Linking Industry 4.0 Technologies to Organizational Performance through Human Skill Capabilities

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ABSTRACT

The Fourth Industrial Revolution (Industry 4.0) is transforming industries worldwide through advanced technologies such as cyber-physical systems, big data analytics, cloud computing, robotics, 3D printing, and augmented reality. This study examines the relationship between Industry 4.0 adoption, human skill capabilities, and organizational performance. Using quantitative research design and survey-based data collection, the research investigates how technological integration and workforce competencies contribute to business outcomes. Findings reveal that Industry 4.0 technologies significantly enhance organizational performance, particularly in efficiency, productivity, and cost-effectiveness. However, the study also emphasizes that technological advancements alone are insufficient; skilled human capital is critical for effective implementation and management. Competent employees are essential to address challenges, optimize the use of new technologies, and sustain organizational growth. The results highlight the need for organizations to balance investments in technology with workforce development, ensuring employees can adapt to rapid changes in the industrial landscape. This study contributes to both theory and practice by demonstrating that aligning technological progress with human capability development is vital for organizations to enhance performance and maintain competitiveness in the Industry 4.0 era.

Keywords: *Capability of Human Skill, Industry 4.0, Organizational Performance, Technology Components.*

INTRODUCTION

The world is approaching the Fourth Industrial Revolution (Industry 4.0), which transforms how businesses innovate, utilize markets, and adopt technology (Prause et al., 2017; Mahmood & Mubarik, 2020; Babeľová et al., 2022). Companies must adapt to remain competitive in this digital era (Harahap & Rafika, 2020). Industry 4.0 emphasizes the integration of digitization and advanced technologies into production systems (Castelo-Branco et al., 2022; Tortorella et al., 2020). Technologies such as IoT, big data, cloud computing, robotics, augmented reality, 3D printing, and cyber-physical systems enhance flexibility, efficiency, and performance while enabling mass customization (Costa et al., 2023; Cunha et al., 2022). Originating from Germany's high-tech strategy, Industry 4.0 reshapes competition and industrial operations (Bidnur, 2020; Sima et al., 2020; Duman & Akdemir, 2021; Asal et al., 2022; Apriyanto et al., 2025; Ritonga et al., 2025).

The Fourth Industrial Revolution is characterized by the integration and management of production processes in a highly flexible and efficient manner (Nagy et al., 2018; Soori et al., 2023). Industry 4.0 introduces a new manufacturing paradigm that significantly transforms human machine interaction (Nardo et al., 2020; Hassoun et al., 2022).

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Throughout history, each industrial revolution has marked a major milestone in human development, with future transformations expected to further advance society (Taşkan & Karatop, 2022). In this context, human involvement remains essential to keep pace with technological progress. Employee engagement enables organizations to enhance productivity, generate insights, and implement improvements based on knowledge and skills (Tortorella et al., 2021). Consequently, human resources must possess adequate competencies to adapt to industrial transformation. Broader technological perspectives also highlight the need for responsible innovation through both short- and long-term technological solutions (Potočan et al., 2021). While automation and system integration improve efficiency and reduce labor dependence, they also create complex interactions between humans, machines, and digital–physical environments, reinforcing the importance of human skills (Romero et al., 2016).

As digital technologies become increasingly embedded in industrial enterprises, significant transformations in operational frameworks are occurring, affecting both system efficiency and the well-being of individuals interacting with technological systems (Kadir & Broberg, 2020). The transition toward Industry 4.0 is reshaping employment patterns and work structures, creating both challenges and opportunities for organizations and workers (Hariharasudan & Kot, 2018; Kadir et al., 2019; Harahap & Rafika, 2020; Nurhasan et al., 2020). To address these challenges and take advantage of emerging opportunities, a deeper understanding of evolving socio-technical interactions is required. Furthermore, adopting human-centric approaches in implementing Industry 4.0 technologies is essential to develop work systems that align with this new industrial paradigm (Pfeiffer, 2016; Kadir et al., 2019). This research investigates whether the integration of Industry 4.0 technologies positively influences organizational performance and whether individuals possess the necessary skills to adapt to these developments. The findings offer practical strategies for companies seeking to optimize costs and streamline operations in the Industry 4.0 era (Soori et al., 2023). Central to this success is the proficiency of human skills, which are essential for overseeing and managing Industry 4.0 technologies. If individuals can effectively manage these advancements, organizations are likely to achieve favorable outcomes (Costa et al., 2023).

This study offers key contributions to both academic literature and practical applications. First, it advances understanding of Industry 4.0 by analyzing how core technologies such as cyber-physical systems, big data analytics, cloud computing, and automation enhance organizational performance through improved efficiency, productivity, and cost-effectiveness. Unlike prior studies focused mainly on technological integration, this research highlights the critical role of human skill capabilities as a mediating factor in successful Industry 4.0 adoption. Second, it proposes a conceptual framework linking digital transformation with human capital development, positioning human skills as a strategic enabler for achieving sustainable competitive advantage. Third, the findings provide practical insights for organizations, particularly in developing economies with limited digital infrastructure and skill readiness. By emphasizing the interaction between technology and human adaptability, the study offers recommendations for workforce upskilling, strategic alignment, and policy development. It presents an integrated perspective combining technological innovation with human-centered strategies to support holistic digital transformation. The purpose of this study is to examine the relationship between Industry 4.0 adoption, human skill capabilities, and organizational performance.

LITERATURE REVIEW & HYPOTHESIS DEVELOPMENT

The Effect of the Capability of Human Skills on Organizational Performance

Organizational performance represents the level of success achieved by an organization in fulfilling its operational and strategic objectives and is commonly used as an indicator of organizational effectiveness and competitiveness. Improving organizational performance contributes directly to increasing firm value and long-term sustainability (Tang & Fiorentina, 2021; Bianco et al., 2023). Within modern business

environments, performance reflects how efficiently organizations achieve market and financial goals while adapting to dynamic competitive conditions. Leadership plays a vital role in ensuring that innovative strategies remain aligned with organizational vision and objectives (Ellitan, 2020). Performance measurement systems also function as benchmarking tools, enabling organizations to evaluate achievements, motivate employees, and identify potential operational issues early. Consequently, organizational performance evaluation becomes an essential managerial instrument supporting informed decision-making and competitive success (Duman & Akdemir, 2021). As organizations increasingly operate in digital environments shaped by social media, mobile platforms, cloud computing, big data, and the Internet of Things, performance outcomes are increasingly influenced by technological capability and human competence simultaneously.

Human skill capability is crucial for organizational performance, especially in Industry 4.0, where tech adoption demands workforce adaptability. Advanced technologies bring improvements only when employees have the competencies to use them effectively (Janis & Alias, 2018; Duman & Akdemir, 2021; Tortorella et al., 2022). Cyber-physical systems enhance production flows but rely on human interaction and decision-making (Tohanean et al., 2018). Organizations that combine automation and big data with skilled employees gain competitive advantages (Costa et al., 2023). Monitoring workforce capability matters because lacking skills hinders technological change (Dabić et al., 2023). Behavioral factors like habits and attitudes also influence productivity outcomes (Jurnali & Supomo, 2002).

H1: The capability of human skills has a positive effect on organizational performance.

The Effect of Industry 4.0 on the Capability of Human Skills

Industry 4.0 refers to using disruptive technologies to digitally transform industry, aiming to improve efficiency and reduce operational costs (Yu & Schweisfurth, 2020; Mukhuty et al., 2022). It emphasizes real-time connectivity between humans, machines, and systems in digital production environments (Zaidin et al., 2018; Kozlovska et al., 2021). These technologies enhance automation and productivity while evolving traditional production into interconnected cyber-physical systems or "smart factories" (Haseeb et al., 2019). Often described as the industrial internet or smart factory paradigm introduced to strengthen competitiveness (Chen & Xing, 2015; Ślusarczyk, 2018; Sima et al., 2020; Duman & Akdemir, 2021), Industry 4.0 integrates people, objects, and processes and has expanded into practical implementation affecting productivity and innovation (Majid et al., 2022; Yang & Gu, 2021; Obermayer et al., 2022).

The adoption of Industry 4.0 technologies significantly reshapes workforce requirements by increasing demand for advanced skills and technological competence. Technologies such as cyber-physical systems, big data analytics, cloud computing, augmented reality, and 3D printing transform organizational operations and require employees to develop new capabilities (Ali & Xie, 2021; Soori et al., 2023). Industry 4.0 enables organizations to generate strategic insights and develop innovative business models aligned with evolving market demands (Anshari & Hamdan, 2022; León et al., 2023). However, successful implementation depends on employees' ability to adapt and learn continuously. Studies highlight that Industry 4.0 adoption encourages skill enhancement through technological interaction and organizational learning processes (Suleiman et al., 2022; Miškić et al., 2023). Advanced technologies also improve flexibility, customer satisfaction, and waste reduction, reinforcing the need for workforce upskilling (Roup, 2024; Pratama, 2025; Ritonga et al., 2025). Consequently, Industry 4.0 acts as a driving force that stimulates the development of human skill capability within organizations.

H2: Industry 4.0 has a positive effect on the capability of human skills.

Capability of Human Skill as a Mediating Variable

The transition toward Industry 4.0 presents both opportunities and challenges, particularly regarding workforce readiness and socio-technical adaptation. Although Industry 4.0 promises enhanced competitiveness through digitalization, organizations often face difficulties in implementation due to limited infrastructure and insufficient skilled labor (Harahap & Rafika, 2020; Tortorella et al., 2021). The evolving interaction between humans and technology requires organizations to address employee well-being and work system design to avoid performance disruptions (Kadir & Broberg, 2020). Scholars emphasize that understanding Industry 4.0 requires integrated perspectives combining technological, organizational, and human dimensions (Obermayer et al., 2022; Suleiman et al., 2022). Effective implementation strategies, including technical training, leadership engagement, and cultural adaptation, have proven essential in overcoming adoption barriers (Mon et al., 2023). These findings indicate that technology alone cannot generate performance improvements without adequate human capability to operate and optimize digital systems.

Human skill capability, therefore, functions as a mediating mechanism linking Industry 4.0 adoption to organizational performance outcomes. Employees contribute value by providing insights, improving processes, and applying knowledge within digital work environments (Tortorella et al., 2021). In developing economies, challenges such as lower education levels and reliance on low-cost labor further emphasize the importance of workforce development for successful transformation (Tortorella et al., 2021). The introduction of digital technologies reshapes work systems and directly affects system performance and employee interaction patterns (Kadir & Broberg, 2020). When organizations invest in human capability development, Industry 4.0 technologies can be leveraged more effectively, leading to higher productivity and organizational success. Conversely, insufficient skills weaken technology utilization and hinder performance improvements (Dabić et al., 2023). Thus, the capability of human skill mediates the relationship between Industry 4.0 and organizational performance by translating technological adoption into measurable organizational outcomes.

H3: The capability of human skills mediates the relationship between Industry 4.0 and organizational performance.

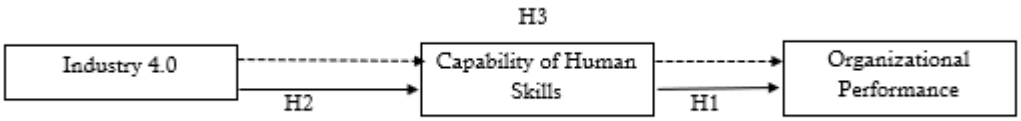

Figure 1. Conceptual Framework

Figure 1 shows the conceptual framework of the study, which illustrates the relationship between the research variables. Industry 4.0 acts as an independent variable that influences human skill capabilities through the H2 pathway. Furthermore, human skill capabilities influence organizational performance through the H1 pathway, suggesting that improving these capabilities can enhance performance. The H3 pathway shows a mediating effect, namely that Industry 4.0 indirectly influences organizational performance through human skill capabilities as an intervening variable. This model emphasizes that the implementation of Industry 4.0 to improve organizational performance depends not only on technology but also on human resources' ability to adopt and utilize it effectively.

RESEARCH METHODS

This study employed a quantitative research design to examine the relationships among Industry 4.0, human skills capability, and organizational performance. The quantitative approach was selected to enable objective measurement and statistical

analysis of the relationships between variables using structured data obtained from respondents. The purpose of this design was to analyze whether Industry 4.0 directly influences organizational performance and whether human skills capability mediates this relationship.

The population of this study comprised organizations that have adopted Industry 4.0 technologies. Respondents were selected from various organizations to capture diverse perspectives regarding the implementation of digital technologies and their organizational impacts. Data were collected from multiple respondents within these organizations to assess whether the emergence of the Industry 4.0 revolution provides beneficial opportunities and performance improvements for enterprises.

This study examines three constructs: Industry 4.0, the capability of human skill, and organizational performance, each measured using four reflective indicators. Industry 4.0 captures respondents' knowledge, duration of familiarity, perceived efficiency improvements, and views on its further development. The capability of human skill assesses the extent to which Industry 4.0 enhances productivity, reduces time and costs, improves organizational efficiency, and enables firms to leverage technology for better performance. Organizational performance evaluates the role of human skills in adapting to Industry 4.0, including their necessity, importance in business adaptation, contribution to successful implementation, and involvement in continuous improvement. All items are measured using a Likert scale to indicate respondents' level of agreement.

The data collection technique utilized a survey method conducted online through the Google Forms platform. Primary data were obtained using a structured questionnaire developed based on previously gathered and analyzed information. The questionnaire employed a five-point Likert scale to measure respondents' perceptions and attitudes toward each research variable, consisting of: 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, and 5 = strongly agree. This scaling approach allowed respondents to indicate their level of agreement with statements related to Industry 4.0 implementation, human skills capability, and organizational performance.

Regarding data analysis techniques, this study applied quantitative statistical analysis to evaluate the relationships among variables and test the proposed conceptual framework. The data analysis tool used in this research was SmartPLS, which supports Partial Least Squares Structural Equation Modeling (PLS-SEM). SmartPLS facilitated the examination of measurement models and structural models simultaneously, enabling the assessment of variable validity, reliability, and inter-variable relationships. The use of SmartPLS enhanced analytical accuracy and provided comprehensive insights into how Industry 4.0 and human skills capability influence organizational performance, thereby offering a robust quantitative understanding of the research model.

RESULTS

The results in Table 1 provide an assessment of the convergent validity of the indicators used in this study. Convergent validity is confirmed when all outer loading values exceed the threshold of 0.6, indicating a strong correlation between each indicator and its respective construct (Kadir & Broberg, 2020). Upon reviewing the data, most indicators meet this requirement, with outer loading values consistently above 0.6. However, one indicator that human skills are a primary aspect of business activities in adapting to the developments of Industry 4.0 has a loading value of 0.465, which falls below the acceptable threshold (Tortorella et al., 2021). This suggests that the item may not adequately measure the intended construct and should be reconsidered or refined in future studies. On the other hand, the highest loading value (0.977) is observed in the indicator, human skills are involved in the development of Industry 4.0, because individuals can provide input and implement improvements based on the knowledge and skills they possess. This indicates a strong relationship between the statement and its construct, making it a significant contributor to the overall measurement model.

Moreover, the outer loadings within each construct exhibit good consistency, reinforcing the reliability of the measurement model. The indicators for Industry 4.0

capability and organizational performance demonstrate strong loadings, confirming that they effectively capture the underlying constructs. This consistency ensures that the collected data can be used for further analysis with confidence.

Table 1. Result of Convergent Validity

Variable	Item	Factor Loading
Industry 4.0	X1	0.675
	X2	0.654
	X3	0.962
	X4	0.948
Capability of Human Skill	Z1	0.73
	Z2	0.83
	Z3	0.833
	Z4	0.783
Organizational Performance	Y1	0.833
	Y2	0.465
	Y3	0.689
	Y4	0.977

As presented in Table 2, the Average Variance Extracted (AVE) values indicate that the capability of human skill reaches 0.632, industry 4.0 attains 0.677, and organizational performance records 0.585; all of these values exceed the recommended threshold of 0.5. This confirms that these constructions capture a significant portion of their respective indicators' variance, meeting the criteria for convergent validity. Among the three constructs, Industry 4.0 has the highest AVE value, indicating that it provides the strongest explanation of its indicators' variance. This high value reinforces the reliability of the Industry 4.0 measurement model, ensuring that the collected data accurately represent the construct. The capability of the human skill construct also shows a solid AVE score, further validating its importance in the study. This high AVE value confirms that the construct is well represented by its indicators and plays a crucial role in the research framework. Meanwhile, the organizational performance construct has an AVE value of 0.585, which, while lower than the other two constructs, still exceeds the 0.5 threshold. This suggests that the construct meets validity requirements but explains slightly less variance compared to the others.

Table 2. Result of AVE Test

Variable	AVE
Capability of Human Skill	0.632
Industry 4.0	0.677
Organizational Performance	0.585

The reliability test results presented in Table 3 evaluate the internal consistency and overall reliability of the measurement model using Cronbach's Alpha (CA) and Composite Reliability (CR). CA assesses the lower threshold of reliability, while CR provides a more accurate measure of how well each construct reflects its indicators. The findings show that the capability of the human skill construct has a Cronbach's Alpha of 0.632, exceeding the 0.6 threshold, which confirms its reliability. Similarly, Industry 4.0 has a higher Cronbach's Alpha of 0.677, indicating strong internal consistency. However, organizational performance records a Cronbach's Alpha of 0.585, slightly below the recommended 0.6 benchmark. This suggests that while the construct is fairly reliable, its measurement indicators may need refinement for better consistency.

Table 3. Result of Reliability Test

Variable	Cronbach's Alpha	Composite Reliability
Capability of Human Skill	0.632	0.873
Industry 4.0	0.677	0.89
Organizational Performance	0.585	0.841

On the other hand, CR values provide further evidence of the model's robustness. The capability of the human skill construct achieves a high CR score of 0.873, confirming its strong reliability. Likewise, Industry 4.0 has the highest CR value at 0.89, reinforcing its validity. Despite its slightly lower Cronbach's Alpha, the organizational performance construct has a CR value of 0.841, which meets the reliability standard. The results confirm that the measurement model is reliable, as all CR values exceed the 0.6 threshold. However, the slightly lower Cronbach's Alpha for organizational performance suggests that future research could refine or expand its indicators to enhance reliability. Despite this minor issue, the test results validate the soundness of the measurement model, ensuring that the data can be confidently used for further analysis.

Table 4. Result of Cross-Loading Test

Variable	Items	Capability of Human Skill	Industry 4.0	Organizational Performance
Industry 4.0	X1	0.552	0.675	0.318
	X2	0.535	0.654	0.32
	X3	0.787	0.962	0.427
	X4	0.776	0.948	0.432
Capability of Human Skill	Z1	0.73	0.634	0.464
	Z2	0.83	0.551	0.734
	Z3	0.833	0.714	0.541
	Z4	0.783	0.707	0.465
Organizational Performance	Y1	0.581	0.405	0.833
	Y2	0.324	0.171	0.465
	Y3	0.481	0.269	0.689
	Y4	0.681	0.484	0.977

Table 4 presents the results of the cross-loading test used to evaluate discriminant validity by comparing the loading value of each indicator across all constructs. The results indicate that most indicators have higher loading values on their respective constructs compared to other variables, showing that each item appropriately measures the intended latent variable. Indicators related to Industry 4.0 demonstrate strong loadings, particularly statements concerning efficiency improvement and technological advancement, indicating good construct representation. Likewise, organizational performance and capability of human skill indicators generally exhibit higher correlations with their own constructs, confirming acceptable discriminant validity. Although several items show moderate cross-loadings with other variables, the dominant loading remains on the corresponding construct. These findings suggest that the measurement model meets the cross-loading criteria and that the indicators are sufficiently distinct in explaining Industry 4.0, human skill capability, and organizational performance constructs.

Table 5. Hypothesis Testing

Hypothesis	Original Sample	Sample Mean	Standard Deviation	t-statistics	p-values
Capability of Human Skill -> Organizational Performance	0.615	0.558	0.291	2.114	0.035
Industry 4.0 -> Capability of Human Skill	0.733	0.735	0.093	7.854	0.000
Industry 4.0 -> Capability of Human Skill-> Organizational Performance	0.451	0.424	0.226	1.999	0.046

Table 5 presents the results of hypothesis testing that examine the direct and indirect relationships among the research variables. The first hypothesis shows that the capability of human skill has a positive and significant effect on organizational performance, indicated by an original sample value of 0.615, a t-statistic of 2.114 (>1.96), and a p-value of 0.035 (<0.05). This result implies that higher human skill capability contributes to improved organizational performance. The second hypothesis indicates that Industry 4.0 has a positive and significant influence on the capability of human skill, with an original sample value of 0.733, a t-statistic of 7.854, and a p-value of 0.000. This finding suggests

that the implementation of Industry 4.0 technologies strongly enhances the development of human skills within organizations. Furthermore, the indirect effect test shows that Industry 4.0 significantly influences organizational performance through the capability of human skill, as reflected by an original sample value of 0.451, a t-statistic of 1.999 (>1.96), and a p-value of 0.046 (<0.05). This indicates that the capability of human skill acts as a mediating variable, confirming that Industry 4.0 improves organizational performance indirectly through the enhancement of human skills.

DISCUSSION

The discussion of the research findings reveals meaningful relationships among the variables examined, namely Industry 4.0, human skill capability, and organizational performance. The direct hypothesis test results indicate that Industry 4.0 has a positive and significant effect on human skill capability, as evidenced by an original sample value of 0.733, a high t-statistic of 7.854, and a p-value of 0.000 (< 0.05). This finding aligns with the literature suggesting that the integration of Industry 4.0 technologies fosters a work environment that encourages the enhancement of personal competencies and technical skills. Technologies such as big data analytics, cloud computing, and cyber-physical systems require new competencies for effective adoption, and their implementation stimulates skill development among employees (Fedotova et al., 2020; Miškić et al., 2023). This supports the notion that while Industry 4.0 represents a technological revolution, its impact at the organizational micro-level depends heavily on the interaction with human capital that is able to understand, adapt to, and productively leverage these technologies.

Furthermore, the capability of human skill is found to have a positive and significant influence on organizational performance, with an original sample of 0.615, a t-statistic of 2.114, and a p-value of 0.035 (< 0.05). This result supports the hypothesis that a highly skilled workforce contributes more effectively to achieving organizational goals. Employees with advanced skills are better positioned to optimize work processes, accelerate task completion, and address complex operational challenges. The literature indicates that performance improvements are strongly associated with individual capabilities in utilizing digital technologies and adaptive skills within the Industry 4.0 context (Dabić et al., 2023). In other words, technology alone is not sufficient; organizations must also develop employees' capabilities to translate technological adoption into tangible performance outcomes.

The analysis of indirect effects further demonstrates that Industry 4.0 exerts a significant indirect influence on organizational performance through human skill capability, as shown by an original sample of 0.451, a t-statistic of 1.999, and a p-value of 0.046 (< 0.05). This suggests that although Industry 4.0 directly enhances human skill capabilities, much of its overall effect on organizational performance occurs through improvements in these skills. In this regard, human skill capability functions as an intervening variable that strengthens the relationship between technology adoption and organizational performance outcomes. This finding underscores the importance of workforce capabilities in converting the benefits of digital technologies into measurable organizational results. Prior research has similarly emphasized that technology implementation without adequate human resource support does not yield optimal performance gains (Duman & Akdemir, 2021; Tortorella et al., 2022).

This interpretation clarifies that, in the era of Industry 4.0, organizations are required not only to adopt advanced technologies but also to enhance their employees' skills and capabilities. This reflects the theoretical view that the transition to Industry 4.0 involves not only technological change but also shifts in competence structures and organizational culture (Obermayer et al., 2022). The ability to learn, adapt, and collaborate within highly digital environments becomes a prerequisite for achieving superior organizational performance. Thus, the results of this study demonstrate a strong interconnection between technological investment and human resource development, which together form the

foundation for effective and sustainable organizational performance amidst the dynamics of the modern industrial revolution.

CONCLUSION

This study confirms that Industry 4.0 technologies significantly improve organizational performance, including operational efficiency, cost reduction, and innovation capacity, and highlights the critical mediating role of human skill capabilities in facilitating successful technological adoption. Organizations leveraging technologies such as cyber-physical systems, big data analytics, cloud computing, and automation achieve higher productivity, but these benefits are most fully realized when employees possess the requisite skills to manage and apply them. The research contributes theoretically by expanding the understanding of how human skills shape Industry 4.0 outcomes and practically by identifying workforce upskilling as a strategic priority.

The implications of these findings suggest that Industry 4.0 initiatives must integrate digital infrastructure investments with human capital development to maximize competitive advantage and adaptability. However, this study has limitations, including its focus on a specific sample and context, which may affect generalizability. The cross-sectional design also restricts causal inference over time. Recommendations include that organizations implement continuous learning and digital literacy programs, adopt human-centered strategies that balance technology with skill development, and encourage partnerships between educational institutions and industry to align training with evolving digital demands. For future research, longitudinal studies and industry-specific analyses are advised to explore workforce readiness across diverse contexts. Such integrated approaches can help ensure sustainable success in the era of the Fourth Industrial Revolution.

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