EXCELLENCIA
INTERNATIONAL MULTI-DISCIPLINARY JOURNAL OF EDUCATION
Volume 02, Issue 04, 2024 ISSN (E): 2994-9521

Digital Technologies, Innovation, and Skills: Evolving Pathways and Challenges

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Annotation. To enhance comprehension of the intricate and dialectical interrelations among digital technologies, innovation, and skills, it is imperative to deepen our knowledge of the coevolutionary dynamics involving the pathways of interconnected digital technologies, organizational innovation routines, and the development of skills. This becomes essential as organizations amalgamate and modify digital technologies, necessitating new competencies to foster innovation, assimilate learning, and adjust to the evolving digital landscapes, while simultaneously, digital technologies alter the codification of knowledge essential for productive and innovative endeavors. Furthermore, the coevolution of digital technologies, innovation, and skills necessitates and is propelled by a reorganization of productive and innovative processes both internally within organizations and externally among them. This phenomenon is evident across all economic sectors, from agriculture to services. Drawing from empirical findings regarding historical technologies in the innovation discourse, it is proposed that a novel set of stylized facts is required to more accurately delineate the principal future trajectories of digital technologies, encompassing their adoption, utilization, and recombination within organizations, thereby enriching our understanding of their implications on productivity, employment, and inequality. The articles in this special issue aim to augment our comprehension of the mutual dependencies among digital technologies, innovation, and skills.

Keywords: digitalization, skills, innovations, human capital, codification

Introduction

Digital technologies profoundly infiltrate and reconfigure all aspects of economic and social endeavors. Their deployment varies; in some instances, they disrupt existing practices, whereas in others,

they incrementally augment and complement them. These technologies may replace existing methods and tasks in certain scenarios, yet in others, they serve to enhance them. Occasionally, digital technologies facilitate the emergence of novel activities, services, innovations, and business prospects. The transformative power of digitalization lies in its capability not only to automate but also to monitor, record, and store extensive data about tasks and activities. This accumulation of data enables detailed analyses and offers opportunities to enhance process efficiencies, organizational work structures and forecasts of future trends. The capability to digitally replicate the analog world has triggered both a surge in innovation and considerable speculation. Technologies such as the Internet of Things, blockchain, additive manufacturing, big data, artificial intelligence, cloud computing, and augmented and virtual reality are at the forefront of discussion. Among these, some like cloud computing are already established, while others may not gain significant relevance; however, new synergies are likely to evolve. The application spectrum of digital technologies covers diverse sectors including agriculture, manufacturing, professional services, health services, and more. There has been substantial focus, both popular and scholarly, on the transformative or disruptive effects of digital technologies on business ecosystems, encompassing new business models, product/service offerings, customer experiences, and organizational structures and processes, as well as their impact on work, education, and society at large. Organizations and workers might need to adapt or even radically transform themselves to succeed in the continually evolving digital world (Brynjolfsson and McAfee, 2014; Frey and Osborne, 2017; Nambisan et al., 2019; Schwab, 2017). Even changes that seem incremental and gradual and follow the learning processes typically observed for new technologies might ultimately become deeply transformational in ways that are unpredictable ex ante. For instance, the ability to codify human tasks in software has a profound effect on skills and the types of jobs available (e.g., Helper et al., 2021). Skill requirements are changing within and across organizations, industries, and countries and making existing ones redundant or obsolete (Autor, 2015; Autor et al., 2015; Cedefop, 2018).

The trajectory of integrating digital technologies within organizational structures, as well as the incorporation of innovations into existing routines, can be influenced by unforeseen occurrences. For example, the COVID-19 pandemic precipitated a rapid transition of numerous face-to-face engagements to virtual platforms. Technologies such as telemedicine, which previously exerted minimal influence, saw their utilization expand significantly within a few weeks. Although the shift to telemedicine represents a seemingly straightforward transition from in-person to video consultations for many routine medical appointments, the benefits and potential limitations became immediately apparent. Consequently, conventional practices may not revert to their original form. Changes that could have taken years to implement were expedited by this unforeseen event.

To enhance our comprehension of the intricate and dialectical interrelationships among innovation, skills, and digital technologies, it is imperative to deepen our understanding of the coevolution involving the trajectories of interconnected digital technologies, corporate innovation strategies, and skills. The progression of digital technologies is not entirely extrinsic; rather, innovation serves both as a result and a catalyst of digital transformations within the economy and society. Digital technologies necessitate the development of unique skills and the integration of varied skills into production processes to facilitate new organizational structures of innovating firms, including their buyers and suppliers. This integration ultimately contributes to a reconfiguration of the division of labor. These elements also exert influence on the innovation process and the emergence of new digital technologies. As digital technologies persist in their evolution, the requisite skills for their development

and adoption are similarly evolving. Indeed, the capacity to adapt to this continual evolution indicates that firms and their personnel must cultivate a "meta-skill," which involves the continuous adaptation of existing skills or the acquisition of new skills to leverage the new capabilities presented by changes in digital technologies.

In Figure 1, we depict the interdependence between innovation, skills, and digital technologies. The three vertices illustrate the dyadic relationships among these three dynamics, which are typically examined in pairs. The systemic interaction among these dynamics necessitates and is propelled by a reorganization of productive and innovative processes, both within and across firms. Drawing from the literature, this paper initially delineates the interconnections among these three dynamics and subsequently discusses their implications for the organization of firms and industries, including how these organizational changes impact the three dynamics and their coevolution.

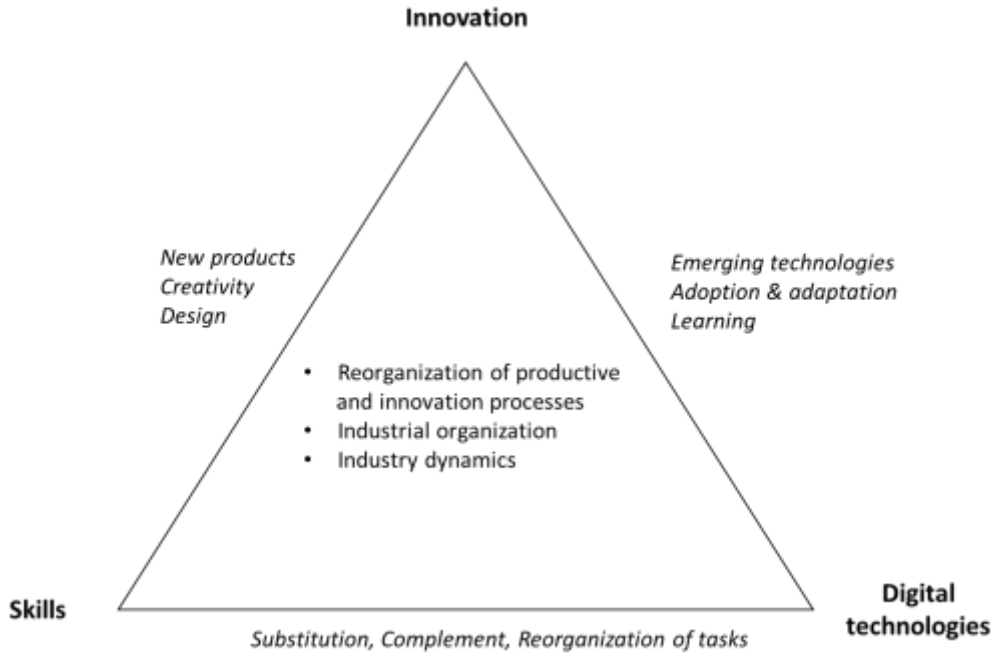

Figure 1. Interconnections between innovation, skills, and digital technologies

Methodology

The advent of von Neumann-based digital computing has catalyzed the widespread emergence of various individual technologies. These range from longstanding tools such as computers and industrial robots to modern "intelligent" machines capable of learning (referred to as machine learning technologies). Given the array of digital technologies, it is not unexpected that different scholarly works offer various definitions and classifications of these technologies. Additionally, these technologies exhibit differences in adoption rates, the spectrum of enterprises implementing them, and their interactive dynamics, though their overall influence and continued progression are profound. For instance, while robotics has been a relatively established technology within the manufacturing sector, its application has expanded significantly into service sectors, notably retail and warehousing. Furthermore, its utility has broadened to encompass a wide array of activities, including the operation of chatbots for answering telephone inquiries. The integration of robotics in manufacturing remains uneven, predominantly being adopted by a select few large corporations.

One perspective on the future development of digital technologies, referred to as the Industry 4.0 "paradigm," was initially introduced by the German government in 2013. This concept has since garnered

significant attention. (Kagermann, 2015; Lasi et al., 2014).

Industry 4.0 envisages a "smart" factory model predicated on cyber-physical systems, which amalgamate advanced technologies within both physical and digital production systems, facilitating integration across data systems of various firms and sectors. The initiative aimed to propel the assimilation of diverse technologies, including factory automation and robotics, data exchange in manufacturing technology, additive manufacturing or 3D printing, cloud computing, the Internet of Things, big data analytics, and artificial intelligence. (e.g., Martinelli et al., 2021).

The interconnected nature of these digital technologies is evidenced by observed adoption patterns. Recent empirical studies indicate that, although the adoption rate of numerous digital technologies remains modest and predominantly skewed towards larger enterprises, there exists a hierarchical pattern. Within this framework, the more sophisticated technologies tend to be adopted only subsequent to the implementation of more foundational applications. (e.g., Zolas et al., 2021).

Sectors such as finance, insurance, mass production, and process industries have demonstrated the most significant enthusiasm in adopting digital technologies. While manufacturing is often regarded as the vanguard of transformative technological advancements, the services sector has received considerably less attention. For instance, a study examining the effects of advanced industrial robotics, additive manufacturing, the industrial Internet of Things, and electric vehicles indicates that these innovations are likely to impact employment by displacing workers. However, it is anticipated that these technologies will also contribute to the enhancement of job roles, the development of hybrid skill sets, and a reduction in monotonous routine tasks. (Eurofound, 2018).

Over recent decades, three principal trends in labor market transformation have emerged due to shifts in organizational structures: (1) upgrading, which involves a linear enhancement in the employment hierarchy, characterized by the most significant growth in highly remunerated positions; (2) polarization, which reflects increased employment growth at both the upper and lower extremes of the job-wage spectrum, leading to a contraction of middle-income roles; and (3) flexibilization, which denotes a rise in nonstandard forms of employment, typified by marginal part-time positions, short-term temporary contracts, and on-demand, often referred to as "gig" work. (De Stefano, 2015)

Results

The discourse surrounding routinized activities and their potential for automation reflects upon Polanyi's differentiation between "tacit" and "explicit" knowledge. This distinction, however, has undergone significant transformation with the advancement of digital technologies. Tasks that were once considered nonroutine and reliant on tacit knowledge have increasingly been standardized, formalized, and thoroughly comprehended, leading to their replication through software and computational systems, thereby rendering them routine and codified (i.e., explicit). The enhancement in digital technologies, characterized by increased computational power, accessibility, the ability to manage large datasets for training purposes, expanded storage capacities, and the development of sophisticated machine learning algorithms, has facilitated the algorithmic execution of tasks previously deemed nonroutine and dependent on human expertise. This technological evolution impacts a broad spectrum of professions, encompassing areas from creative and engineering design to legal and other specialized fields.

The efficacy of advanced digital technologies in executing tasks formerly regarded as nonroutine lies not in mimicking human cognitive processes, but rather in the standardization of certain segments of these tasks to facilitate their compatibility with computerized processing. By deconstructing these complex, integrated processes into modular components, they become more amenable to automation.

This reduction in complexity and modularization of processes thereby empowers machines to either substitute for human capabilities or augment and complement them.

In the context of the fourth industrial revolution, there are emerging dynamics of substitution and complementarity between machines and human workers in the realm of non-routine cognitive tasks. Notably, as creative tasks—a significant portion of these nonroutine cognitive activities—gain prominence, dynamics of complementarity are expected to become increasingly crucial. Machines are particularly adept at augmenting human efforts in tasks that involve the processing of extensive data and information, thereby enhancing the experiential and emotional judgment of professionals in fields such as medicine and law. For instance, AI-based software used in diagnosing skin cancer from dermatological images, which integrates biopsy results, can achieve higher diagnostic accuracy than trained physicians, although both computers and humans exhibit distinct error patterns.

Conversely, certain activities resist simplification into codifiable and automatable components. Tasks involving the recognition and response to emotional cues, for example, are currently challenging to encode within the framework of digital technologies. This limitation underscores the growing importance of social skills. As such, the acquisition of interpersonal and social competencies is increasingly valued, potentially offering greater returns than proficiency in STEM fields.

Conclusions

The significant variability in the literature regarding the potential impact of automation and certain digital technologies on employment highlights the inherent uncertainty in forecasting the skills required for future jobs. Digitalization often leads to the displacement and profound transformation of activities and their organization, rather than a straightforward one-to-one job replacement. These transformations, frequently unpredictable, evolve in tandem with changes in innovation routines and skill sets. For example, while existing skills may be threatened by innovation and the repetitive nature of tasks may increase along with software use, an analysis of changes in the O*NET occupational skills from 2005 to 2015 indicated only modest shifts in occupational skills.

The plasticity of digital technologies and the ease with which new software can be introduced and disseminated contribute to the challenges in predicting their impact on skills. The continuous and widespread experimentation with software, inherently "incomplete by design" and open to ongoing modification, underlines this dynamic.

This phenomenon is observable across various industries. In agriculture, for instance, digital technologies are transforming traditional farming practices. Merely training farmers to program machinery is insufficient to prevent displacement; instead, farmers are likely to assume roles as higher-level decision-makers concerning software and equipment upgrades, which demands competencies in both software and accounting. Furthermore, automation allows for a reduction in the workforce through the integration of hardware and software, challenging farmers to discern when software delivers poor decisions or recommendations.

The case of airline pilots facing competition from drones illustrates the difficulty in responding to technological changes within highly skilled professions; acquiring more advanced pilot training or software programming skills might not be sufficient. The importance of lifelong learning is evident, yet the crucial question remains: what should individuals learn to ensure employability and a middle-class income?

The unpredictable trajectory of digitalization was further complicated by the COVID-19 pandemic, which rapidly shifted the physical location of numerous jobs to remote settings, thereby

accelerating the digitalization required for organizations to function effectively in the short term and to increase resilience in the long term. This shift also spurred a reevaluation of the impact of digitalization on the demand for and supply of skills, highlighting skill mismatches, shortages of skilled labor, and related needs.

This special issue encourages further research to enhance our understanding of how digitalization affects innovation and skills by examining the coevolution of digital transformation, innovation routines, and skill changes, and their implications for the organization of firms and industries. The included papers explore these interrelationships, and future research is called for to delve into the endogenous features of these dynamics, potentially through interdisciplinary approaches and multiple levels of analysis to identify new patterns in how innovation practices are transforming, with implications for work, jobs, and skills.

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