search process began with brainstorming around the core themes identified—namely *digital skills*, *skill gaps*, *industrial revolution*, *Industry 4.0*, *digitalization*, and *digital transformation*. An initial list of keywords was generated based on these themes and used to perform a preliminary search.

As relevant literature was gathered, the keyword list was refined through multiple iterations by incorporating frequently occurring terms and relevant synonyms. In parallel, the emerging themes and terminology identified through expert interviews (as detailed in Section 3.1) were also integrated into the evolving keyword set.

The final search was conducted using this comprehensive and refined corpus of keywords, applied across the *title*, *abstract*, and *keywords* fields to ensure broad yet targeted coverage of relevant studies.

Search strings: ("Digital" OR ""Digital competency" OR "Workforce digitalization" OR "Digital training" OR "21st-century skills" OR "Technology skills challenges" OR "Future skills" OR "Industry 4.0" OR "Factory of Future" OR "Fourth Industrial Revolution" OR "Digitization" OR "Digitalization" OR "ICT" OR "Technolog*" OR "Data Science" OR "Analytic*" OR "Machine Learning" OR "Artificial Intelligence" OR "Big Data" OR "Business Intelligence" OR "Robotics" OR "Cloud" OR "IoT" OR "Workforce" OR "Employ*") AND ("skill gap*" OR "skills gap*").

The search focused on English-language journal articles in Social Sciences, Engineering, Computer Science, Business, Psychology and Decision Sciences (Inclusion criteria). The initial database search returned a total of 1,416 documents: 525 from Scopus, 567 from ScienceDirect, and 324 from EBSCO. After removing duplicates, 570 unique articles remained. A detailed screening of titles and abstracts was then conducted to assess relevance, resulting in 206 articles selected for their focus on the determinants of digital skill gaps and the evolving demands for digital skills.

Following a thorough full-text review and quality assessment, a final corpus of 144 articles was retained for in-depth analysis. Fig. 2 represents the systematic selection process, including the criteria for quality appraisal and relevance.

## Findings

The findings of the SLR reveal the major enablers and barriers of digital skill gaps. "Enablers" are the factors that assist the process of bridging digital skills gaps while "barriers" hinder the process. or improved clarity and accessibility. Table 2 exhibits a listed summary of the key enablers and barriers identified through the PRISMA-driven SLR process.

### *Enablers*

#### *Accessible and affordable technology infrastructure*

Affordability of services and infrastructure is a critical factor for Information and Communication Technology (ICT) access (Dewan & Riggins 2005; Maji & Laha 2022). High cost of services can widen the disparity between rich and poor, and bandwidth and speed can affect the ability to transmit knowledge (Hernandez & Roberts 2018). The pandemic forced work and education online, highlighting the shortcomings of digital infrastructure (Middleton 2021). There is a need for policymakers to expand their attention toward building inclusive and cost-effective frameworks for digital skilling programs (Ho et al. 2025;

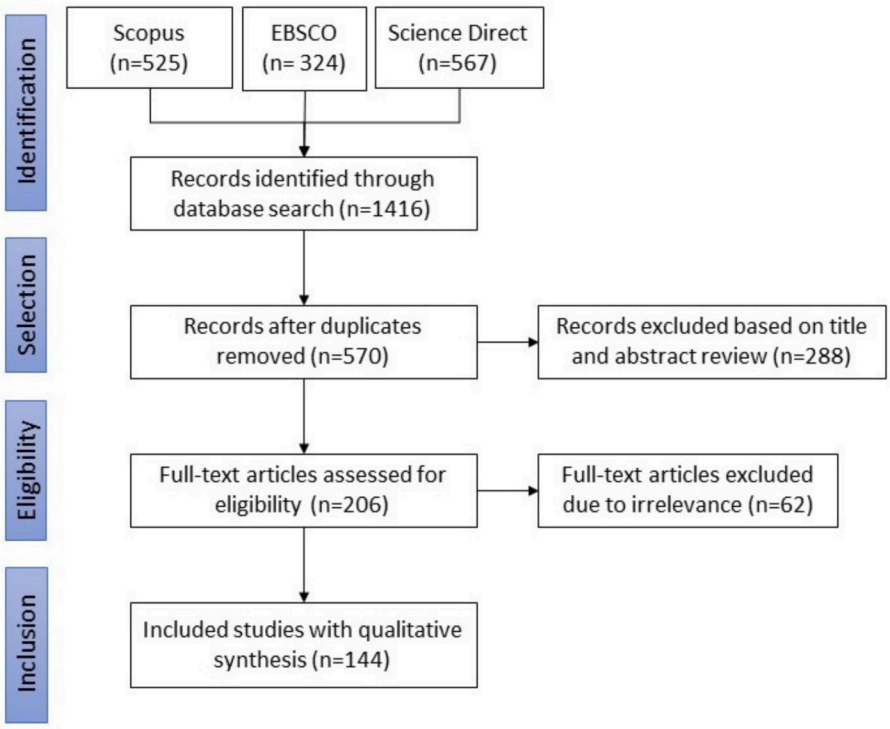


**Fig. 2.** PRISMA Flow Diagram.

**Table 2**
Summary of Enablers and Barriers to Bridging Digital Skill Gaps.

| Enablers | Barriers |
|---|---|
| Accessible and affordable digital infrastructure | Limited access to educational and digital infrastructure |
| Government-led digital literacy campaigns | Outdated curricula misaligned with industry demands |
| Inclusive policies for marginalized and underserved populations | Lagging regulatory and policy frameworks |
| Inclusive policies for marginalized and underserved populations | Lagging regulatory and policy frameworks |
| Industry-aligned and future-ready curricula | Low awareness and digital readiness in certain regions |
| Community-based learning and grassroots skilling platforms | Fragmented implementation of digital initiatives |
| Strategic investments in digital skilling and workforce development | Scarcity of affordable and flexible training opportunities |
| Collaboration between academia, industry, and government | Resistance to change within traditional institutions |
| Organizational digital maturity and workplace learning support | Digital divide due to socio-economic or geographic disparities |

Middleton 2021; Taylor 2018).

*Investments in digital skilling*

According to Ho et al. (2025) and Wesche & Handke (2024), digital training plays a critical role in upgrading workforce skills. Beyond infrastructure, deliberate investment in inclusive and wide-ranging digital skilling efforts can substantially reduce skill gaps and contribute to a fairer digital environment (WEF 2016). Organizations, sectors and countries where there have been less investments in digital skilling initiatives have reported wider digital skill gaps (Feijao et al. 2021).

*Inclusive policies*

Inclusivity, diversity, and equity (IDE) policies aim to bridge digital skill gaps by addressing systemic and social barriers, promoting equal opportunities, and empowering individuals from diverse backgrounds (WEF 2016). The disparities can be because of several factors and, thus, certain groups can be more deprived than others, such as rural areas (Kapetaniou 2020; OECD 2020), older generations (European Commission 2020), women (Martínez-Cantos 2017; West et al. 2019), and some ethnicities and low-income groups (Turner 2016; Van Dijk 2020). The pandemic highlighted the unequal access to digital technology in society (Reisdorf & Rhinesmith 2020). IDE policies are being strengthened to address systemic barriers to access, such as the US Technology Inclusion and Diversity Act (2017) and the Digital Agenda initiative by the European Union (European Commission 2010; Martínez-Cantos 2017).

*Government-led digital literacy campaigns*

Digital literacy campaigns can help bridge digital gaps by expanding digital training and promoting digital literacy in education (Pirzada & Khan 2013). Governments can address the digital divide by developing and implementing policies for digital access and education, internet access, providing free devices and low-cost services (UNESCO 2018). Few of the government-led digital literacy and skilling initiatives which yielded positive outcomes are National Digital literacy Mission, and Prime Minister's Village Digital Literacy Mission (India), Digital Readiness Initiative (Singapore), Digital Skills for everyone (UK), Digital Literacy and Skills Strategy (Australia).

*Community-based learning platforms*

Innovative technologies and new media open up exciting avenues for rethinking educational practices, university coursework, and community-oriented learning models (Fischer et al. 2007). The mobile learning community can provide informal, community-based education to people with socioeconomic, cultural, and environmental difficulties (Palalas 2017). Online learning is an effective and financially appealing way to teach high-level technical skills. It is crucial for those without traditional education. It uses ICT to improve digital skills through courses (Berger & Frey 2016; Várallyai & Herdon 2013). Digital platforms are essential for low-skilled workers (Lyons et al. 2019) as they offer flexibility, sustainability, and cost-effectiveness, benefiting

underprivileged groups struggling with cost and infrastructure barriers to skill development (Hernandez & Roberts 2018; Taylor 2018).

*Industry Digital Maturity*

The concept of digital maturity in industry denotes the level of progress an organization has achieved in adopting and integrating digital technologies (Chanias & Hess, 2016). Within the context of Industry 4.0, an organization's skill requirements are closely linked to its level of digital maturity (Plawgo & Ertman, 2021; Spitzer et al., 2015). While certain sectors demonstrate a higher degree of readiness for Industry 4.0, others, such as manufacturing, continue to lag behind (Dutta et al., 2020; Mikalef & Krogstie, 2019; Pessot et al., 2021). One major barrier to effective digital skilling is the absence of a strong digital culture within organizations (Pessot et al., 2021). Furthermore, digital maturity has a direct influence on employees' proactive skill development, especially when they perceive digitalization as both achievable and an opportunity for personal and professional growth (Ostmeier & Strobel, 2022).

*Industry-aligned curriculum*

Curriculum reform in higher education, tailored to the demands of Industry 4.0, is crucial for equipping graduates with the skills needed to thrive in an evolving job market (Brezeanu & Lazarou 2020; Dutta et al. 2020). The conventional curricula are slow in adapting to the changes in the real world (Granger et al. 2007; McGann et al. 2007). Work-integrated learning is a typical strategy of incorporating practical, real-world work experience into academia (Carmichael et al. 2018).

*Barriers*

*Limited access to educational resources*

Technological innovation has surged in developed nations, yet the digital divide remains a major obstacle to digital literacy in developing countries (Miah & Omar 2012). One of the primary barriers in reducing skill gaps is the inaccessibility and inequity of online training and lack of formal training programs (Forde & O'Brien 2022; Poulose et al. 2024). This limitation negatively impacts lifelong learning, social inclusion, and employment (Lyons et al. 2019). To narrow the digital skills gap, it is essential to ensure that training initiatives are both accessible and affordable, catering to diverse populations regardless of demographic or geographic differences (Feijao et al. 2021; Maji & Laha 2022; Vassilakopoulou & Hustad 2023).

*Lagging regulatory framework*

The policy and regulatory framework has lagged in keeping pace with rapid technological advancements (Nelson, 2017), contributing to widening skill gaps and leaving industries struggling to find adequately skilled workers. Technological advancements rapidly create new jobs and demand new skills, simultaneously eliminating existing ones, emphasizing the dynamic nature of the labor market and the need for workers to adapt (OECD 2020). Enterprises operate inside government rules and regulatory frameworks, which need consistent guidelines. Employees feel more empowered and less anxious when they can adjust quickly to changes (Shanthi & Sharma 2019). The governments must address various restraints influencing the business climate, particularly those in the regulatory framework, skills development, and infrastructure (Mbaye et al. 2021).

*Scarcity of affordable infrastructure*

The digital divide is a concept that illustrates pre-existing social inequalities in the ability to access and effectively use digital technologies, influenced by factors such as education, income, economy, and urbanization (van van Duersen & van Dijk 2010; Feijao et al. 2021). Potential digital talent is sometimes ignored due to disparate access to digital infrastructure and skills based on socioeconomic class (Feijao et al. 2021). Barriers to adopting digital infrastructure may vary depending on cost-effectiveness, internet bandwidth, and access to digital tools and devices, including computers, mobile phones, and relevant applications (Hernandez & Roberts 2018). Other factors influencing this divide are age (Choudrie et al. 2022; Vassilakopoulou & Hustad 2023), gender (Martínez-Cantos 2017), geography and economy (James 2021), physical access to digital infrastructure (Van Deursen & Van Dijk 2019), and ease of access (Maji & Laha 2022).

*Insufficient collaboration*

Public-private collaboration (PPC) can advance digital skills within a knowledge-based economy. It helps close knowledge gaps, aligns training with industry needs, and leverages private sector expertise and resources (Mikalef & Krogstie, 2019). Embedding PPC into curriculum design and delivery is essential for developing relevant digital competencies (Lyons et al., 2019). Such collaboration drives innovation, supports economic transformation, and fosters sustainable competitive advantage (Akyazi et al., 2020; Elnasr Sobaih & Jones, 2015). Engagement with HR professionals (Goulart et al., 2022) and structured internships (Belinda, 2023) also offers critical insights into sector-specific skill demands, enhancing alignment between education and labor market expectations.

*Outdated Curricula*

The inability of traditional academic models to equip students with relevant digital skills has led to a persistent misalignment between graduate capabilities and labor market expectations. This issue arises from curriculum inertia, outdated pedagogical approaches, and a lack of integration with the dynamic requirements of the digital workforce (Enders et al. 2019). Stronger coordination with industry and continuing interaction are required to ensure that study programs and curriculum remain relevant (Mikalef & Krogstie 2019) for different industries, such as food (Akyazi et al. 2020), manufacturing (Saniuk et al. 2023), and accountancy (Akande & Atiku 2022).

## Conceptual framework of digital skills gaps and their determinants

We propose a conceptual framework for digital skilling inspired from three frameworks, namely the TOE (Tornatzky & Fleischer 1990), TAM (Davis, 1989a, 1989b), and RBV (Barney 1991). The adoption of digital technology requires individuals to acquire relevant digital skills, which in turn facilitates and reinforces the effective use of digital tools workplace environments.

The constructs of the TAM, namely *Perceived Usefulness* (PU) and *Perceived Ease of Use* (PEOU), which are widely employed in the literature to explain digital technology adoption intentions, can also play a symbiotic role in shaping individuals' intentions toward digital skilling. Our proposed framework integrates key constructs within the Technology–Organization–Environment (TOE) framework, creating a complementary model in which TOE factors influence the TAM determinants of digital skilling intention. This integrative approach aligns with a growing body of research that effectively merges TOE and TAM to explain the adoption of digital technologies and skills across various domains, including healthcare (Abdekhoda et al., 2019), education (Gholami et al., 2018; Sulaiman et al., 2023), and sectors like IT, manufacturing, and finance (Gangwar et al., 2014).

This framework integrates the TOE model with the Resource-Based View (RBV), aligning organizational resources, such as technological infrastructure and institutional support, with TOE components, while capabilities are embodied by digitally skilled personnel who effectively deploy these resources. As shown in Fig. 3, the model combines TOE, TAM, and RBV to explain how TOE factors influence user perceptions, namely, PU and PEOU, along with behavioural intentions and decisions related to digital skill acquisition. Through this process, the framework supports the development of individual competencies and contributes to broader organizational outcomes (Bryan & Zuva, 2021).

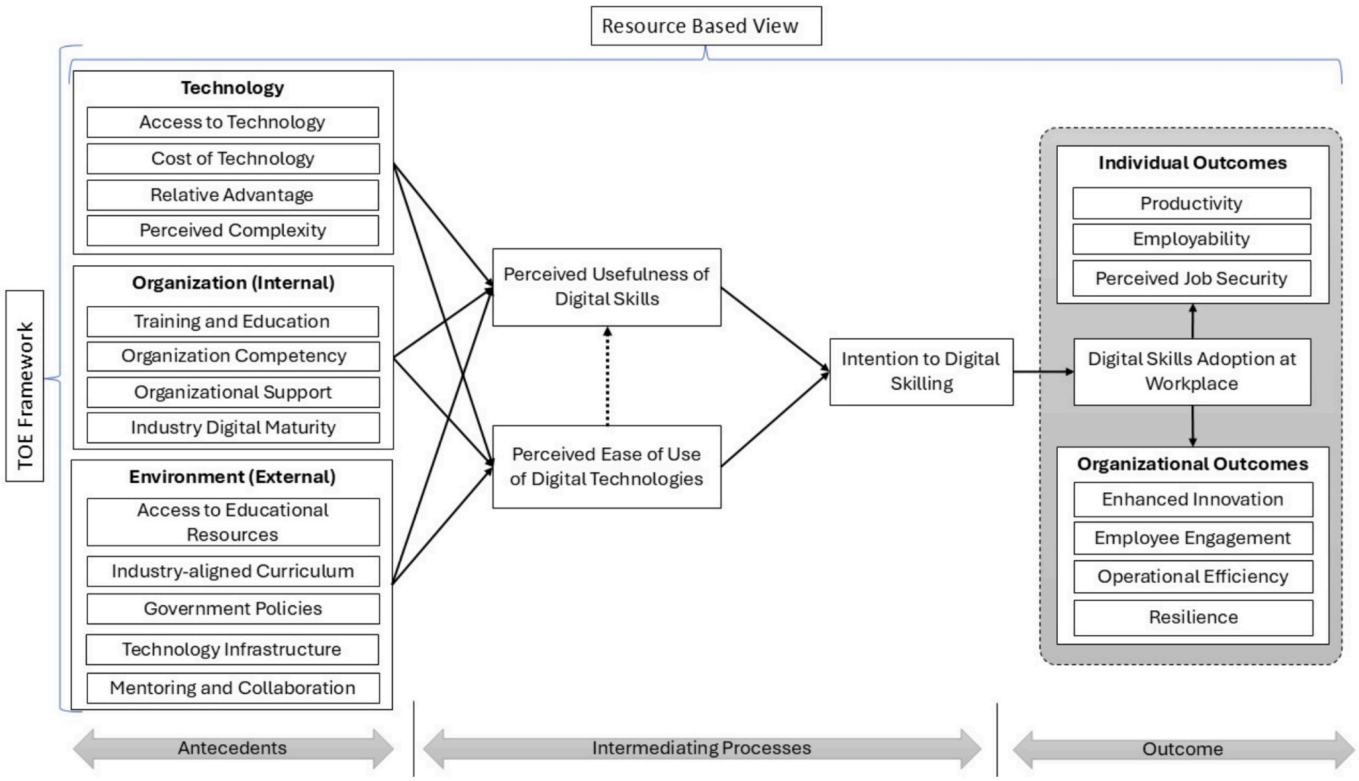


**Fig. 3.** Proposed TOE-TAM-RBV Framework for addressing Digital Skills Gaps.

The user's attitude toward digital technology, particularly their perceptions of usefulness and ease of use, is influenced by the interaction of organizational, technological, and environmental dimensions within the TOE framework. Technological factors, such as the clarity and complexity of the learning process (Awa et al., 2017), perceived career benefits of digital competencies (Gholami et al., 2018), and individual cost-benefit evaluations related to skill acquisition (Na et al., 2022), influence these perceptions. Individuals who view digital skills as professionally advantageous and relatively easy to acquire are more likely to pursue digital upskilling. Additionally, techno-economic factors, such as access to technology and the financial costs associated with learning tools (e.g., software, hardware, infrastructure), further influence intentions and behaviours related to digital skill development (Awa et al., 2017; Bryan & Zuva, 2021).

Organizational factors influence employees' perceptions of both the usability and value of digital technologies. A workplace culture that prioritizes digital literacy and supports continuous learning fosters a motivational environment conducive to digital skill development. Strategic commitment and active involvement from top management are particularly influential, serving as key drivers of successful digital transformation (Elnadi & Abdallah, 2024). Empirical studies highlight the importance of strong organizational and managerial support in enhancing employee proficiency in emerging digital tools (Awa et al., 2017; Chatterjee et al., 2021; Gupta et al., 2022; Na et al., 2022; Nadkarni & Prügl, 2021). Targeted training initiatives not only mitigate technophobia and reduce uncertainty but also help build a more confident, adaptable, and resilient workforce (Abdekhoda et al., 2016; Gangwar et al., 2014). This dual role, promoting technology adoption and improving the employee experience, positions organizational support as key to effective digital capability building (Joshi et al., 2024).

Organizational competence, encompassing the collective expertise, skills, and capabilities of employees, is a key enabler of digital transformation. It enhances employees' perceptions of the value of digital upskilling, thereby boosting motivation to adopt emerging technologies (Chatterjee et al., 2021; Gholami et al., 2018). While internal factors like technological readiness and organizational support are vital, external environmental conditions also play a critical role in influencing digital learning behaviours.

Access to enabling resources is particularly important. Affordable, high-quality educational content (Feijao et al., 2021; Maji & Laha, 2022) and reliable digital infrastructure (Van Deursen & Van Dijk, 2019) significantly improve skill development outcomes. In contrast, high costs and poor infrastructure can limit the effectiveness of training programs (Hernandez & Roberts, 2018). To address these challenges, government agencies and PPC bodies must lead targeted skilling initiatives, raise digital literacy through awareness efforts, and implement policies that encourage investment in digital education (Awa et al., 2017).

Organizations dedicated to digital skill development strategically leverage a combination of technological, organizational, and environmental enablers. Technological infrastructure, such as digital platforms and software systems, serves as the foundation for skilling efforts. Organizational resources, including skilled human capital, and strategic investments, reinforce and scale these initiatives. Meanwhile, environmental factors like accessible educational content, supportive policies, and cross-sector collaboration enrich the broader digital learning ecosystem. When effectively integrated, these enablers enhance workforce capabilities, driving higher skill levels, productivity, and adaptability.

The proposed framework synthesizes these multidimensional drivers through the integration of the TOE framework, TAM, and RBV. While emphasizing structural and behavioral enablers, the model also incorporates temporal flexibility, acknowledging that digital skill development is shaped by both immediate interventions and long-term systemic change. This layered approach enables a nuanced understanding of how digital competencies evolve across different timeframes and institutional settings, benefiting both individual employability and organizational resilience. Short-term interventions, such as targeted training programs, corporate upskilling workshops, and mentoring initiatives, can be rapidly deployed within organizational settings to

address immediate digital competency gaps. These measures often rely on existing infrastructure and are shaped by organizational readiness and industry digital maturity, which the model captures under the internal "Organization" and "Technology" domains.

In contrast, long-term interventions require sustained efforts at the policy and ecosystem levels. These include reforming national curricula to align with future digital competencies, enhancing access to educational infrastructure, building resilient broadband and technology ecosystems, and implementing inclusive digital education policies. These systemic levers are represented in the model through external "Environment" factors such as government policies, access to educational resources, and technology infrastructure.

By combining structural and behavioral dimensions, the proposed framework serves as a flexible tool for identifying context-specific interventions aligned with institutional readiness, skill needs, and strategic goals. It clarifies the complexity of digital skill development while offering practical guidance for sequencing and scaling efforts. Its temporal adaptability ensures alignment with both immediate priorities and long-term systemic change, maximizing impact across diverse settings.

## Discussion

### *Theoretical Contributions*

This study proposes a theoretical framework that models the antecedents of digital skilling intention and its adoption, integrating TOE, TAM, and RBV perspectives. The framework highlights how factors related to organizational context, technology, and the external environment shape the perceptions of digital skills' usefulness and ease of use, influencing employees' intention to upskill. By combining these theories, it offers a novel lens to understand the interaction between internal structures, technology access, and external influences in driving digital skill adoption in the workplace.

The framework also extends RBV by showing that strategic assets, like digital skills, are shaped by both internal capacities and external enablers such as educational resources and policy support. It links digital skilling to individual outcomes (productivity, employability, job security) and organizational gains (innovation, engagement, efficiency), offering a holistic view of digital transformation. The inclusion of mediating constructs like perceived usefulness and intention further strengthens its explanatory power of the framework, bridging critical gaps in technology adoption and workforce development literature in the context of Industry 4.0.

### *Managerial and Social Implications*

Organizations and managers must recognize that a digitally skilled workforce is essential for competitiveness and resilience in the evolving digital economy. Our proposed framework offers a practical roadmap for HR leaders, managers, and policymakers to design and implement effective digital skilling initiatives across sectors.

Leaders must create supportive environment through accessible resources, strategic investment, and mentorship. Lifelong learning and personalized upskilling programs are key to keeping the workforce future-ready. To boost employee commitment, organizations should align performance management, incentives, and leadership practices with digital skill development goals.

By leveraging the framework, organizations can strengthen enablers, such as training, support, and investment, while addressing and eliminating barriers to digital skilling. Collaboration with governments, policymakers, educational institutions, and private partners is essential to close digital skill gaps.

As digital globalization accelerates, bridging these gaps has become a shared priority across both developed and developing economies. The framework supports international cooperation, enabling policy harmonization, cross-border knowledge exchange, and multilateral skilling initiatives. It offers actionable insights for institutions like the World Economic Forum, UNESCO, and national governments to build inclusive digital skilling ecosystems aligned with the demands of Industry 4.0 and beyond.

### *Limitations*

This study has a few scope-related limitations. The literature was sourced from three major English-language databases, Scopus, EBSCO, and ScienceDirect, which may have excluded some relevant studies from other bibliometric databases such as Web of Science or IEEE Xplore or ProQuest. Additionally, the keyword search was limited to titles, abstracts, and keywords, potentially omitting articles where key terms appeared only in the main text. However, such articles are unlikely to have focused centrally on the study's core themes. Future research could expand database coverage and search depth to further enrich the findings.

## Conclusion and scope for future research

This review systematically examines and integrates existing research on the determinants—both enablers and barriers—underpinning digital skill gaps in the context of Industry 4.0. By identifying the structural, behavioural, and contextual factors influencing digital skilling, the study provides a nuanced understanding of how these gaps emerge and persist across sectors. Beyond diagnosis, the review emphasizes the strategic benefits of closing digital skill gaps, including enhanced competitiveness, resilience, innovation, productivity, profitability, and long-term sustainability.

Drawing from these findings, the research introduces a unified conceptual model grounded in the TOE framework, RBV and TAM. This interdisciplinary approach connects organizational dynamics, technological adoption behaviors, and strategic resource utilization to explain the formation and mitigation of digital skill gaps. The framework serves as both a diagnostic and strategic tool for organizations, policymakers, and educators aiming to develop targeted interventions.

Future research can enrich and validate this framework through empirical testing across industries, geographies, and job roles. Sector-specific investigations could map evolving digital skill demands and assess the long-term shifts in skilling needs post-pandemic. In particular, India, despite its large population, digital ambitions, and policy momentum, remains under-researched in this space. Rigorous impact assessments of national digital skilling initiatives could yield valuable lessons for emerging economies and inform global strategies to bridge digital divides and build inclusive digital workforces.

## CRediT authorship contribution statement

**Pravin Mhaske:** Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Biplab Bhattacharjee:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Methodology, Formal analysis, Data curation, Conceptualization. **Nivedita Haldar:** Writing – review & editing, Validation, Supervision, Resources, Project administration. **Parijat Upadhyay:** Writing – review & editing, Validation, Supervision, Resources. **Anandadeep Mandal:** Writing – review & editing, Supervision, Software, Resources, Project administration.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## *Further reading*

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