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Competency Mapping for Industry 4.0: An Empirical Study of Kazakhstan's Entrepreneurial Sector

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ABSTRACT

Amid rapid digitalization and the ongoing transformation of the economy, the need to revise approaches to the assessment and development of human capital is growing. This study aims to develop an empirically grounded competency map to support strategic human capital management in Kazakhstan's entrepreneurial sector. The research employed a cross-sectional survey of 368 enterprises, selected through proportional stratified sampling to reflect the official structure of small, medium, and large businesses. The data was collected using an online questionnaire that included 12 key competencies: cognitive, soft, digital, environmental, and technological skills. Primary data processing employed indexing and tabular aggregation methods, while the analysis involved descriptive statistics, analysis of variance (ANOVA), and clustering techniques, implemented using Jamovi software. The results show that basic cognitive and soft competencies such as adaptability (59.9%) and environmental thinking (65.9%) are most common in all types of enterprises, while advanced digital and technological skills, including working with robotic systems (33.4%) and artificial intelligence (38.0%), remain underdeveloped., especially in the SME sector. ANOVA revealed statistically significant differences ($p < 0.05$) for 11 of the 12 competencies in terms of enterprise size, with large companies demonstrating a higher level of digital and technological skills. The findings formed the basis for the development of a visualized radar map reflecting the integrated competency profile by enterprise size. The results presented contribute to the formation of evidence-based strategies for the development of human capital under conditions of industrial and digital transformation.

KEYWORDS: Human Capital, Knowledge Economy, Industry 4.0, Digital Transformation, Innovative Economy, Competence Map, Business Development

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1. INTRODUCTION

Radical changes in the structure and dynamics of the global labor market, driven by the accelerated development of digital technologies, automation, and the transition to sustainable forms of production, are challenging traditional models of human resource management. The emergence of the Industry 4.0 concept is accompanied not only by technological transformation but also by institutional and behavioral shifts that shape the demand for new forms and combinations of competencies. Under these conditions, human capital is no longer viewed solely as an aggregate of labor resources. Still, it emerges as a key factor in innovation-driven growth, resilience, and digital maturity of enterprises.

Nevertheless, despite the growing interest in the topic of competencies in both academic and applied literature, several research challenges remain unresolved. Most studies on human capital focus either on general skill development strategies or on isolated aspects of digital training, without addressing the multidimensional structure of competencies or their variability across sectors, enterprise sizes, and levels of digital maturity. Moreover, a significant share of existing research is concentrated on countries with high levels of economic development, whereas the regional specifics of competency formation in transition economies, including Kazakhstan, remain highly fragmented.

For instance, the study by Kusumastuti and Nuryani (2020) emphasised the heterogeneity of digital literacy levels across ASEAN countries, which can be interpreted as an indicator of institutional and educational disparities in the training of digital personnel. Similarly, Caroline et al. (2024) and Farias-Gaytan et al. (2023) argued that the successful digital transformation of organisations is impossible without the development of digital culture and support from knowledge management systems. These aspects are often overlooked in standard competency models built on formal skills and qualifications. Critics of non-empirical approaches highlight the weak verification of theoretical models based solely on secondary source analysis, without reference to data obtained from real enterprises (Jiangmei & Ghasemy, 2025). The lack of systematic efforts to integrate micro-level data (such as employee surveys, job vacancy profiles, and HRM practice analytics) results in most studies failing to offer applicable competency typologies relevant to the realities of the digital economy in specific national contexts.

Accordingly, the research question of the present study is formulated as follows:

RQ: Which types of competencies are most essential for different categories of enterprises in the context of digitalization and sustainable development, and how can their structure be empirically identified and visualized?

The working hypothesis posits that the structure of in-demand competencies varies significantly depending on the size of the enterprise and its level of digital maturity, and that the traditional distinction between “soft” and “hard” skills fails to capture the actual complexity of competency requirements in the context of Industry 4.0.

Given the above, the aim of this study is to develop an empirically grounded competency map to support strategic human capital management in Kazakhstan’s entrepreneurial sector. The scientific contribution lies in the synthesis and refinement of a competency typology that reflects the regional context. In contrast, the practical significance lies in the development of a tool for diagnosing and forecasting workforce needs.

2. LITERATURE REVIEW

The rapid digital transformation and the emergence of Industry 4.0 and 5.0 have fundamentally changed the requirements for human capital, emphasizing the need for multidimensional competencies that combine cognitive, technological, and sustainability-oriented skills. Organizations and economies are increasingly facing the challenge of aligning workforce capabilities with technological and ecological transitions, as well as the growing role of human-centric strategies. Academic research on competencies and human capital in this context can be broadly categorized into three interconnected directions. The first focuses on the strategic and theoretical conceptualization of competencies as a core resource for innovation-driven growth. The second examines the formation and assessment of digital, technological, and sustainability competencies that underpin organizational adaptability in the era of Industry 4.0 and 5.0. The third direction addresses methodologies for competency mapping and empirical modeling, including factor analysis, cluster analysis, and concept mapping, which enable the identification, classification, and practical application of workforce skills. This structured approach allows for a comprehensive understanding of how human capital development supports innovation, resilience, and sustainable competitiveness in both developed and transition economies.

The first direction is associated with viewing competencies as a strategic resource for innovation-led growth. The Human Capital 4.0 typology proposed by Flores et al. (2020) conceptualized the individual as the central element of digital interactions, endowed with an architectural capacity for integration into innovation ecosystems. This understanding is further developed in the works of Marlapudi and Lenka (2024), which revisit definitions of "talent" and "competency" in the digital era, as well as in the study by Hecklau et al. (2016), which emphasized the need for strategic human resource management. Intellectual capital, which integrates knowledge, skills, and experience, plays a critical role in shaping core organizational competencies and sustaining competitive advantage (Hartanti et al., 2024). Empirical support for these approaches is provided in the studies by Kowal et al. (2022) and Saeedikiya et al. (2024), which underscore the importance of integrating technical, digital, and soft skills. Leadership and human resource strategies also emerge as key drivers for building workforce readiness in the context of Industry 4.0 (Kartikasari et al., 2025). A model of sustainable leadership competencies within the context of sustainable development was proposed by Ruwanika and Massyn (2024), while Mach and Ebersberger (2024) demonstrated how sustainability competencies are being embedded into continuing education programs.

The second direction focuses on the measurement of digital and technological skills. Analyses by Alhloul and Kiss (2022), Jiangmei and Ghasemy (2025), and Vaszkun and Mihalkov Szakács (2025) show widespread use of bibliometric and qualitative methods, whereas quantitative approaches remain less prevalent. Mäkelä and Stephany (2025) and Romero (2024) highlight the increasing importance of computational thinking, critical analysis, and interdisciplinary skills in response to AI development. This research stream also underlines the growing importance of digital literacy, AI and machine learning skills, big data analytics, and interdisciplinary problem-solving for Industry 4.0 and 5.0 adaptation (Emad et al., 2024; Nugroho, 2025). Digital skills are increasingly assessed through validated tools in both corporate and educational settings to ensure workforce readiness (Pelaez-Sanchez et al., 2024). Simultaneously, sustainability competencies – including ecological awareness, circular economy skills, and human-centric adaptability – are becoming integral to human capital models (Bratić et al., 2025; Ciucu-Durnoi et al., 2024; Picinin et al., 2023). Industry 5.0 studies emphasized that integrating digitalization with sustainable practices enhances resilience and reduces ecological footprints, while also requiring continuous reskilling and organizational support (Akhavan et al., 2025; Slavic et al., 2024).

The impact of the digital environment on students' adaptability and employability is demonstrated in the works of Imjai et al. (2025). Kumar et al. (2023) emphasized the role of digital financial literacy as a mediator of financial resilience, while Kawaguchi and Toriyabe (2022) revealed regional and gender-based differences in the economic returns on skills, drawing on PIAAC data. Special attention to skill formation in the context of the circular economy is paid in studies by Buyukyazici and Quatraro (2025), which exposed institutional and regional challenges in assessing relevant competencies.

The third direction encompasses methodologies for competency mapping, including clustering, factor analysis, ANOVA, and empirical surveys. At the conceptual level, competency mapping is increasingly recognized as a strategic tool for aligning organizational values, innovation strategies, and employee capabilities (Badie & Rostomyan, 2025). Recent empirical studies apply factor analysis, cluster analysis, and concept mapping to identify meaningful skill groups, develop competency maps, and guide talent management strategies (Chahuán-Jiménez et al., 2025; Fernández-Luque et al., 2021; Kaur et al., 2023). Applications span IT, healthcare, higher education, and sustainability-focused professions (Ogden et al., 2021; Venn et al., 2022). Some authors applied bibliometric and network analysis to construct meta-models of entrepreneurial competencies (Donaldson et al., 2025; Reis et al., 2021). Russo et al. (2023) raise the issue of the effectiveness of digital platforms in learning and knowledge transmission. Abbritti and Consolo (2024), Hensvik and Skans (2023), and Rouwendal and Koster (2025) point to territorial and institutional disparities in the demand for skills and their distribution. A separate body of literature addresses the unique challenges of workforce development in transition economies. Research highlights generational and sectoral disparities, the role of absorptive capacity, and the need for targeted upskilling programs to enhance innovation potential (Ikenga & van der Sijde, 2024). Job vacancy analyses confirm the relevance of digital, analytical, and communication skills as key components of the sought-after competency profile (Andersson & Molinder, 2025; Bottasso et al., 2025; Daly et al., 2025; Garcia-Lazaro et al., 2025; Usabiaga et al., 2022). Analytical reports such as The Future of Jobs Report 2025 by the World Economic Forum (WEF, 2025) affirm the growing significance of meta-competencies–analytical thinking, leadership, creativity, digital literacy, and learning agility–as core drivers of the sustainable competitiveness of human capital.

Despite the growing body of research on human capital and competencies in the context of Industry 4.0 and 5.0, several critical gaps remain. First, most existing studies are either conceptual or limited to descriptive sectoral analyses, lacking large-scale empirical evidence from enterprises, particularly in transition economies. Second, current competency models rarely integrate cognitive, digital, ecological, and high-tech skills into a unified framework that reflects the multidimensional nature of human capital in the digital era. Third, the practical applicability of these models for workforce planning and innovation management remains limited, as they often do not account for enterprise size, sectoral specialization, or regional differences.

This study addresses these gaps by developing an empirically grounded three-cluster competency map based on survey data from 368 enterprises in Kazakhstan. Unlike prior research, the proposed model integrates cognitive (soft), digital-ecological, and specialised technological competencies, relying on factor and cluster analysis to visualise the structure of human capital and its innovation potential. This approach not only contributes to the empirical literature on human capital in transition economies but also provides a practical tool for talent management, reskilling strategies, and innovation-oriented decision-making.

3. RESEARCH METHODS

The study was designed as a cross-sectional survey targeting small and medium-sized enterprises (SMEs) in Kazakhstan to evaluate the structure of human capital competencies and their contribution to innovation potential. The research was conducted in four stages:

Questionnaire design and pilot testing based on international frameworks of Human Capital 4.0, Industry 4.0/5.0 competencies, and previous empirical studies. The final questionnaire included blocks on cognitive and soft skills, digital and ecological competencies, technological skills, human resource practices, and innovation performance.

Official dissemination of the survey in partnership with the Chamber of Entrepreneurs of the East Kazakhstan region. Enterprises received an official invitation letter from the university to increase trust and response rates. The survey was distributed online via Google Forms over 10 weeks.

Data collection and validation. A total of 368 enterprises completed the survey (response rate 96% of the planned 383 enterprises, calculated for a 95% confidence level and 5% margin of error).

Data processing and analysis. The dataset was cleaned, coded, and analyzed using descriptive statistics, factor analysis, cluster analysis, and ANOVA to construct the competency map and identify patterns relevant to innovation potential.

The general population of entrepreneurial structures in Kazakhstan comprises 211,356 registered and active small, medium, and large enterprises, according to the Bureau of National Statistics of the Republic of Kazakhstan (hereinafter – BNS) as of September 1, 2024. The survey sample of 368 enterprises was designed using proportional stratified sampling, ensuring that the distribution of respondents reflects the official structure of enterprises by size and is adequate for statistically reliable analysis.

Table 1 compares the sample with the official BNS data by enterprise size, confirming that the structure of the survey is proportional to the general population.

TABLE 1. Comparison of the sample structure with official BNS data by enterprise size

Enterprise size	Total enterprises (BNS)	BNS (%)	Sample (N)	Sample (%)
Small	202635	95.7	352	95.7
Medium	6366	3.3	12	3.3
Large	2355	1.0	4	1.0
Total	211356	100	368	100

Note: compiled by the authors based on Bureau of National Statistics (2024)

To reflect the geographic distribution of entrepreneurial activity, the sample also maintained regional proportionality. Table 2 shows the regional and size-based distribution of surveyed enterprises, illustrating that the study covers the entire territory of Kazakhstan.

TABLE 2. Regional and size-based distribution of surveyed enterprises

No.	Region	Small	Medium	Large
1	Abai	7	-	-
2	Akmola	13	-	-
3	Aktobe	15	1	-
4	Almaty region	17	1	-
5	Atyrau	10	-	-
6	West Kazakhstan	11		-
7	Zhambyl	9	1	-
8	Zhetysu	7	-	-
9	Karaganda	19	1	-
10	Kostanay	13	1	-
11	Kyzylorda	8	1	-
12	Mangystau	10	-	-
13	Pavlodar	14	-	-
14	North Kazakhstan	11	-	-

15	Turkistan	15	1	-
16	Ulytau	3	-	-
17	East Kazakhstan	12	1	-
18	Astana city	58	1	2
19	Almaty city	100	2	2
20	Shymkent city	16	1	-
Total		368	12	4

Note: compiled by the authors

The survey instrument was designed to capture the prevalence of twelve key human capital competencies within each participating enterprise. The selection of these twelve competencies was informed by the literature on Human Capital 4.0 and the competency frameworks for Industry 4.0 and 5.0, which emphasize the integration of cognitive, soft, digital, and technological skills as key drivers of innovation (Flores et al., 2020; Hecklau et al., 2016; Kowal et al., 2022; Saeedikiya et al., 2024).

Respondents were asked to indicate the share of employees possessing each competency as a percentage of the total workforce. To ensure comparability across enterprises of different sizes, the collected percentage values were averaged for each competency and enterprise type (small, medium, and large businesses). These mean values served as the empirical basis for the subsequent statistical procedures, including descriptive analysis, analysis of variance (ANOVA), and cluster analysis, aimed at identifying structural patterns in the formation of key competencies and their distribution across different categories of entrepreneurial structures.

Each competency was assigned a variable code (X1–X12) to enable standardized processing in the statistical software environment. The list of competencies and their corresponding variable codes is presented in Table 3.

TABLE 3. List of Competencies under investigation

Code group 1	**Competency**	**Code group 1**	**Competency**
X1	Adaptability and flexibility, %	X7	Artificial intelligence and machine learning skills, %
X2	Creativity and innovative thinking, %	X8	Knowledge in the field of biotechnology, %
X3	Critical thinking and problem-solving skills, %	X9	Programming and operation of robotic systems, %
X4	Teamwork and communication skills, %	X10	Knowledge in environmental safety and energy technologies, %
X5	Ecological thinking and commitment to sustainable development goals, %	X11	Cybersecurity and data protection capabilities, %
X6	Knowledge of current technological trends, %	X12	Big data analytics and data analysis capabilities, %

Note: compiled by the authors

The collected data were processed and analyzed using a combination of descriptive and multivariate statistical methods in the Jamovi software environment (version 2.5). The objective of the analytical stage was to identify structural patterns in human capital competencies, compare competency formation levels across enterprise sizes, and construct an integrated competency map to support the assessment of innovation potential.

At the first stage, descriptive statistics (arithmetic means, medians, standard deviations, and minimum and maximum values) were calculated for all twelve competency variables (X1–X12). This provided a comprehensive overview of the distribution of competencies across the surveyed enterprises and served as the empirical basis for subsequent multivariate analysis. The second stage involved one-way ANOVA to evaluate statistically significant differences in competency formation levels among small, medium, and large enterprises. For each variable, F-statistics and p-values were computed, and Levene's test was applied to verify the homogeneity of variances. In contrast, the Shapiro–Wilk test confirmed the approximate normality of residual distributions. This procedure ensured that the observed differences were statistically valid and interpretable in the context of enterprise size heterogeneity. Next, a hierarchical cluster analysis was conducted to classify enterprises according to the similarity of their competency profiles. The clustering procedure used Ward's method and the Euclidean distance metric, which are standard in competency profiling studies. The optimal number of clusters was determined based on dendrogram inspection and agglomeration coefficients, resulting in stable clusters that represent typical configurations of workforce skills. This step allowed for the identification of empirically grounded competency typologies across the surveyed firms.

The final stage involved the construction and visualization of an integrated competency map, which aggregated the average values of the twelve competencies for each cluster and enterprise size. A radar chart was selected as the visualization tool due to its ability to represent multi-dimensional competency profiles and highlight structural differences in human capital across enterprise types. This map forms the foundation for subsequent strategic recommendations and the assessment of innovation potential in the context of Industry 4.0 (Flores et al., 2020; Hecklau et al., 2016; Kaur et al., 2023).

4. FINDINGS AND DISCUSSION

4.1 Descriptive Analysis of Competencies

At the initial stage of the analysis, descriptive statistics were calculated for each of the twelve competencies, reflecting the proportion of employees possessing the respective skills within the workforce of each surveyed enterprise. The resulting mean values make it possible to identify competencies with high prevalence and those exhibiting notable deficits in the human capital structure of Kazakhstani entrepreneurial organizations.

The overall prevalence of competencies among the surveyed enterprises. Soft and environmental competencies – in particular, environmental mindset (X5), teamwork and communication skills (X4), critical thinking and problem-solving (X3), and creativity and innovative thinking (X2) – demonstrate the highest average values. This indicates a gradual shift in human resource management priorities toward sustainable development, the cultivation of collective culture, and the formation of adaptive behavioral models (Table 3).

TABLE 4. Prevalence of competencies among the workforce of entrepreneurial structures

Competency	Average value (%)	Stnd. Dev.	Competency	Average value (%)	Stnd. Dev.
X1	59.9	22.7	X7	38.0	29.2
X2	61.0	21.0	X8	36.1	23.8
X3	60.6	19.1	X9	33.4	26.4
X4	60.6	21.1	X10	52.0	26.7
X5	65.9	23.5	X11	48.8	27.9
X6	51.5	23.5	X12	48.8	27.9

Note: compiled by the authors

Conversely, hard digital and technological competencies – including programming and operation of robotic systems (X9), biotechnology (X8), artificial intelligence and machine learning (X7), as well as big data analytics (X12) – exhibit significantly lower prevalence. These findings reflect both limited access to specialized educational resources and technological infrastructure, and the still-modest level of digital transformation in many enterprises, especially at the regional level.

To explore structural differences in competency profiles by enterprise size, group means and standard deviations were calculated for small, medium, and large enterprises. Table 5 presents the detailed average prevalence of each competency across the three categories.

TABLE 5. Average values and standard deviations of competencies by enterprise size (Mean ± SD)

Competency	Small (Mean ± SD)	Medium (Mean ± SD)	Large (Mean ± SD)
X1	48.7 ± 14.5	60.5 ± 12.9	71.9 ± 6.8
X2	66.6 ± 11.0	49.0 ± 10.1	88.8 ± 12.8
X3	37.8 ± 6.6	66.7 ± 5.5	87.6 ± 13.9
X4	32.9 ± 13.7	67.3 ± 6.7	73.9 ± 14.2
X5	60.1 ± 12.1	42.9 ± 14.5	53.5 ± 7.0
X6	31.0 ± 14.7	83.5 ± 13.1	51.8 ± 8.3
X7	71.6 ± 7.1	53.7 ± 6.0	65.5 ± 7.7
X8	39.1 ± 6.8	70.8 ± 9.4	83.1 ± 8.6
X9	45.2 ± 10.2	45.5 ± 10.0	61.2 ± 10.4
X10	51.6 ± 7.9	41.5 ± 14.1	55.6 ± 13.0
X11	60.6 ± 6.4	51.6 ± 11.6	53.0 ± 14.9
X12	44.6 ± 8.7	54.0 ± 10.2	80.9 ± 7.0

Note: compiled by the authors

According to the data presented, large enterprises demonstrate the most significant prevalence of advanced digital and technological competencies. Small businesses are characterized by a higher level of basic cognitive and soft skills, but have pronounced deficits in high-tech areas. Medium-sized enterprises occupy an intermediate position, showing moderate values in both soft and digital competencies. Next, Figure 1 provides a visual representation of these distributions with error bars corresponding to one standard deviation (SD).

The combined presentation of Table 3 and Figure 1 allows for both numerical assessment and visual comparison of competency profiles. Table 3 facilitates precise identification of mean values and variability for each competency, whereas Figure 1 clearly highlights structural differences across enterprise sizes.

The analysis reveals pronounced disparities in competency profiles. For example, adaptability and flexibility (X1) demonstrates relatively stable levels across all enterprise sizes, though small enterprises exhibit greater variability, which may reflect heterogeneous HR strategies. Teamwork and communication (X4) and environmental mindset (X5) are more balanced across groups, with slightly higher prevalence in medium and large firms, indicating a more systematic approach to soft skills and sustainability in mature organizations.

By contrast, technological and digital competencies – including artificial intelligence and machine learning (X7) and big data analytics (X12) – are primarily concentrated in large enterprises, highlighting their higher digital maturity and greater investment in innovation. The most notable gap is observed in knowledge of current technological trends (X6), where small firms lag significantly behind large ones, likely due to limited access to information and differences in strategic priorities.

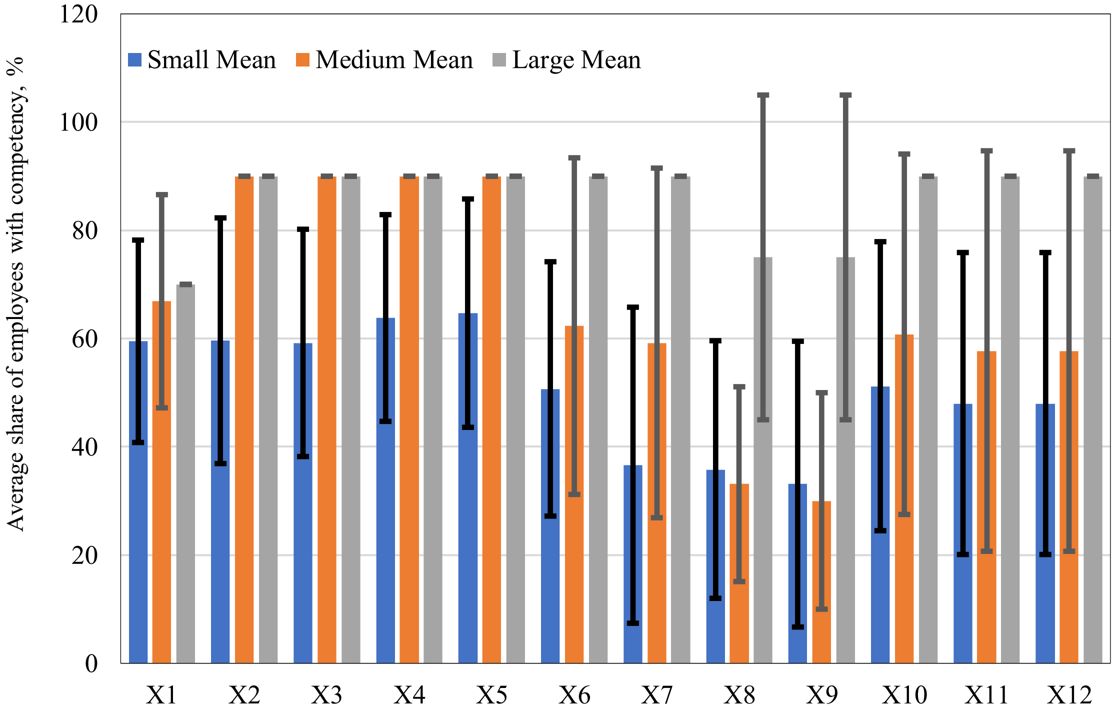

FIGURE 1. Distribution of twelve key human capital competencies across small, medium, and large enterprises (Mean ± SD)

The analysis confirms that competency profiles in Kazakhstani entrepreneurial structures are highly dependent on enterprise size, with small businesses exhibiting deficits in advanced digital and technological skills. Medium and large firms show stronger positions in soft skills, environmental orientation, and technological readiness, which together underpin higher innovation potential.

These findings emphasize the importance of targeted capacity-building programs for SMEs, particularly in digital literacy, technological trend awareness, and advanced analytics. Addressing these gaps is critical for enhancing the innovation ecosystem and supporting the transition to Industry 4.0 in Kazakhstan.

4.2 Analysis of Variance (ANOVA)

The next stage of the study involved a one-way analysis of variance (ANOVA) aimed at identifying statistically significant differences in the formation levels of the twelve key human capital competencies across enterprises of different sizes (small, medium, and large). The proportions of employees possessing each competency (X1–X12) served as the dependent variables, while enterprise size was used as the grouping factor.

The statistical analysis was conducted in the Jamovi environment. Preliminary diagnostics included the Levene's test to verify the homogeneity of variances, Shapiro–Wilk tests to assess the normality of distributions, and pairwise deletion for handling missing values. This ensured the validity of subsequent ANOVA calculations. The results of the one-way ANOVA indicate that almost all competencies demonstrate statistically significant differences by enterprise size, with the exception of X1 (adaptability and flexibility). The F-values and p-values for each competency are summarized in Table 6.

TABLE 6. Results of the one-way analysis of variance (ANOVA)

Competency	F-value	P-value	Competency	F-value	P-value
X1	1.58	0.207	X7	10.17	<0.001
X2	15.23	<0.001	X8	5.55	0.004
X3	18.25	<0.001	X9	5.16	0.006
X4	15.92	<0.001	X10	4.85	0.008
X5	12.19	<0.001	X11	5.09	0.007
X6	6.84	0.001	X12	5.09	0.007

Note: compiled by the authors

As shown in Table 4, competencies related to digital and technological skills (X6–X12) display the most pronounced differences between enterprise size categories. This reflects the higher digital maturity and resource availability in large enterprises compared to small businesses, which often face limited access to advanced technologies and training. Conversely, adaptive (X1) and soft competencies (e.g., X4 teamwork and communication, X5 environmental mindset) are relatively evenly distributed across enterprise sizes, which may indicate their universal relevance regardless of organizational scale.

To provide a clear visual representation, Figure 2 illustrates the F-values for all twelve competencies along with the critical F-value threshold ($F \approx 4.0$, $p = 0.05$).

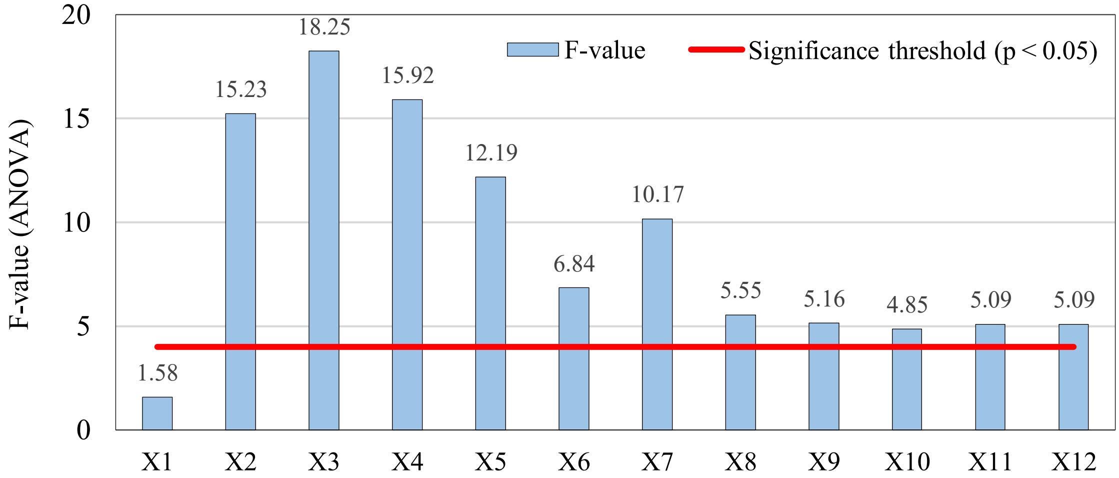

FIGURE 2. Mean competency levels by enterprise size (X1–X12)

Note: bars represent F-values; the red line indicates the critical F-value corresponding to $p = 0.05$

Bars exceeding this threshold indicate statistically significant differences in competency levels between enterprise groups. The visualization confirms that most competencies, particularly digital and technological ones, vary significantly with enterprise size, highlighting the structural heterogeneity of human capital in the context of digital transformation. These findings emphasize the need to consider enterprise size when designing competency development programs and innovation strategies.

4.3 Cluster Analysis of Competencies

Hierarchical cluster analysis was applied to group the twelve studied competencies (X1–X12) into meaningful clusters based on their prevalence across enterprises and their functional orientation. The analysis was conducted in the Jamovi software environment using Ward's method with the Euclidean distance metric, which allows for the stepwise aggregation of variables according to their statistical proximity.

Competencies merging at shorter distances indicate stronger interrelationships and functional similarity. The resulting dendrogram illustrates the process of cluster formation, where horizontal distances reflect the degree of dissimilarity (Figure 3).

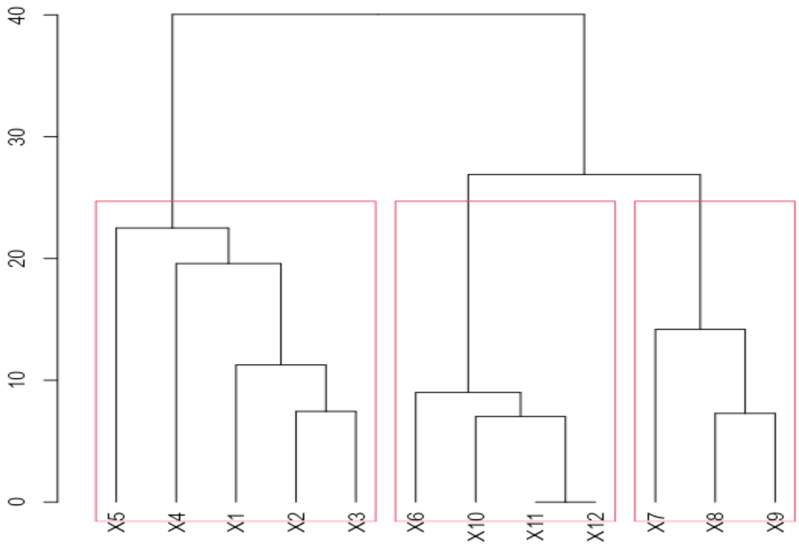

FIGURE 3. Results of competency cluster analysis (Dendrogram)

Interpretation of the dendrogram revealed three stable clusters of competencies. Basic cognitive and flexible competencies (X1–X5) – adaptability, creativity, problem solving, teamwork, ecological thinking. Digital-ecological and analytical competencies (X6, X10–X12) – technological trends, eco- and cybersecurity, Big Data. Specialized technological skills (X7–X9) – AI & ML, biotechnology, and robotics.

These clusters reflect a functional typology of human capital, ranging from universal soft skills to highly specialized, knowledge-intensive capabilities, and provide the basis for a comprehensive competency map. This structure highlights the gradual transition from foundational skills that are widely present in SMEs to advanced digital and technological competencies concentrated in large enterprises. To facilitate practical application and policy recommendations, the identified clusters were systematized in Table 7, which includes their main content, general characteristics, and priority support measures for development.

TABLE 7. Summary description of competency clusters and directions for their development

Cluster	Main competency	General characteristics	Priority support measures
Cluster 1: Basic cognitive and flexible competencies	X1–X5: Adaptability, teamwork, environmental friendliness, creativity, problem solving	Universal basic soft skills, most fully developed, especially in the environment of small and medium-sized enterprises	Maintenance and development through in-house training, team building and eco-initiatives

Cluster 2: Digital-ecological and analytical competencies	X6, X10–X12: Technological trends, eco- and cybersecurity, Big Data	Transitional-level competencies requiring systems thinking and digital literacy	Development of advanced training programs, digital training, industry seminars
Cluster 3: Specialized technological skills	X7–X9: AI and machine learning, biotechnology, robotics	High-tech and knowledge-intensive competencies, poorly distributed in SMEs, require significant investment and high qualifications	Government subsidies, partnerships with universities, acceleration programs and grants for R&D

Note: compiled by the authors

4.4 Competency Map Visualization (Radar Chart)

To provide an integrated visualization of the identified competency clusters and their distribution across enterprises of different sizes, a competency map was constructed in the form of a radar chart. This visualization allows for the simultaneous comparison of all twelve competencies (X1–X12) for small, medium, and large enterprises. The plotted values represent the average share of employees possessing the corresponding competencies, expressed as a percentage of the total workforce in each enterprise category.

The radar chart highlights the structural differences in competency profiles:

Large enterprises demonstrate the most balanced and developed competency portfolio, with consistently high values across all clusters, particularly in digital-ecological and specialized technological skills.

Medium-sized enterprises exhibit a similar structure but lower intensity in digital and technological competencies, reflecting limited access to advanced infrastructure and innovation resources.

Small enterprises show pronounced gaps in high-tech competencies (Cluster 3: AI & ML, robotics, biotechnology) and analytical digital skills (Cluster 2: Big Data, cybersecurity), despite the relatively strong presence of universal cognitive and soft skills (Cluster 1).

So, the above is shown in more detail in Figure 2.

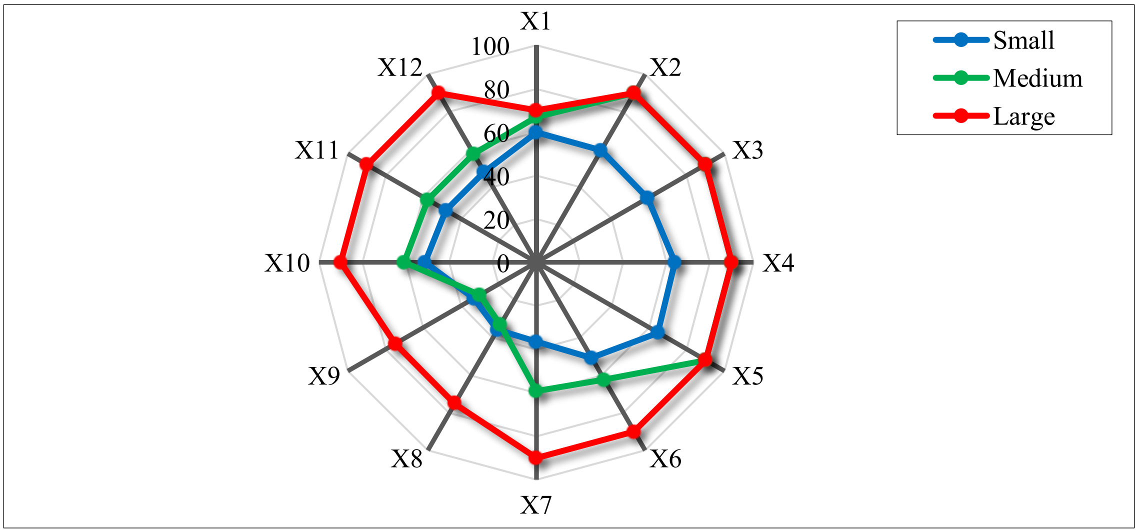

FIGURE 4. Radar chart visualizing the competency map by enterprise size

Note: values represent the average share of employees (%) possessing each competency within enterprises of different sizes

This distribution illustrates the systemic competency gap between enterprise types and underscores the need for targeted HR development programs to support SMEs in the transition to Industry 4.0 and sustainable digital transformation. The radar chart serves as a synthesizing element of the competency map, combining the results of descriptive statistics, ANOVA, and hierarchical clustering. Its structure facilitates: identification of competency strengths and gaps by enterprise size; alignment of human capital strategies with digital maturity levels; prioritization of targeted training and R&D initiatives to enhance innovation potential.

The integrated application of descriptive statistics, one-way ANOVA, and hierarchical cluster analysis ensured a comprehensive assessment of the human capital competency structure in Kazakhstani enterprises. Descriptive statistics provided a general profile and highlighted preliminary differences among enterprise sizes, ANOVA statistically confirmed the heterogeneity of competency formation, and cluster analysis revealed the underlying functional grouping of competencies into three meaningful clusters. The resulting radar chart served as a synthesizing visualization, combining the outcomes of all stages and offering a practical competency map for diagnosing strengths and gaps, supporting evidence-based human capital development strategies, and guiding SMEs in their transition to Industry 4.0 and sustainable digital transformation.

5. CONCLUSIONS

This study developed and empirically validated a competency map of human capital for entrepreneurial structures in Kazakhstan in the context of Industry 4.0. By integrating descriptive statistics, one-way ANOVA, and hierarchical cluster analysis, the research identified three interrelated clusters of competencies, which together form the foundation of enterprises' innovation potential.

This integrative approach not only systematizes the structure of key human capital competencies but also provides an evidence-based foundation for multi-level decision-making in enterprise and policy contexts.

At the enterprise level, the competency map serves as a diagnostic and planning tool. It enables managers to: identify strengths and gaps in the workforce by competency cluster; design targeted upskilling and reskilling programs; align HR strategies with digital transformation priorities.

For small enterprises, this may involve prioritizing basic digital skills and participation in shared innovation initiatives; medium firms can focus on integrating analytical and eco-digital competencies; and large enterprises can leverage the map to plan high-tech workforce expansion and R&D activities.

At the policy and ecosystem level, the map provides insights for: defining priority areas for government support; designing programs for SMEs in transition to Industry 4.0; fostering industry–university collaboration to close specific competency gaps. Such alignment helps ensure that public initiatives and training programs directly address the real distribution of human capital competencies in the national entrepreneurial landscape.

Finally, in the context of Industry 4.0 and sustainable digital transformation, the competency map supports the transition of Kazakhstan's enterprises from a reliance on universal soft skills toward comprehensive digital and specialized technological readiness. By linking empirical analysis with actionable recommendations, the study offers practical guidance for enhancing the innovation potential of the national entrepreneurial ecosystem and creates a framework for long-term human capital development in a rapidly changing technological environment.

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