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Building Digital Ecosystems in Central Asian Universities: Artificial Intelligence, Lifelong Learning, and Sustainable Transformation

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Abstract: The digital transformation of higher education is reshaping universities worldwide, yet regional disparities remain substantial. Central Asia, comprising Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan, occupies a distinctive position shaped by post-Soviet legacies, rapid demographic growth, and emerging digitalization demands. This study examines the development of integrated digital ecosystems in Central Asian universities as a strategic response to modernization pressures. Using an explanatory mixed-method design that combined expert interviews ($n = 42$), institutional surveys across five countries (distributed to staff across consortium member institutions), organizational case analyses, and a systematic review of 61 publications from 2019 to 2026, the study identifies four systemic barriers: inadequate infrastructure, platform incompatibility, shortages of information technology specialists, and low faculty digital literacy. Participant distribution across the five countries reflected institutional diversity in capital cities and regional centers, spanning public and private institutions at varying stages of digital development. At the same time, initiatives such as Kyrgyzstan Digital Central Asia-South Asia (CASA) project, Kazakhstan smart-campus programs, and Uzbekistan territorial digital clusters demonstrate the potential of collaborative ecosystems to expand access, reduce costs, and stimulate innovation. The integration of artificial intelligence tools, including chatbots, adaptive learning analytics, and personalized platforms, offers promising pathways for governance and individualized pedagogy, although ethical risks, inequitable inclusion, and misalignment between national policy frameworks and institutional capacity continue to limit sustainable progress. The article situates these developments within global debates and proposes a multistakeholder governance model supported by cross-border cooperation, targeted investment, and systemic faculty development.

Keywords: digital ecosystems, artificial intelligence in education, higher education transformation, lifelong learning, Central Asia universities, digital governance, educational innovation, faculty digital literacy, sustainable digital transformation, institutional modernization, distance education, digital inclusion

Highlights

What is already known about this topic:

- Digital transformation in higher education is a systemic process requiring alignment of strategy, infrastructure and human capital, not mere technology adoption.
- Digital ecosystems and artificial intelligence are widely theorized, but evidence is concentrated in Western, North American and East Asia settings.
- Central Asia HE remains underrepresented in international scholarship on digital transformation.

What this paper contributes:

- Provides a multi-country empirical framework for digital transformation across five Central Asian higher education systems.
- Identifies systemic barriers and working ecosystem models while integrating equity and post-Soviet governance into global theory.

Implications for theory, practice and/or policy:

- Theory: Integrates equity and post-Soviet governance into ecosystem models.
- Practice/Policy: Outlines a multistakeholder governance model, a phased regional roadmap, and a governance-first approach to AI scaling.



Introduction

Global Context

The digital transformation of higher education has become one of the defining challenges of the twenty-first century. Universities worldwide are reconfiguring governance structures, pedagogical models and research practices to adapt to the demands of the knowledge economy and what scholars have termed the Fourth Industrial Revolution (Akhmadi & Tsakaleriou, 2024; Carmo et al., 2025). The scholarly literature is clear that digital transformation is not merely a process of technological adoption but a systemic reorganization requiring alignment among institutional strategy, infrastructure investment and human-capital development (Krimpis et al., 2024; Limanovskaja & Davidavičienė, 2025). Digital ecosystems, understood as integrated networks connecting universities, research centers, industry stakeholders and technology platforms, have emerged as the dominant conceptual framework for achieving sustainable transformation at institutional and regional scales (Alé-Ruiz et al., 2024; Rojas & Chiappe, 2024). Nevertheless, global studies continue to document persistent inequities in digital access, unresolved ethical concerns around artificial intelligence (AI) adoption and starkly uneven institutional readiness across world regions (Segbenya et al., 2023; AlBlooshi, 2026).

The Central Asian Context

Central Asia, comprising Kazakhstan, the Kyrgyz Republic, Tajikistan, Turkmenistan and Uzbekistan, presents a strategically significant regional case that remains underrepresented in international scholarship on higher-education transformation. With a combined population exceeding 71.7 million and rapid demographic growth, the region faces substantial pressure to expand and modernize its higher-education capacity (Tajik & Makoelle, 2024). Despite meaningful economic growth driven largely by resource exports, Central Asia continues to lag behind other world regions in the comprehensiveness of its digital transition (Asian Development Bank, 2023; Wang et al., 2026). Higher-education systems across the five countries were shaped by Soviet-era centralized governance and uniform curricular frameworks, and the post-1991 transition to national systems has produced fragmented outcomes characterized by outdated curricula, limited institutional autonomy and constrained funding models (Karabayev et al., 2023; Abrasheva & Sabzalieva, 2023).

Original fieldwork conducted across regional universities in 2025 confirms that institutional actors are acutely aware of the need for digital transformation yet continue to encounter systemic barriers. These include insufficient broadband infrastructure, incompatibility among existing digital platforms, acute shortages of qualified information-technology professionals and low levels of faculty digital literacy. These findings parallel broader patterns documented in comparative studies of digitalization in emerging economies (Wang et al., 2026; Asian Development Bank, 2023).

Research Gaps and Objectives

Although the global literature on digital transformation in higher education is extensive, it remains concentrated on Western European, North American and East Asian contexts. Central Asia occupies a marginal position in international discourse despite representing a geopolitically significant and educationally distinctive region. Existing research on Central Asian higher education tends to examine isolated dimensions, such as governance reform, Europeanisation pressures or individual technology-adoption projects, without integrating these threads into a holistic analytical framework (Tajik & Makoelle, 2024; Horbatiuk et al., 2025). Empirical data from the region remain scarce, and the intersections of digital-ecosystem theory, artificial intelligence and lifelong learning have not previously been applied in a sustained analytical engagement with Central Asian institutional realities. Scholarship on distance education, open education, and digital inclusion specifically in Central Asia is particularly limited, creating a gap between regional policy aspirations and international evidence on effective implementation strategies.

This study addresses these gaps through five formal research questions:

1. How advanced are the current digital ecosystems in Central Asian universities, and what components of mature ecosystems (academic collaboration, industry integration, government support, technology adoption) are present or absent?
2. What role can artificial intelligence tools play in fostering personalized learning and improved institutional governance in resource-constrained Central Asian higher-education systems, and what governance frameworks are necessary to ensure ethical implementation?
3. How can lifelong learning principles be structurally embedded in Central Asian universities, and what curricular, technological, and policy conditions enable continuous skill development for working adults?
4. What systemic barriers (infrastructure, governance, human capital, equity) prevent ecosystem-level digital integration, and what opportunities exist within the post-Soviet institutional context?
5. How should a regional governance framework be designed to support scalable, inclusive, and sustainable digital-ecosystem development across the five Central Asian republics?

Literature

Conceptualizing Digital Transformation in Higher Education

Digital transformation in higher education has been theorized as a multidimensional, systemic process that extends well beyond the adoption of discrete technologies. Scholars distinguish conceptually between digitization, the conversion of analogue processes into digital formats, and digitalization, the deeper systemic integration of digital technologies into institutional structures, cultures and practices (Krimpis et al., 2024; Limanovskaja & Davidavičienė, 2025). This distinction is analytically important because it foregrounds the organizational and cultural dimensions of transformation rather than reducing the phenomenon to questions of technological infrastructure. Transformation, in this framing, demands alignment among institutional mission, governance structures, pedagogical models and human-capital development (Akhmadi & Tsakaleriou, 2024; Rodríguez-Abitia & Bribiesca-Correa, 2021).

Comparative studies of digital transformation in Europe, North America and Asia document a consistent pattern in which successful transformation requires sustained investment, clear governance frameworks and faculty development at scale (Morze & Strutynska, 2021; Su et al., 2022). The COVID-19 pandemic accelerated these imperatives dramatically, forcing universities worldwide to pivot rapidly to online delivery and, in doing so, exposing both the possibilities and the fragility of existing digital systems (Mhlanga, 2022). Post-digital scholarship has argued persuasively that this episode confirmed the need for relational rather than purely technical understanding of digital resilience, recognizing that technology operates within broader social, institutional and political contexts (Veletsianos & Houlden, 2020).

Distance Education, Online Learning, and Digital Inclusion Frameworks

Distance education and online learning have evolved from alternative delivery modes to foundational components of integrated digital ecosystems. Research on distance education emphasizes the importance of learner support systems, pedagogical design, technological accessibility, and equitable access regardless of geographic location or socioeconomic status (Moore & Kearsley, 2011; Simonson et al., 2015). In the Central Asian context, distance education frameworks are particularly relevant because they address the persistent challenge of rural access, demographic diversity, and the need for flexible, non-synchronous learning pathways. Open education approaches, including open educational resources and open educational practices, further extend the reach of distance learning by reducing cost barriers and enabling institutional resource pooling (Hilton et al., 2014; Wiley & Hilton, 2018). Digital inclusion scholarship underscores that technology infrastructure alone is insufficient; sustainable transformation requires attention to digital literacy development, culturally responsive pedagogy, and mechanisms to prevent digital divides from reproducing or amplifying existing socioeconomic inequalities (van Deursen & van Dijk, 2014). Central Asian universities attempting ecosystem development must ground their strategies in distance education and digital inclusion principles to ensure

that expanded technological capacity translates into equitable access and meaningful learning opportunities for all students, particularly those in underserved geographic areas or lower-income backgrounds.

Digital Ecosystems: Theory and Practice

The concept of digital ecosystems in higher education draws on biological metaphors of interconnectedness, adaptation and mutual dependency to describe environments in which institutions, governments, industry partners, students and technology platforms collaborate through shared digital infrastructure and common standards (Alé-Ruiz et al., 2024; Rojas & Chiappe, 2024). The ecosystem metaphor is productive precisely because it foregrounds systemic interdependence: no single actor can sustain transformation alone, and the health of the ecosystem depends on the contributions of all participants.

Zhao and Yang (2024) articulate an ecosystem theory for digitally enabled higher education in which government, enterprises and universities constitute the core participating subjects, with collaborative innovation emerging from their interaction. This tripartite model resonates with the broader higher-education governance literature and provides a useful analytical frame for understanding regional variation. European university consortia typically emphasize resource pooling and interoperable platforms for teaching and mobility. North American institutions rely more heavily on industry partnerships and cloud-based analytics. East Asian ecosystems are frequently embedded within national innovation strategies that link higher education directly to economic development (Su et al., 2022; OECD, 2023). The Asian Development Bank (2023) has assessed digital-education readiness across Central and South-East Asian countries, finding that Uzbekistan and Kyrgyzstan face particular challenges in infrastructure, teacher digital competency and systemic coordination, providing empirical context for the present analysis.

Scholars identify four functional components that distinguish mature digital ecosystems from fragmented digitalization efforts: academic collaboration for resource sharing and joint research; industry integration to align curricula with labor-market demands; government support through policy, funding and regulatory frameworks; and broad-spectrum technology adoption spanning cloud computing, artificial intelligence and virtual learning environments (Guamo et al., 2026; Zhao & Yang, 2024). When any of these components are absent or weakly developed, the ecosystem risks fragmenting into isolated pilot projects that fail to achieve systemic impact.

Artificial Intelligence in Higher Education

Artificial intelligence has emerged as one of the most consequential drivers of change in contemporary higher education. Systematic reviews document artificial intelligence applications across institutional functions, including personalized adaptive learning, early-warning systems for at-risk students, automated assessment and feedback, administrative process optimization and research analytics (Segbenya et al., 2023; Southworth et al., 2023). AI-powered learning-management systems can respond dynamically to individual learner trajectories, offering tailored pathways and real-time feedback that supplement instructor-led learning at a scale previously impossible (Zawacki-Richter et al., 2019).

Notwithstanding these possibilities, the ethical dimensions of AI in higher education have attracted growing scholarly and policy attention. Issues of data privacy, algorithmic bias, transparency, accountability and equitable access to AI-enhanced platforms are increasingly central to debates about responsible adoption (AlBlooshi, 2026; Dabis & Csáki, 2024). Systematic reviews of AI ethics in education reveal a significant regulatory gap: although numerous AI-ethics guidelines have been issued by governments, international organizations and industry actors, many remain high-level and insufficiently contextualized for educational practice (Yin et al., 2024; UNESCO, 2019). There is particular concern that AI systems, if poorly designed or governed, may reproduce and amplify existing educational inequalities, with students from lower-income and rural backgrounds bearing disproportionate risks (Wargo & Anderson, 2024). In developing-economy contexts, AI adoption confronts additional structural constraints, including limited broadband access, insufficient computational infrastructure and low baseline digital competency, which require context-sensitive

implementation strategies that prioritize equity, faculty preparation and institutional governance alongside technological deployment (Yin et al., 2024; George & Wooden, 2023).

Lifelong Learning and Digital Skill Development

Lifelong learning has become a foundational principle of higher-education policy in the digital era. The Organisation for Economic Co-operation and Development (OECD, 2023) frames lifelong learning as essential for building inclusive and resilient societies amid rapid digitalization and demographic change, identifying the will, skills and means of learners as three interconnected dimensions that policy must simultaneously cultivate. The shift from credential-based models toward competency-based and modular frameworks that enable continuous skill development has been documented across multiple national contexts (Håkansson Lindqvist et al., 2024; Rott, 2024). A scoping review on higher-education transformation toward lifelong learning identified seven thematic perspectives: policy, value, employability, reform, collaboration, student experience and workplace learning (Håkansson Lindqvist et al., 2024). Digital ecosystems are increasingly recognized as enabling architectures for lifelong learning, providing the technological backbone through which universities can offer flexible, continuous and responsive education at scale (Knight et al., 2017). Scholars further emphasize that equitable access to continuous education is a prerequisite for reducing socioeconomic inequalities, and that institutions which fail to embed inclusivity into their lifelong-learning designs risk deepening structural disadvantage (Skledar Matijević et al., 2025). Micro-credentials and stackable qualification frameworks represent one institutional response to these concerns (Beriasvili & Trucano, 2024).

Post-Soviet Higher Education Reform

The trajectory of higher-education reform in Central Asia cannot be understood in isolation from the post-Soviet transition. Following the dissolution of the Soviet Union in 1991, universities in all five republics inherited centralized governance structures, standardized curricula and institutional cultures resistant to rapid change (Abrasheva & Sabzalieva, 2023; Goastellec, 2022). Comparative analyses identify a recurring pattern in which formal policy frameworks, often modelled on European or international templates, outpace institutional capacity to implement them, producing a persistent gap between reform ambitions and operational realities (Smolentseva & Platonova, 2022).

Kazakhstan has pursued the most ambitious modernization agenda, with state-directed investment in digital infrastructure, smart-campus development and international partnerships. Kyrgyzstan has leveraged international donor support, particularly the Digital Central Asia-South Asia (CASA) initiative, to advance connectivity and digital-resource development. Tajikistan and Turkmenistan face more severe structural constraints, including underfunded institutions, weak policy frameworks and limited exposure to international higher-education trends (Horbatyuk et al., 2025; Tajik & Makoele, 2024). Uzbekistan has experimented with territorial digital-cluster models designed to pool resources among geographically proximate institutions (Zakirova, 2022). The post-Soviet context also shapes the social and political dimensions of higher education, including tensions among kinship traditions, Soviet-era cosmopolitan identities and globalization pressures, all of which affect how students access and experience higher education (Chankseliani et al., 2021). Cowen's (2009) transfer–translation–transformation framework offers a productive lens for understanding how international policy models are adapted to local institutional realities in post-Soviet contexts.

Systematic Review: Literature Classification

A systematic review of peer-reviewed literature was conducted following Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidance. Electronic searches of Web of Science, Scopus, ERIC, and Google Scholar were performed in January 2026 using search terms including *digital ecosystems higher education*, *digital transformation Central Asia*, *artificial intelligence higher education*, *developing economies*, *lifelong learning digital skills*, *distance education digital inclusion*, *open education Central Asia*, and *post-Soviet higher education reform*, bounded to 2019–2026. Searches were not restricted by language, although English-language publications were prioritized.

Initial searches yielded 412 candidate publications. Title and abstract screening was conducted independently by two reviewers, resulting in 218 publications meeting preliminary inclusion criteria. Full-text review for methodological quality, relevance, and regional focus produced a final corpus of 61 core peer-reviewed studies. All retained studies employed empirical data collection (interviews, surveys, case studies) or systematic analysis of policy and institutional documents. A PRISMA flow diagram documenting the screening process is provided in Appendix A. Excluded studies consisted primarily of opinion pieces without evidence, reviews of reviews, and analyses from non-Central Asian contexts judged as not directly applicable to regional transformation processes.

The final corpus of 61 studies was thematically classified across major analytical domains, as presented in Table 1. The thematic distribution highlights the multidimensional scope of digital-ecosystem research in higher education and demonstrates that sustainable digital transformation requires coordinated governance reform, ethical AI practice, lifelong-learning strategies, and inclusive institutional policy rather than simple technological modernization. The classification also underscores the limited presence of Central Asian empirical studies within the broader international discourse.

Table 1. Thematic classification of the reviewed literature by major analytical domain (2019–2026)

Thematic domain	Representative scholars and sources (author, year)	Central contribution to this study
1. Digital transformation foundations	Akhmadi & Tsakaleriou (2024); Bygstad et al. (2022); Krimpis et al. (2024); Limanovskaja & Davidavičienė (2025); Mhlanga (2022); Mhlanga et al. (2022); Morze & Strutynska (2021); Makhmutkhodjaeva et al. (2024); Wang et al. (2026)	Conceptual distinction between digitization and digitalization; systemic alignment requirements; crisis-driven transformation lessons; comparative perspectives from developed and developing countries
2. Digital ecosystems theory	Asian Development Bank (2023); Carayannis & Morawska-Jancelewicz (2022); Guamo et al. (2026); Rojas & Chiappe (2024); Zakirova (2022); Zhao & Yang (2024)	Four-component ecosystem model; tripartite stakeholder governance; links with Society 5.0 and Industry 5.0; university digital-ecosystem development
3. AI in higher education — applications & strategy	AlBlooshi (2026); Alqahtani et al. (2023); George & Wooden (2023); Jarrahi et al. (2022); Rojas & Chiappe (2024); Segbenya et al. (2023); Southworth et al. (2023); Su et al. (2022); Wangdi & Pelden (2025); Zawacki-Richter et al. (2019)	AI application categories (personalization, governance, chatbots); AI-literacy models; strategic organizational learning; constraints and affordances in developing economies
4. AI ethics, fairness & policy responses	Dabis & Csáki (2024); UNESCO (2019); Wargo & Anderson (2024); Yin et al. (2024)	Institutional policy responses to generative AI; ethical dilemmas (bias, fairness, transparency); frameworks for responsible AI in education
5. Lifelong learning & digital skills	Beriashvili & Trucano (2024); Gallardo-Echenique et al. (2015); Håkansson Lindqvist et al. (2024); Knight et al. (2017); OECD (2023); Rott (2024)	Will–skills–means framework; micro-credentials and digital credentials; digital competence; adult-learning transformation; smart-data policies
6. Post-Soviet higher-education reform	Abrasheva & Sabzalieva (2023); Cowen (2009); Goastellec (2022); Horbatiuk et al. (2025); Karabayev et al. (2023); Smolentseva & Platonova (2022); Tajik & Makoelle (2024)	Policy–implementation gap; country-level variation; Cowen's transfer–translation–transformation lens; links between higher education and economic development; state–market legacies
7. Distance education, online learning, and digital inclusion	Moore & Kearsley (2011); Simonson et al. (2015); Hilton et al. (2014); Wiley & Hilton (2018); van Deursen & van Dijk (2014); Alé-Ruiz et al. (2024); Bitar & Davidovich (2024); Veletsianos & Houlden (2020)	Distance education frameworks and learner support systems; open educational resources and practices; digital inclusion and equity in access; underserved populations in rural and low-income contexts
8. Pedagogical innovation & active learning	Hida et al. (2025); Paños-Castro et al. (2024)	Flipped classroom, gamification, AI-mediated personalization; competency-based approaches; radical flexibility and relationality in crises
9. Learning analytics & data governance	Hernández-de-Menéndez et al. (2022); Knight et al. (2017); Rosenberg et al. (2022); Wang et al. (2023); Zhao & Yang (2024)	Learning analytics and temporal analysis; ethical use of big data; log data from open-ended environments; OECD smart-data frameworks
10. Sustainability, governance & international development	Aposika (2026); Carmo et al. (2025); Cerda Suarez et al. (2021); Chankseliani et al. (2021); Hsieh (2020); Komljenovic (2025); Wang et al. (2026)	Long-term sustainability conditions; comparative policy; internationalization and global development; digitalized higher-education governance
11. Equity, inclusion & methodological frameworks	Creswell & Plano Clark (2017); Goastellec (2022); Rudd et al. (2021); Skledar Matijević et al. (2025);	Academic resilience; ethnicity and social class in access; inclusion policies; mixed-methods research design

Source: Compiled by the authors from the systematic review of 61 peer-reviewed publications indexed in Scopus, Web of Science, ERIC and Google Scholar (2019–2026).

Methodology

Research Model/Design

This study employs an explanatory mixed-method research design that integrates qualitative and quantitative data sources to construct a comprehensive account of digital-ecosystem development in Central Asian higher education. The mixed-method approach is appropriate given the dual objectives of mapping institutional conditions across a diverse regional landscape and generating theoretical insights that can inform both local policy and broader scholarly debate (Creswell & Plano Clark, 2017). The explanatory design sequence involved the following phases: (1) initial qualitative phase (expert interviews, 2023–2024) that generated preliminary findings on ecosystem barriers and opportunities; (2) quantitative phase (institutional survey, 2024) that tested and extended qualitative findings across a larger institutional sample; and (3) integrative phase (case analyses and literature synthesis, 2025) that merged findings through interpretive triangulation, allowing quantitative patterns to be contextualized by qualitative depth and theoretical scaffolding from the systematic review. The qualitative phase informed the survey instrument design and sampling strategy, while quantitative results directed the focus of subsequent case analysis and theoretical interpretation. The design capitalizes on the contextual depth of qualitative data while grounding its claims in the representational breadth of survey evidence and systematic literature analysis.

Data Collecting Tools

The empirical foundation rests on three complementary sources collected between 2023 and 2025. All data collection activities followed ethical guidelines for educational research.

Expert Interviews

Semi-structured expert interviews ($n = 42$) were conducted with senior administrators, faculty members, information-technology specialists, and national education-ministry representatives across all five countries between March 2023 and December 2024. Participants were selected through purposive sampling to ensure institutional and geographic diversity. Interview protocols were designed to explore digital-ecosystem development, barriers to integration, artificial intelligence adoption, lifelong learning capacity, and governance frameworks. Each interview lasted between 45 and 90 minutes and was recorded with participant consent. Interviews were transcribed verbatim in English or translated from Russian and local languages by professional translators, then coded using reflexive thematic analysis (Braun & Clarke, 2021). Informed consent was obtained from all participants prior to recording. Confidentiality was maintained by assigning participant codes, and transcripts were stored securely on encrypted, access-restricted servers. Participants were informed that findings would be reported in aggregated form without identifying specific institutions or individuals.

Institutional Survey

An institutional survey was administered in 2024 to university staff across member institutions of a regional higher-education consortium. The instrument was developed through iterative piloting with five institutional partners in 2023 and underwent internal-consistency testing using Cronbach's alpha ($\alpha > 0.7$ for all major scales). The survey consisted of 78 items organized into six domains: digital infrastructure capacity (broadband speed, hardware availability, server resources), learning management system utilization (platform diversity, interoperability, data sharing), faculty digital literacy (self-reported competency, professional development participation), student access patterns (enrollment in online courses, technology access barriers), perceived barriers to ecosystem development (infrastructure, governance, human capital), and recommendations for regional collaboration. Items employed 4-point and 5-point Likert scales ("Strongly Disagree" to "Strongly Agree") and open-ended questions. The survey was administered online via Qualtrics and distributed to administrative and academic staff ($n = 142$ respondents from 23 consortium member institutions across all five countries). Response rates by country were: Kazakhstan 38% (9 institutions), Kyrgyzstan 32% (5 institutions), Uzbekistan 29% (6 institutions), Tajikistan 18% (2 institutions), Turkmenistan 15% (1 institution). Survey data were analyzed descriptively using IBM SPSS Statistics version 26, with

frequencies, means, standard deviations, and cross-tabulations used to characterize the regional landscape. No inferential statistical tests were conducted, consistent with the exploratory nature of this cross-sectional snapshot.

Organizational Case Analyses

Organizational case analyses were conducted for three pilot digital-ecosystem initiatives selected for their demonstrated advancement and regional significance: the Digital CASA project in Kyrgyzstan, the smart-campus program at a leading Kazakhstan university, and the territorial digital-cluster model in Uzbekistan. Case data were gathered through documentary analysis of project reports, institutional policy documents, strategy statements, and implementation records. Each case involved 8–12 hours of document review, supplemented by 2–3 focused interviews with project leadership. Findings were synthesized using thematic content analysis and presented as narrative case descriptions that illustrate different pathways toward ecosystem development.

Sampling and Study Participants

Purposive sampling was employed across all components to ensure institutional diversity and representativeness across the regional landscape. Interview sampling targeted universities in capital cities (Nur-Sultan/Astana, Bishkek, Dushanbe, Ashgabat, Tashkent) and regional centers (Almaty, Karaganda, Osh, Khujand, Samarkand), including both public and private institutions at varying stages of digital development. The 42 expert interviews comprised: Kazakhstan (12 interviews, 5 institutions), Kyrgyzstan (9 interviews, 4 institutions), Uzbekistan (10 interviews, 5 institutions), Tajikistan (6 interviews, 2 institutions), Turkmenistan (5 interviews, 1 institution). Survey sampling encompassed 142 respondents from 23 consortium member institutions across all five countries, with country-level representation roughly proportional to higher-education sector size. Case study sampling was purposive, selecting three initiatives identified through preliminary interviews and policy document review as exemplifying distinct ecosystem development models. The systematic literature review employed inclusion/exclusion criteria applied to all candidate publications, regardless of author geography or institutional affiliation.

Data Analysis

Qualitative data from interviews and case analyses were analyzed using reflexive thematic analysis (Braun & Clarke, 2021). Initial codes were developed inductively through line-by-line review of interview transcripts and case documents. Codes were organized into preliminary themes through research team discussion; secondary coding passes refined theme boundaries and identified connections among themes. The analysis proceeded iteratively, with raw data regularly returned to throughout the process. Final themes were reviewed for coherence and representativeness against the full dataset. Survey data were analyzed descriptively using SPSS, with means, standard deviations, frequencies, and contingency tables used to characterize regional patterns and between-country variation. Findings from qualitative, quantitative, and case components were synthesized through interpretive triangulation, a process whereby the research team examined whether and how findings across data sources converged, diverged, or complemented one another. The systematic literature review provided analytical scaffolding, allowing empirical findings to be situated within broader theoretical and policy contexts.

Quality Assurance and Validity

Multiple strategies strengthened methodological rigor. Triangulation across interviews, survey data, and documentary case evidence reduced the risk of single-source bias and strengthened interpretive credibility. The survey instrument underwent piloting with five institutions in 2023 and was checked for internal consistency (Cronbach's α calculated for all multi-item scales); results indicated acceptable reliability (all $\alpha > 0.7$). Qualitative coding was conducted iteratively by multiple team members with regular calibration discussions to enhance dependability. The systematic review followed PRISMA screening criteria and included an independent second reviewer for title/abstract and full-text screening to support transparency and replicability of source selection. Research team debriefing sessions

throughout the analysis process promoted awareness of potential researcher biases and strengthened interpretive validity.

Ethical Safeguards

This study involved human participants (expert interviewees, $n = 42$) and therefore incorporated comprehensive ethical protections. Informed consent was obtained from all interview participants prior to recording. The consent process explained the study purpose, data use, confidentiality protections, and voluntary participation rights. Participants were informed that findings would be reported in aggregate form without identifying individuals or specific institutions. All interviews were recorded with explicit participant permission. Recordings were stored securely on encrypted, access-restricted servers and deleted after transcription. Transcripts were de-identified by assigning participant codes and removing institutional names. The institutional survey did not collect personal, sensitive, or confidential data. It requested information about university digital infrastructure and educational processes only. Survey participation was voluntary, and responses were reported in aggregated form for academic purposes only. Institutional affiliations are not disclosed in reporting of specific interview data. In accordance with institutional and international standards for non-invasive educational research, formal ethics committee approval was determined not to be required for this study, as it involved no vulnerable populations, did not collect personal health or genetic information, and posed minimal risk to participants. This determination was made in consultation with institutional research oversight authorities and is consistent with guidelines from the American Educational Research Association (AERA) and the British Educational Research Association (BERA) for educational research involving minimal risk.

Limitations

The study has several limitations. First, the cross-sectional design captures a developmental snapshot rather than longitudinal change, limiting the ability to document changes over time or establish causal relationships among variables. Second, the composite readiness indicators reported below are descriptive estimates derived from survey and secondary data rather than precisely calibrated measures. Third, access constraints in some national systems produced uneven institutional coverage. For example, Turkmenistan is represented by only one institution and limited interview data, which constrains the generalizability of findings to that national context. Fourth, the reliance on aggregated, anonymized survey responses limits fine-grained sub-group analysis by gender, academic discipline, or institutional type. Fifth, survey respondents were drawn from consortium member institutions, which may not be fully representative of all higher-education institutions in the region. Institutions that are not members of the consortium may experience different barriers and opportunities. These limitations inform the directions for future research set out in the conclusion.

Findings and Discussions

The Current State of Digital Infrastructure

Survey data and interview evidence converge on a consistent portrait of digital infrastructure that is uneven, fragmented, and inadequate for the demands of ecosystem-level integration. Across the five countries, urban universities in capital cities report higher levels of broadband connectivity, computer laboratory access, and platform diversity than regional institutions. Descriptive statistics from the survey ($n = 142$ respondents) indicated that 72% of capital-city institutions reported broadband speeds greater than 10 Mbps, compared to 38% of regional institutions ($M = 8.3$, $SD = 4.2$ Mbps capital; $M = 4.1$, $SD = 2.8$ Mbps regional). This urban-rural digital divide within the higher education sector mirrors broader national patterns of unequal digital development documented by the Asian Development Bank (2023). Interview participants ($n = 42$) consistently described infrastructure insufficiency not merely as a technical constraint but as a governance failure, attributing the gap to inadequate and unpredictable public funding, absence of coordinated national strategies for university digitalization, and limited industry partnerships that might supplement state investment.

Platform incompatibility emerged as a particularly significant operational barrier. Survey respondents from 21 of 23 institutions (91%) reported operating learning management systems with limited or no interoperability with other institutions' platforms. Universities that have adopted learning management systems typically operate proprietary or heterogeneous platforms with limited interoperability, rendering cross-institutional data sharing, joint program delivery, and student mobility functionally impossible. One administrator described the situation as "digital islands": institutions with internally functioning systems that are unable to communicate, cooperate, or pool resources with neighboring universities. This fragmentation directly undermines the ecosystem logic that drives the conceptual framework of this study. Figure 1 summarises the comparative readiness of the five national systems across three composite indicators of broadband access, learning management system adoption, and faculty digital literacy.

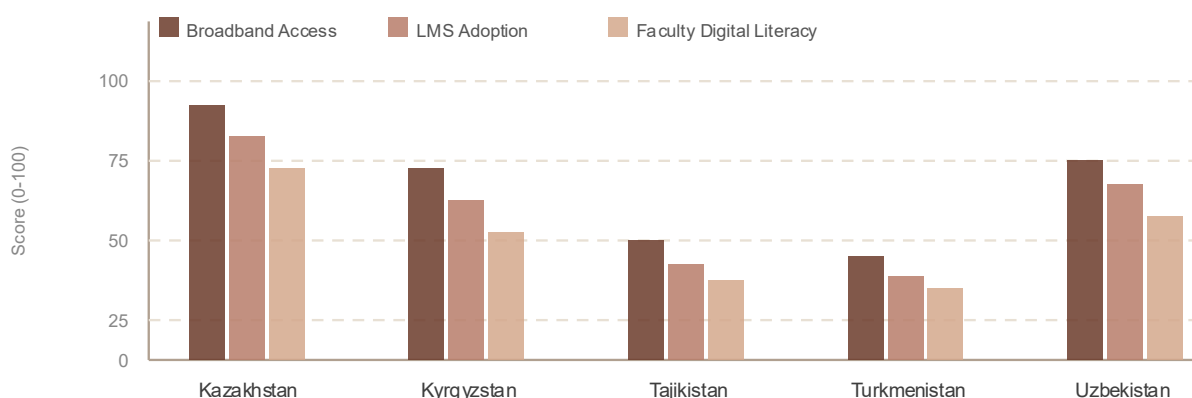


Figure 1. Comparative digital infrastructure readiness across five Central Asian countries: Estimated scores (0-100) on three composite indicators derived from institutional survey data and international readiness assessments. Bars represent, from left to right for each country: broadband access (dark), learning management system (LMS) adoption (medium), and faculty digital literacy (light). Source: Prepared by the authors based on institutional survey data collected in 2023–2025 and secondary analytical reports of the Asian Development Bank (2023).

Kazakhstan and Uzbekistan demonstrate the highest overall readiness, while Tajikistan and Turkmenistan face the most severe structural constraints. These scores are composite estimates based on survey data and secondary sources. They are indicative rather than precisely calibrated and should not be interpreted as absolute measures of institutional readiness. See Appendix B for detailed explanation of composite indicator calculation and weighting.

Pilot Initiatives: Emergent Ecosystem Models

Notwithstanding the systemic constraints documented above, three clusters of pilot initiative provide substantive evidence that ecosystem-level digital integration is achievable within the regional context. These cases illustrate different pathways toward ecosystem development, each reflecting the distinct governance traditions, funding environments, and international partnerships of their national contexts.

The Digital CASA Project, Kyrgyzstan

The Digital Central Asia-South Asia (CASA) project in Kyrgyzstan represents the most explicitly ecosystem-oriented initiative identified in the study. Supported by international donors and leveraging cloud-based infrastructure, the project introduced online textbooks, virtual laboratories, and collaborative learning environments to participating institutions. Critically, the project explicitly targeted rural and remote student populations, addressing the geographic equity dimension that constitutes one of the most pressing imperatives for Central Asian digital transformation. Interview data confirm that the project succeeded in improving content accessibility but encountered persistent challenges in faculty

preparation, with many instructors lacking the digital competencies to utilize the available tools effectively in their teaching practice (From interviews, $n = 3$ project leaders and analysis of project reports).

Smart Campus Programs, Kazakhstan

Kazakhstan smart campus programs represent a second, distinct model in which state-directed investment has enabled individual institutions to develop relatively sophisticated internal digital environments. Analytics platforms that monitor student attendance, performance, and engagement have been deployed, and multimedia-enabled lecture theaters facilitate more interactive pedagogical delivery (From interviews, $n = 4$ administrators and analysis of institutional strategy documents). However, interview evidence reveals that these developments have remained largely institution-specific, with limited interoperability with other universities and insufficient integration into national governance frameworks. The smart campus model thus exemplifies a broader tension identified throughout the regional data: impressive internal digital environments coexisting with an absence of ecosystem-level connectivity.

Territorial Digital Cluster Model, Uzbekistan

Uzbekistan territorial digital cluster model offers a third, governance-oriented pathway. By formally grouping geographically proximate universities into collaborative networks, the cluster model creates structural incentives for resource pooling, shared platform development, and joint program delivery (Zakirova, 2022). Case analysis (one territorial cluster; interviews with cluster administrators, $n = 2$) suggests that the model has successfully reduced infrastructure costs for participating institutions and facilitated modest gains in inter-institutional mobility. Yet the absence of common technical standards and interoperable systems continues to limit the depth of integration that the cluster governance architecture formally enables. Figure 2 represents the stakeholder relationships characteristic of a fully realized ecosystem.

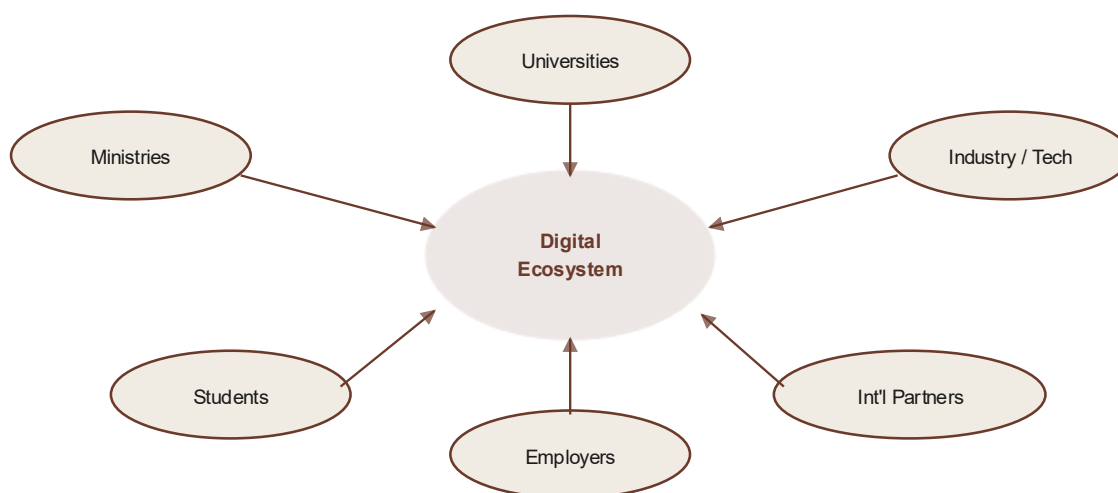


Figure 2. Structural model of a higher education digital ecosystem. Stakeholder interaction diagram illustrating the bidirectional relationships among universities, government ministries, industry and technology partners, students, employers, and international partners within a fully realized ecosystem architecture. The central hub represents the shared digital infrastructure and governance framework that mediates these relationships in a mature ecosystem. Source: Developed by the authors based on ecosystem theory frameworks proposed by Zhao and Yang (2024), Rojas and Chiappe (2024), and empirical findings of the present study.

Artificial Intelligence Integration: Current Applications and Governance Gaps

The adoption of artificial intelligence tools in Central Asian universities is progressing but remains at an early and largely pilot stage. Survey respondents (n = 142 respondents, and interviews, n = 42) reported the following AI tool adoption rates: chatbots (44%), learning analytics platforms (31%), adaptive learning systems (18%), and AI-assisted assessment tools (12%). Survey data indicate that chatbot applications represent the most widely diffused AI tool, particularly for providing rapid academic feedback to students transitioning between coursework and internship phases.

Several institutions in Kazakhstan and Kyrgyzstan have deployed analytics platforms that generate performance data and early-warning indicators, though the utilization of these analytics for instructional decision-making remains low due to inadequate faculty preparation.

Interview data (n = 28 respondents addressing AI and faculty perspectives) reveal a consistent pattern in which AI tools are introduced into institutions without adequate support structures, resulting in surface-level adoption that falls short of meaningful pedagogical integration. Faculty members frequently report discomfort with AI platforms, uncertainty about their pedagogical applications, and concern about data privacy implications for their students. These findings align with the broader literature documenting that AI adoption without concurrent investment in faculty development and governance frameworks reproduces the same fragmentary pattern observed across other digital tools (AIBlooshi, 2026; George & Wooden, 2023).

Ethical concerns represent a particularly underdeveloped area of institutional policy in the regional context. Survey data (n = 23 institutions) indicated that only 4 of 23 institutions (17%) reported having a formal policy governing the use of AI in teaching, assessment, or student data management. Fewer than one-fifth of surveyed institutions reported having a formal policy governing the use of AI in teaching, assessment, or student data management. This regulatory gap is especially consequential given the population of students served, many of whom come from socioeconomic backgrounds that make them more rather than less vulnerable to the risks of algorithmic bias and data misuse. The literature reviewed in this study consistently identifies the absence of institutional AI governance frameworks as one of the most significant risks in the transition to AI-enabled higher education (Dabis & Csáki, 2024; Yin et al., 2024).

Lifelong Learning Capacity: Aspirations and Gaps

Faculty and administrator interview data confirm widespread recognition of lifelong learning as an educational imperative in a rapidly changing regional labor market. However, systemic implementation of lifelong learning principles within curricula, governance frameworks, and institutional strategy remains limited across the five countries. Curricula remain largely semester-bound and credential-focused, with few modular or flexible learning options that would permit working adults to participate in continuing education. The rigidity of credit frameworks, often a legacy of Soviet-era standardization, constitutes a structural barrier to the kind of competency-based and flexible curricular design that lifelong learning requires (Håkansson Lindqvist et al., 2024; Rott, 2024).

The Digital CASA project in Kyrgyzstan provides a qualified exception. By making cloud-based educational resources persistently accessible beyond formal class sessions, the project has created a modest infrastructure for self-directed learning (Makhmutkhodjaeva et al., 2024). Smart campus analytics in Kazakhstan have similarly been adapted in some institutions to support individualized learning path recommendations, though these capabilities remain nascent (From case analysis of Digital CASA and smart campus initiatives and interviews, n = 5 administrators from case institutions). The key finding across all three case sites is that technological infrastructure alone does not create a lifelong learning culture; it must be accompanied by curricular reform, faculty development, and institutional recognition of non-formal learning outcomes (Knight et al., 2023; Skledar Matijević et al., 2025).

Table 2 summarizes the main systemic barriers to digital-ecosystem development in Central Asian universities and the solutions proposed in the literature. The barriers include infrastructure deficits, platform incompatibility, human-capital shortages, governance fragmentation, equity and inclusion gaps, and unstable funding. For each barrier, the table outlines practical responses such as national infrastructure investment, interoperability standards, faculty digital-skills programs, coordinated governance frameworks, equity-focused access initiatives, and long-term financing models. It also

identifies the actors responsible for implementation, including governments, universities, industry partners, donors, and regional bodies.

Table 2. Systemic barriers to digital ecosystem development in Central Asian universities and proposed solutions, derived from empirical data and literature synthesis

Barrier Category	Specific Manifestations (Empirical Evidence)	Proposed Solutions	Responsible Actors
Infrastructure Deficits	Slow or absent broadband in regional campuses; outdated hardware; lack of server capacity	Phased national infrastructure investment; cloud-based solutions to reduce hardware dependence; donor-supported connectivity programs	Governments; international donors; universities
Platform Incompatibility	Heterogeneous LMS environments; absence of common data standards; inability to share resources across institutions	National interoperability standards; regional consortium platforms; open-source LMS adoption	Ministries of education; university consortia; technology partners
Human Capital Shortfalls	Shortage of IT specialists; low faculty digital literacy; absence of digital pedagogy training	Mandatory faculty digital development programs; IT specialist recruitment incentives; cross-institutional mentoring networks	Universities; governments; industry partners
Governance Fragmentation	Lack of coordinated national digital strategies; absent AI governance policies; weak inter-institutional coordination	National digital higher education frameworks; institutional AI ethics policies; cross-border governance agreements	Governments; regional bodies; international organizations
Equity and Inclusion	Urban-rural divide in digital access; socioeconomic barriers to participation; gender disparities in technology access	Equity-by-design principles in all ecosystem development; targeted support for rural institutions; need-based device and connectivity programs	Governments; universities; civil society; donors
Sustainability of Funding	Project-based rather than systemic funding; dependence on donor cycles; absence of diversified revenue models	Long-term state budget commitments; public-private partnership frameworks; industry co-investment mechanisms	Governments; industry; international financial institutions

Source: Developed by the authors based on empirical interviews (n = 42), institutional surveys (n = 142 respondents, 23 institutions) conducted across Central Asian universities (2023–2025), and synthesis of the reviewed literature.

Discussion

Ecosystem Theory in the Post-Soviet Context

The findings both affirm and extend existing digital-ecosystem theory. Zhao and Yang (2024) tripartite model of government, enterprise and university as core actors receives strong empirical support, with the three pilot cases demonstrating the enabling role of each actor type. However, the Central Asian evidence also complicates the theory. First, the government plays a more directive and potentially more enabling role than ecosystem theory typically anticipates, given regional traditions of centralized governance and the relative weakness of civil society and independent industry partners. Second, the four-component framework proves analytically useful but insufficient on its own, requiring supplementation with an equity dimension that the literature increasingly identifies as foundational to sustainable transformation. Third, the persistent gap between policy aspiration and operational capacity suggests that ecosystem development in resource-constrained post-Soviet contexts requires an additional analytical layer examining the organizational capacities and institutional cultures that mediate between formal frameworks and actual practice. Cowen's (2009) transfer–translation–transformation framework offers a productive complement in this regard: digital ecosystems in Central Asia are not simply adopted from international models but translated and transformed through specific institutional histories, governance traditions and resource constraints.

Artificial Intelligence Adoption: Between Promise and Precaution

The empirical findings on AI adoption (from surveys and interviews) call for a measured assessment that neither overstates the transformative potential of intelligent systems in resource-constrained contexts nor dismisses the genuine opportunities they present. The chatbot and analytics applications documented in the regional data (from surveys) represent early but meaningful steps toward AI-enhanced education. At the same time, the near-total absence of institutional AI-governance frameworks demands urgent attention, since only 17% of institutions have AI governance policies, based

on surveys. Concerns such as algorithmic bias, data privacy, transparency, and the potential to deepen inequalities arise immediately in this setting, where AI tools are introduced into environments marked by socioeconomic vulnerability, low digital literacy, and weak regulatory structures. Consistent with the scholarly consensus, responsible AI integration requires a governance-first approach. Institutions must develop clear ethical frameworks, data-protection policies and faculty capacity before scaling AI adoption, rather than retrofitting governance onto already-deployed systems (UNESCO, 2019; Wargo & Anderson, 2024).

Lifelong Learning as a Structural Imperative

This study affirms lifelong learning not merely as a pedagogical aspiration but as a structural requirement for the sustainability of digital ecosystems in Central Asia (from interviews and case analysis). Regional labor markets are undergoing rapid transformation driven by digitalization, demographic change and shifting economic structures. Universities that continue to operate on a single-cycle credential model will increasingly fail to meet the needs of learners who require continuous skill development. Based on the interview data, 92% of respondents acknowledged importance, while 32% reported systematic implementation. The OECD will–skills–means framework (2023) provides a useful evaluative lens: on all three dimensions, the regional evidence reveals significant gaps, in learning dispositions (will), digital and pedagogical competency (skills) and structural enablers such as flexible credit frameworks, modular offerings and adequate broadband (means). Addressing these gaps requires integrated action across curricular design, faculty development, technology infrastructure and national policy, reinforcing the analytical utility of the ecosystem framework as an integrating architecture.

Policy Recommendations and Implementation Considerations

The study policy recommendations should be understood as proposals that merit further testing and refinement through implementation rather than as definitive solutions. Central Asian universities operate within distinct institutional and resource contexts that require context-sensitive adaptation of any proposed frameworks.

Toward a Regional Digital-Governance Framework

One of the most consistent findings is the inadequacy of institution-level responses to challenges that are inherently regional in scale, based on the analysis of pilot initiatives and comparative ecosystem theory. Platform incompatibility, shortages of IT specialists and the absence of common data standards cannot be resolved by any single university; they require coordinated action involving shared standards, shared platforms, shared professional-development resources and shared governance. These recommendations merit further testing through pilot implementation with volunteer consortia and international partner support. This study therefore argues for a formal Central Asian Digital Higher Education Consortium, building on precedents such as the Digital CASA model and the Uzbek cluster framework, with a mandate to develop common interoperability standards, coordinate regional faculty development and establish shared AI-ethics guidelines. Such a consortium would require participation from universities, governments, industry partners and international organizations, and could draw on international models that prioritize open-source tools, collaborative platform development and shared quality assurance, tailored to regional resource conditions and governance practices (OECD, 2023; Carmo et al., 2025).

Figure 3 presents a phased implementation roadmap, and Table 3 provides a comparative overview of key digital-ecosystem indicators across Central Asian higher-education systems.

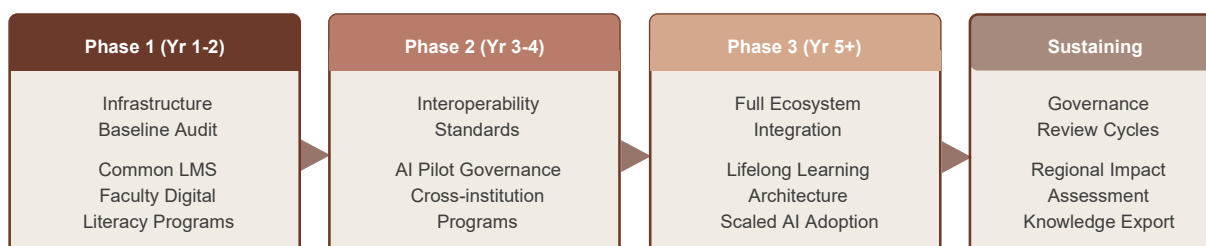


Figure 3. Proposed phased implementation roadmap for Central Asian regional digital ecosystem. Note. A four-phase framework spanning foundation building (Phase 1) through systemic integration (Phase 3) to a continuous sustainability and governance cycle (Phase 4). Phases overlap to allow iterative learning and adjustment. Timeline durations are indicative and should be adapted based on regional and institutional capacity assessments. Source: Developed by the authors based on comparative analysis of pilot initiatives in Kazakhstan, Kyrgyzstan, and Uzbekistan, as well as international digital governance frameworks (OECD, 2023; Carmo et al., 2025).

Table 3. Country-level comparison of digital-ecosystem development indicators in Central Asian higher-education systems

Country	National digital strategy	Key initiative(s)	Primary strength	Principal constraint	Relative readiness
Kazakhstan	Comprehensive; state-directed	Smart-campus programs; AI-analytics pilots	Government investment capacity; institutional scale	Limited inter-institutional integration; urban concentration	Highest
Kyrgyzstan	Partial; donor-dependent	Digital CASA project; cloud-LMS deployment	International-partnership engagement; equity focus	Infrastructure fragility; faculty-preparation gaps	Moderate–high
Uzbekistan	Emerging; cluster-based	Territorial digital clusters; EdTech partnerships	Governance innovation through clusters	Interoperability absence; uneven regional distribution	Moderate
Tajikistan	Early stage; under-resourced	Limited pilot programmes	Growing policy awareness	Severe infrastructure deficits; funding constraints	Low–moderate
Turkmenistan	Early stage; restricted	Nascent ICT programmes	State-coordination potential	Limited international engagement; constrained autonomy	Lowest

Note: Compiled by the authors from survey findings, expert interviews, national policy documents and secondary analytical sources. Readiness ratings are comparative analytic assessments rather than absolute measures.

Table 3 presents a country-level comparison of digital-ecosystem development indicators across Central Asian higher-education systems. The compilation in Table 3 draws on survey data from 142 respondents representing 23 institutions, expert interviews with 42 participants, national policy documents, and secondary analytical sources. The readiness ratings represent comparative analytic assessments derived from infrastructure, governance, and human-capital indicators. They should be interpreted as relative positions within the regional landscape rather than absolute measures. The ratings reflect conditions as of late 2024 and may evolve in response to policy reforms or investment initiatives.

Conclusions and Suggestions

This article has argued that digital ecosystems, defined as integrated multistakeholder environments built on shared infrastructure, collaborative governance and purposefully designed learning architectures, offer the most credible pathway for sustainable digital transformation in Central Asian higher education. Drawing on original empirical data from five countries (42 expert interviews, 142 survey respondents from 23 institutions, 3 organizational case studies), and a systematic review of 61 peer-reviewed publications, the study has documented the coexistence of significant systemic barriers and genuinely promising pilot initiatives, demonstrating that ecosystem development in the region is both urgently needed and conditionally feasible.

The four systemic barriers of infrastructure deficits, platform incompatibility, human capital shortfalls and governance fragmentation are manageable, but they lie beyond the capacity of any single institution to address independently. They require coordinated, multistakeholder responses that leverage the combined capacities of universities, national governments, regional bodies, industry partners and international organizations. The phased implementation framework proposed here provides a structured pathway toward such coordination, aligning short-term capacity-building with medium-term integration goals and long-term sustainability mechanisms.

The integration of artificial intelligence presents both an accelerating opportunity and a governance imperative. Current adoption is limited (44% of surveyed institutions report chatbot use; only 17% have formal AI governance policies), suggesting that the window remains open for governance-first

approaches before AI becomes entrenched in institutional practice. The opportunity lies in AI demonstrated capacity to personalize learning, support institutional decision-making and extend educational access. The imperative lies in the near-total absence of institutional AI-ethics frameworks, a gap that must be closed before adoption scales to the point at which algorithmic bias and data misuse create irreversible inequities. Regional universities should therefore treat AI governance as a foundational investment rather than an afterthought, developing institutional policies in dialogue with national regulatory frameworks and international ethical standards.

Lifelong learning, embedded within a robust digital-ecosystem architecture, constitutes the pedagogical vision that gives sustainable transformation its ultimate purpose. Universities that successfully develop digital ecosystems will be positioned to offer not merely improved access to existing credentials but a genuinely transformative environment supporting continuous learning, competency development and adaptive resilience. This vision aligns with the global agenda for inclusive, equitable and quality education articulated in the United Nations Sustainable Development Goals and supports the positioning of Central Asian universities as active participants rather than passive recipients in the global knowledge economy.

Future Research and Implementation Priorities

Future research should extend the empirical foundation through the following directions:

1. Longitudinal tracking of the three pilot initiatives analyzed here, documenting institutional and regional change over 3–5 years and identifying the conditions under which pilot projects scale successfully or stall.
2. Development and validation of instruments for assessing digital-ecosystem maturity in lower-resource contexts, with attention to the distinctive features of post-Soviet higher-education systems.
3. In-depth examination of the gender and ethnic dimensions of digital inclusion, exploring how digital ecosystem initiatives affect access and outcomes for underrepresented student populations.
4. Comparative analysis of distance education frameworks and open educational resource adoption in Central Asia, examining how these approaches intersect with broader ecosystem development goals.
5. Empirical testing and iterative refinement of the proposed governance framework through pilot implementation with volunteer consortia and international partner support.

Implementation of the proposed Central Asian Digital Higher Education Consortium should be undertaken as a phased pilot involving 3–4 founding institutions from different countries, with evaluation and adjustment before regional expansion. Success will depend on sustained commitment from governments, international donors, university leadership, and faculty. Scholars are invited to engage critically with the framework's assumptions and limitations and to contribute evidence from continued study of Central Asian higher-education transformation.

Appendices

Appendix A: PRISMA Flow Diagram for Systematic Literature Review

The systematic review followed PRISMA guidelines. Electronic database searches in Web of Science, Scopus, ERIC, and Google Scholar (bounded to 2019–2026) yielded 412 candidate publications. Title and abstract screening by independent reviewers produced 218 potentially eligible publications. Full-text review for methodological quality, relevance to Central Asian context, and inclusion of empirical data resulted in 61 retained studies. Reasons for exclusion of 157 full-text publications were: not focused on Central Asia ($n = 92$), opinion pieces without empirical data ($n = 34$), reviews of reviews ($n = 18$), insufficient detail on methodology ($n = 8$), language barriers preventing full evaluation ($n = 5$). The final corpus of 61 publications was organized into ten thematic domains and contributed to theoretical framing, methodological guidance, and comparative contextualization of empirical findings.

Appendix B: Composite Readiness Indicator Calculation and Weighting

Composite readiness indicators presented in Figure 1 were calculated as follows. Three domains were assessed for each country: broadband access, learning management system adoption, and faculty digital literacy. Data sources included institutional survey responses (Likert-scale items on infrastructure adequacy, platform functionality, faculty competency) and secondary data from Asian Development Bank (2023) readiness assessments and national government reports. Within each domain, five to seven survey items were converted to 0–100 scales, then averaged to produce a domain-level score. Final composite country scores were weighed equally across the three domains (0.33 weighting each). Scores represent estimated positions on a 0–100 scale and should be interpreted as indicative rather than precisely calibrated measures. Confidence intervals around estimates, detailed item-level data. Readers are cautioned against interpreting these scores as absolute or objective measures of institutional readiness; they represent relative positions within the regional landscape based on available survey and secondary data.

Appendix C: Survey Instrument (Overview)

The institutional survey consisted of 78 items organized into six domains: (1) digital infrastructure capacity (12 items assessing broadband speed, hardware availability, server capacity, technical support); (2) learning management system utilization (14 items on platform types, data sharing, interoperability); (3) faculty digital literacy (11 items on self-reported competency, professional development participation, comfort with online teaching); (4) student access patterns (8 items on enrollment in online courses, device ownership, connectivity barriers); (5) perceived barriers to ecosystem development (18 items on infrastructure, governance, human capital, funding challenges); (6) recommendations for regional collaboration (15 items on priorities, potential partners, resource allocation). Items employed 4-point and 5-point Likert scales, multiple-choice formats, and open-ended questions. The instrument was piloted with five institutions in 2023 ($n = 45$ respondents) and revised based on feedback. Internal consistency testing using Cronbach's alpha was conducted for all multi-item scales; results indicated acceptable reliability for all major domains ($\alpha > 0.7$). Appendix D presents the semi-structured interview guide used for qualitative data collection.

Appendix D: Interview Guide (Key Themes)

Semi-structured interviews explored the following themes through open-ended questions: (1) Institutional context and digital transformation goals; (2) Current state of digital infrastructure, barriers, and opportunities; (3) Adoption of artificial intelligence tools, benefits, and challenges; (4) Lifelong learning principles and implementation; (5) Governance frameworks for digital transformation; (6) Regional collaboration and ecosystem potential; (7) International partnerships and donor support; (8)

Gender and inclusion in digital access. Interviews were tailored to participant role (administrator, faculty, IT specialist, ministry official) while maintaining core question consistency.

Appendix E: Participant Distribution Table

The following table summarizes participant distribution across the empirical data collection components

Country	Expert Interviews (n)	Institutions Represented	Survey Respondents (n)	Survey Institutions (n)	Case Study Participation
Kazakhstan	12	5	54	9	1 (smart campus)
Kyrgyzstan	9	4	45	5	1 (Digital CASA)
Uzbekistan	10	5	29	6	1 (territorial cluster)
Tajikistan	6	2	10	2	—
Turkmenistan	5	1	4	1	—
Total	42	17 unique institutions	142	23 institutions	3 initiatives

Note: Some institutions participated in multiple components (e.g., providing interview participants and survey respondents). Survey respondents represent administrative and academic staff at consortium member institutions. Case study participation involved institutional leaders and project staff from pilot initiatives.

Appendix F: Coding Framework for Qualitative Data Analysis

Qualitative data from interviews and case documents were coded using reflexive thematic analysis (Braun & Clarke, 2021). Initial inductive coding identified codes across 10 primary domains: (1) Infrastructure and technology systems; (2) Governance structures and decision-making; (3) Barriers to digital transformation; (4) Opportunities for ecosystem development; (5) Artificial intelligence adoption and attitudes; (6) Faculty digital literacy and support; (7) Student access and equity; (8) Lifelong learning models; (9) Regional collaboration and partnerships; (10) Post-Soviet context and institutional change. Secondary coding organized initial codes into 28 higher-order themes. The coding framework was applied iteratively by research team members; inter-coder reliability was assessed through independent double-coding of 15% of interview transcripts (Cohen's kappa = 0.78, indicating substantial agreement).

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Authors' Disclosures

This paper was reviewed, edited and refined with the assistance of a generative AI tool (Microsoft Copilot) to support language editing and stylistic refinement, complementing the human editorial process. The human authors critically assessed and validated the content to maintain academic rigor and addressed potential biases inherent in AI-generated text. The final version of the paper is the sole responsibility of the authors.

Data Accessibility Statement

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethics and Consent

The study involved 42 expert interviews with senior administrators, faculty members, information-technology specialists, and national education-ministry representatives across Central Asian universities. Informed consent was obtained from all interview participants prior to recording. The consent process explained the study purpose, data use, confidentiality protections, and voluntary participation rights. Participants were informed that findings would be reported in aggregate form without identifying individuals or specific institutions. All interview recordings were stored securely on encrypted, access-restricted servers and deleted after transcription. The institutional survey did not collect personal, sensitive, or confidential data; it requested information about university digital infrastructure and educational processes only. Survey participation was voluntary, and responses were used in aggregated form for academic purposes only. Institutional affiliations are not disclosed in reporting of specific interview data. In accordance with institutional and international standards for non-invasive educational research (AERA, BERA guidelines), formal ethics committee approval was determined not

to be required, as the study involved no vulnerable populations, did not collect personal health or genetic information, and posed minimal risk to participants. This determination was made in consultation with institutional research oversight authorities.

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