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DIGITAL LITERACY AND ENTERPRISE INNOVATION: REGIONAL-LEVEL EVIDENCE FROM KAZAKHSTAN

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Abstract:
The aim of this study is to identify the relationship between the level of digital literacy among the population and the innovation activity of enterprises across different regions of Kazakhstan. The research is motivated by the growing significance of digital competencies in enhancing innovation capacity, particularly in the context of regional disparities in technological readiness. A mixed-method approach was applied, including correlation analysis and structural equation modeling (SEM), using regional statistical data for the period 2021-2023. Key variables included R&D expenditures, digital infrastructure accessibility, and indicators of enterprise innovation activity. Data normalization (Z-score) and region grouping were used to ensure the comparability of results across newly established administrative boundaries. The results reveal a nuanced relationship that differs markedly across regions. In major urban centers such as Almaty and Astana, a clear and strong link is observed between digital literacy and innovation activity. In contrast, in many other regions, this relationship appears weak or even negative. Among the most impactful variables are household Internet access, external R&D funding, and the presence of innovation-oriented enterprises. Structural equation modeling highlights the indirect influence of digital infrastructure and innovation density on this relationship. Model fit statistics (CFI = 0.921; p = 0.207) support the adequacy of the analytical framework. These findings point to the importance of developing tailored strategies at the regional level – ones that address specific digital skill gaps and innovation barriers. The study offers practical implications for policymakers and enterprise leaders seeking to strengthen regional innovation ecosystems through targeted digital development.

Key words: correlation analysis, digital literacy, innovation activity, regional analysis, structural equation modeling (SEM)

INTRODUCTION

Innovative activity and digital literacy are key drivers of economic competitiveness. Amid globalization and digitalization, enterprises must adopt innovations and enhance digital skills of employees and citizens [1]. In the Republic of Kazakhstan, as in other developing countries, the level of innovative activity of enterprises and digital literacy of the population varies by region, which is due to differences in economic, territorial and social factors.

This study examines the link between enterprise innovation and population digital literacy across Kazakhstan's regions. It explores how ICT skills affect firms' capacity to adopt and develop innovations.

In recent years, Kazakhstan has actively pursued policies to support digital transformation. Innovation activity remains uneven due to disparities in development, infrastructure, and Internet access. According to a survey by the Bureau of National Statistics of the Republic of Kazakhstan [2], the main barriers to innovation include a shortage of qualified personnel, insufficient R&D funding, and limited Internet access.

The main hypothesis of the study is that in regions with a high level of digital literacy of the population, enterprises demonstrate higher innovative activity compared to regions where the level of digital literacy of the population is lower.

LITERATURE REVIEW

Numerous international studies confirm that digital transformation and digital literacy are key drivers of enterprise innovation. Digital tools enhance innovation in small and medium-sized enterprises, improve sustainability, and support organizational learning. Moreover, organizational culture – including psychological safety and collectivism – directly influences innovation performance in digitally transforming environments. The digital literacy of employees enables companies to swiftly adapt to changes and implement innovations at all levels [3, 4, 5]. Recent frameworks also emphasize the role of structured competence development and ontological modeling in strengthening digital capabilities across education and industry, contributing to more adaptive and innovation-ready organizations [6, 7].

Digital transformation has also improved business efficiency and reduced operational costs across various sectors [8, 9]. In the EU, high digital literacy correlates with increased innovativeness, facilitating the adoption of new technologies and product development [10], [11]. Countries like Finland and Sweden, leaders in digital readiness, exhibit strong synergy between digital skills and innovation, fostering sustainable business growth [12, 13]. Similarly, high digital literacy in South Korea and Singapore contributes to superior innovation outcomes and technological readiness [14, 15, 16].

Growing interest in the link between digital skills and entrepreneurship has prompted studies highlighting its multifaceted impact. For instance, digital literacy not only enhances employees' innovation acceptance but can even outweigh innate innovativeness in shaping behavior, as shown in the pharmaceutical industry case [17]. This is echoed by findings emphasizing digital literacy's role in boosting organizations' adaptability and productivity [18]. Digital competencies also mediate the relationship between enterprise digitalization and R&D collaboration [19]. In tourism, digital literacy expands business opportunities and indirectly improves community welfare [20]. Recent studies show that digital culture, combined with digital competencies, drives organizational transformation and enhances competitiveness [21]. Well-designed motivation systems for managers support organizational adaptability and strengthen innovation implementation during digital transformation [22]. Additionally, students' intentions to pursue digital entrepreneurship depend more on digital skills and income expectations than on digital tools alone [23].

While a growing body of international research confirms the role of digital skills in driving innovation and entrepreneurship, the Central Asian context remains largely understudied. Few works have addressed regional disparities or examined the link between digital literacy and enterprise innovation using empirical methods such as SEM. Recent bibliometric findings emphasize the need for a more inclusive and systemic approach to digital entrepreneurship, highlighting the transformative role of digital platforms and intersectoral collaboration in fostering equitable digital development [24]. Furthermore, the socio-economic dimensions of sustainable innovation are still underexplored in this region, particularly in connection with evolving needs and institutional responses [25].

This study contributes to closing these gaps by offering a regionally disaggregated, data-driven analysis of Kazakhstan. It reveals both direct and mediated relationships between digital literacy and innovation and provides new evidence to inform region-specific digital transformation strategies.

Despite the growing consensus that digital competencies positively affect enterprise performance, the underlying causal mechanisms require further conceptual elaboration. Digital literacy is not only about access to digital technologies but also about the ability to critically navigate, evaluate, and utilize them – a distinction often framed as the "second-level digital divide" [26, 27, 28]. This capacity enhances absorptive and transformative capabilities, enabling organizations to incorporate external knowledge and engage in digital innovation [29, 30].

Studies show that digital literacy can directly influence innovative work behavior by fostering employee engagement, creative self-efficacy, and proactivity [31, 32].

Moreover, digital competencies allow employees to better align with organizational innovation strategies, acting as a catalyst for both individual and collective transformation [33, 34]. Strategic frameworks further suggest that digital literacy acts as a foundation for distributed innovation, open collaboration, and ecosystem engagement [35, 36].

These mechanisms, though widely recognized in developed economies, are understudied in transitional contexts. This study contributes to the literature by empirically investigating these links across Kazakhstan's regions, where disparities in infrastructure, institutional support, and human capital may mediate the relationship between digital literacy and innovation activity.

METHODOLOGY OF RESEARCH

To examine the link between digital literacy and enterprise innovation across Kazakhstan's regions, a mixed-methods approach combining correlation analysis and structural equation modeling (SEM) was applied. This allowed for a comprehensive assessment of key factors and regional differences.

At the first stage, correlation analysis identified major variables influencing both innovation and digital literacy, focusing on ICT skills, innovation uptake, R&D spending, Internet access, and qualified personnel. Digital literacy was gauged via ICT usage and skills, while innovation activity was measured by the number and share of innovative enterprises.

In the second stage, SEM assessed interdependencies across regional clusters. All variables were standardized using the Z-score method to ensure comparability.

The study uses data from 2021-2023, capturing post-pandemic recovery and ongoing digitalization. Though the period is brief, it reflects a phase of structural change in digital infrastructure and innovation.

Following Kazakhstan's administrative reform (Government Resolution No. 887, May 3, 2022), some regional boundaries shifted. To ensure data consistency, aggregated indicators for 2022-2023 were used: East Kazakhstan includes Abay, Almaty includes Zhetisu, and Karaganda includes Ulytau.

Table 1 outlines variables used in the correlation analysis, covering internal and external drivers of innovation and digital literacy – such as R&D expenditures, education, Internet access, and structural constraints.

Table 1

Variables used in correlation analysis

Variables used in correlation analysis of innovative activity of enterprises	Variables used in correlation analysis of digital literacy of the population
Y – number of enterprises with innovations	Y – level of digital literacy of the population
X1 – level of activity in the field of innovation	X1 – ICT user distribution by higher education
X2 – volume of innovative products	X2 – number of ICT specialists, people
X3 – costs of implementing innovations	X3 – ICT costs
X4 – internal R&D costs	X4 – level of activity in the field of innovation, in %
X5 – external R&D costs	X5 – households with Internet access
X6 – acquisition of modern equipment	X6 – enterprises with innovations
X7 – number of enterprises with all innovation types	X7 – innovation implementation costs
X8 – lack of financial resources	X8 – internal R&D costs
X9 – lack of competent personnel	X9 – external R&D costs
X10 – difficulty finding innovation partners	X10 – lack of financial resources

In this study, digital literacy is approximated through region-level indicators such as internet access and ICT penetration, consistent with practices in macro-regional studies [33, 35]. While these proxies do not measure individual digital competencies directly, they reflect infrastructural readiness and access conditions that significantly affect the development of digital skills [26, 31]. The analysis therefore treats these variables as structural enablers and contextual conditions of digital literacy at the regional level.

For SEM analysis, regions were grouped into six macro-areas: North, East, South, West, Central Kazakhstan, and cities of republican significance. This facilitated detection of regional disparities and latent patterns in innovation and digital literacy.

RESULTS AND DISCUSSION

The study identifies key factors affecting innovation and digital literacy across Kazakhstan's regions, highlighting their varying influence depending on socio-economic context and infrastructure maturity.

Correlation analysis confirmed that external R&D expenditures (X5) and shortage of skilled personnel (X9) are the most influential factors for enterprise innovation. This supports Zygmunt's findings [37] on the importance of external knowledge flows and strategic partnerships in green innovation. In Atyrau, Karaganda, and Turkestan, strong correlations between R&D costs and innovation indicators underscore the role of domestic and international funding in advancing technological development (Figure 1).

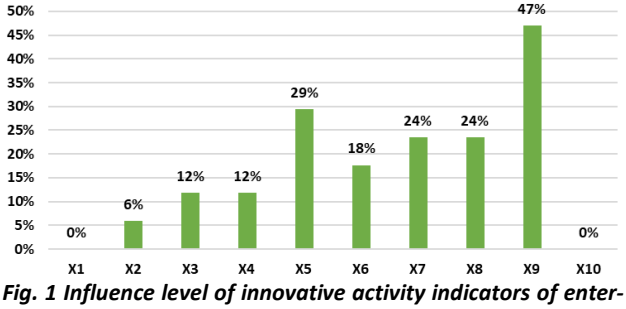

Fig. 1 Influence level of innovative activity indicators of enterprises by indicators

The shortage of skilled personnel (X9) emerged as the main barrier to innovation in Akmola, Zhambyl, West and East Kazakhstan, and Shymkent, pointing to systemic flaws in vocational training and education. Xu et al. [38] similarly highlighted the role of institutional support and teacher competence in developing innovation-related skills. In Zhambyl, four variables (X2, X4, X5, X9) influenced innovation simultaneously, indicating a multifactorial, non-linear regional innovation system.

The analysis revealed strong regional variation in digital literacy determinants. Household Internet access (X5) was the most influential factor, especially in Karaganda, East Kazakhstan, and major cities like Almaty and Shymkent (Figure 2). Internet availability underpins digital skills and online access. This aligns with Shatila et al. [39], who found that digital accessibility and literacy enhance entrepreneurial resilience and innovation in tech-driven settings.

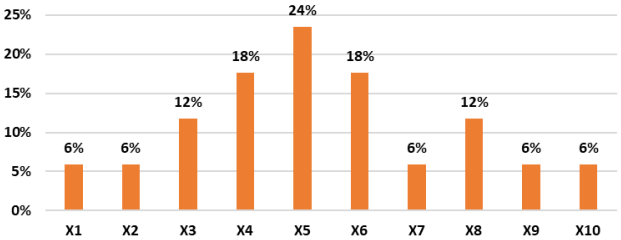

Fig. 2 Influence level of the indicators of digital literacy level of the population by indicators

Beyond identifying key individual factors, it is important to examine their interactions. A correlation matrix showed that regional innovation activity (X4) correlates positively with digital literacy, notably in Atyrau, Kostanay, and Turkestan. Active innovation likely boosts demand for digital tools and tech-skilled labor. These findings echo Caroline et al. [40], who highlighted digital literacy as a foundation for innovative behavior in organizations.

Likewise, the number of innovative enterprises (X6) correlated positively with digital literacy in Akmola, West Kazakhstan, and Mangystau, suggesting that such firms foster both tech adoption and digital skill development. As

shown in Figure 3, most variables have weak intercorrelations, indicating that the innovation-literacy link is driven by indirect, non-linear mechanisms.

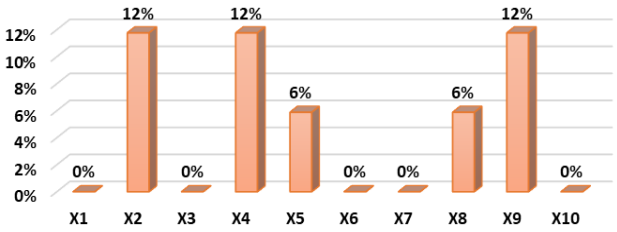

Fig. 3 Level of correlation among indicators on indicator Y in the analysis of the level of digital literacy of the population

To validate the results, SEM with maximum likelihood estimation was applied. The model included two endogenous variables-enterprise innovation (Endogenous1) and digital literacy (Endogenous2) – and two exogenous groups: Exogenous1 (X5: Internet access, X9: external R&D) and Exogenous2 (X4: innovation level, X6: number of innovative firms).

The model showed a good fit ($\chi^2 = 5.90$, df = 4, p = 0.207, CFI = 0.921). Internet access (X5) had a strong positive effect on innovation (coefficient = 1.00), confirming its central role in a digital innovation ecosystem. In contrast, external R&D costs (X9) had a weak, non-significant effect (coefficient = 0.205, p = 0.490), likely due to irregular funding (Table 2).

Table 2
SEM analysis results table

Variables	Ratio estimation	Standard Error (SE)	p-value
Exogenous1 → x5	1.00	0.00	-
Exogenous1 → x9	0.205	0.297	0.490
Exogenous2 → x4	1.00	0.00	-
Exogenous2 → x5	1.509	2.527	0.550
Exogenous2 → x6	0.947	0.348	0.006
Endogenous1 → y1	1.00	0.00	-
Endogenous2 → x1	1.00	0.00	-
Exogenous2 → Endogenous1	0.3807	0.153	0.013
Endogenous1 → Endogenous2	0.215	0.162	0.184

Exogenous2 variables had a strong effect on digital literacy: innovation activity (X4) (coefficient = 1.00, p < 0.001) and number of innovative enterprises (X6) (coefficient = 0.947, p = 0.006) confirmed that innovation environments stimulate digital competencies. The weak link between innovation and digital literacy (coefficient = 0.215, p = 0.184) suggests that digital skills alone are insufficient without systemic support, echoing findings by Farias-Gaytan et al. [41] on the need for coordinated institutional efforts (Figure 4).

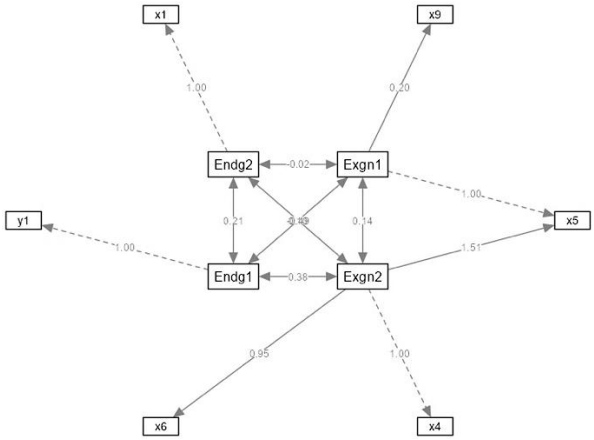

Fig. 4 Diagram of relationships between exogenous and endogenous variables

To explore regional heterogeneity, a multi-group SEM was applied ($\chi^2 = 36.7$, df = 10, p < 0.001) across six regional groups. Results revealed significant variation in the strength and direction of the digital literacy – innovation relationship (Table 3).

Table 3
The relationship between digital literacy and innovation activity by group of regions

Group of regions	Coefficient of correlation	Description
Northern Kazakhstan	-0.4600	An inverse relationship is observed between the variables, which may indicate that digital literacy is not the main driver of innovation in this region.
East Kazakhstan	0.0717	The relationship between variables is weak. This region may need to improve its digital infrastructure and workforce skills.
Western Kazakhstan	-0.1078	There is an inverse relationship between the variables. This may indicate a low dependence of innovation on the level of digital literacy in a given region.
South Kazakhstan	0.3664	There is a positive but insignificant relationship between the variables. This indicates the need to improve digital literacy to support innovative development.
Central Kazakhstan	-0.1488	There is a feedback loop between variables, which may indicate the need to develop digital infrastructure to stimulate innovation.
Cities of republican significance	1.1763	In cities of national significance such as Almaty, Astana and Shymkent, a strong positive relationship between the variables is observed. This indicates the importance of digital skills for innovative development in these regions.

In Almaty and Shymkent, digital skills strongly correlated with innovation (1.1763), supported by robust ICT infrastructure and academic ecosystems. Conversely, in Northern and Western Kazakhstan, the relationship was negative (e.g., -0.46), suggesting reliance on traditional sectors. Eastern and Southern regions showed weak or insignificant links, underscoring the need for tailored regional strategies. Central Kazakhstan (-0.1488) reflected systemic underdevelopment in both innovation and digital capacity.

From a production engineering standpoint, these results highlight the need for region-specific strategies. Regions with low digital readiness require investment in infrastructure, ICT training, and education-industry collaboration. More advanced areas should prioritize smart technologies – like AI-based quality control, IoT, and cloud manufacturing–to strengthen innovation outcomes.

These findings cover a three-year period and are based on regional-level data. While offering valuable insights, validation using enterprise-level and sector-specific indicators-especially in production–would enhance robustness. The results are particularly relevant for manufacturers adjusting digital strategies to regional contexts. In low-literacy areas, adopting automation, quality control, or real-time systems is challenging. Addressing these gaps requires targeted investments in digital skills and infrastructure beyond general policy measures.

A limitation of this study is the reliance on proxy variables, such as internet access rates, to capture digital literacy. Although these indicators reflect structural and infrastructural dimensions of digital readiness, they do not fully represent the actual skill levels or functional digital capabilities of employees or enterprises. Future research should incorporate firm-level data or direct assessments of digital competencies to more accurately evaluate the impact of digital literacy on innovation performance.

While the SEM model provides valuable insights into the structural relationships between digital literacy and enterprise innovation, the cross-sectional nature of the data limits our ability to make strong causal claims. It is possible that more innovative regions also invest more in digital capacity building, suggesting reverse or bidirectional causality. Furthermore, unobserved contextual factors such as institutional quality, access to venture capital, or regional governance practices may also mediate or confound the observed relationships. Future research should employ longitudinal data or experimental designs to better identify causal pathways and rule out alternative explanations.

CONCLUSION

This study examined regional disparities in digital literacy and their link to enterprise innovation in Kazakhstan. Although more digitally literate regions generally showed higher innovation, the patterns were more complex than expected. The relationship was mediated by factors such as Internet access, R&D intensity, innovation density, and skilled labor availability.

Correlation and SEM analyses revealed substantial regional variation in the digital literacy – innovation link. In Northern and Western Kazakhstan, innovation appears constrained by infrastructural or institutional barriers, despite digital literacy levels. In contrast, cities like Almaty and Astana showed a strong, direct relationship, highlighting the role of favorable digital conditions. The study contributes both theoretically and practically by confirming this link and underlining regional mediators. It offers a foundation for region-specific strategies to enhance digital infrastructure and human capital in support of innovation.

The findings confirm the interdependence between digital literacy and innovation activity, though their relationship varies by region. Enhancing enterprise innovation potential requires region-specific strategies for developing digital skills and infrastructure, aligned with local socio-economic contexts.

These findings are vital for advancing production systems in digitally lagging regions, where adoption of smart manufacturing and automation faces persistent constraints. To address these challenges, we recommend a set of region-specific policy actions. First, develop and implement certified digital upskilling programs for SME employees through partnerships with regional vocational centers and innovation hubs. Second, introduce targeted subsidies or tax incentives for enterprises adopting digital tools (e.g., ERP systems, digital accounting, e-commerce platforms) in low-innovation areas. Third, encourage the creation of regional innovation support centers that provide mentoring, digital diagnostics, and access to digital infrastructure. Finally, national agencies should collect and monitor firm-level data on digital competencies to guide evidence-based policy and track progress in digital transformation.

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