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MICRO-CREDENTIALS IN HIGHER EDUCATION: INTERNATIONAL TRAJECTORIES OF INSTITUTIONALIZATION AND THE EMERGING KAZAKHSTAN MODEL

Abstract. Micro-credentials have become increasingly prominent in higher education, yet their institutional role remains unsettled across policy and academic contexts. This article examines how the concept has evolved internationally, how different trajectories of institutionalization have emerged across higher education systems, and how micro-credentials are being adapted within a transitional and regulated higher education system. The study combines a narrative literature review with comparative policy analysis of international policy documents, academic research, and Kazakhstan-specific regulatory and institutional materials. The findings show that micro-credentials do not follow a single global model but develop through different combinations of framework integration, market responsiveness, institutional mediation, and labor-market alignment. Four major international trajectories are identified – top-down regulated, supranational collaborative, decentralized market-driven, and hybrid – and Kazakhstan is analyzed as an emerging hybrid, multi-tiered model in which state-defined categories, qualifications frameworks, university-level implementation, and labor-function orientation are being assembled into a regulated but institutionally mediated system. To interpret these dynamics, the article proposes a Macro-Meso-Micro conceptual framework for transitional higher education systems, capturing the interdependence between regulatory architecture, institutional capability, and learner-facing recognition mechanisms. The study concludes that the credible integration of micro-credentials depends less on rapid expansion than on coordinated development across all three levels simultaneously.

Keywords: micro-credentials; higher education; lifelong learning; qualification frameworks; labor market; professional standards; Kazakhstan.

Introduction

Micro-credentials have become a prominent reference point in contemporary debates on higher education reform, lifelong learning, and workforce adaptation. Their growing visibility reflects a convergence of structural pressures: accelerating digital transformation, rapid skills obsolescence, and rising institutional and policy demand for shorter, more flexible, and more targeted forms of certified learning (Council of the European Union, 2022; OECD, 2021). In this context, higher education institutions face pressure to respond not only through full degree programs, but also through smaller learning units that can be completed, recognized, and, in some cases, accumulated toward larger qualifications over time. The appeal of micro-credentials lies in their apparent capacity to expand access to continuing education, support upskilling and reskilling at scale, and create more flexible pathways between formal education and labor-market needs (Cedefop, 2022; Brown et al., 2021; McGreal & Olcott, 2022). For this reason, they are increasingly discussed as a mechanism through which universities may diversify provision without abandoning the degree structure that remains central to higher education systems worldwide.

Yet rapid expansion has not produced conceptual clarity. What counts as a micro-credential, how it should be quality assured, whether it belongs inside formal higher education, and how it relates to national qualifications frameworks remain genuinely contested rather than settled questions. The 2022 Council of the European Union Recommendation sought to establish common principles for the development, recognition, and quality assurance of micro-credentials in the context of lifelong learning and employability, yet the literature consistently shows that their design, governance, and recognition are shaped by different

educational traditions, regulatory environments, institutional strategies, and stakeholder expectations (Oliver, 2019; Brown et al., 2021; UNESCO, 2022; Varadarajan et al., 2023). This lack of consensus is not a minor definitional issue. It shapes how micro-credentials are institutionalized across national and institutional settings and determines whether they become credible components of qualifications systems or remain fragmented at the margins of higher education.

Despite the rapid growth of research in this field, the literature remains concentrated primarily on mature, market-driven systems – particularly in North America, Australia, and Western Europe – and on general definitional, policy, and stakeholder questions (Brown et al., 2021; Kato, Galán-Muros, & Weko, 2020; Varadarajan et al., 2023). Significantly less attention has been paid to how micro-credentials develop within transitional and more strongly regulated higher education systems, where institutionalization depends not only on flexibility and employer demand, but also on state steering, qualification frameworks, stakeholder alignment, and institutional implementation capacity (Ahsan et al., 2023; McGreal & Olcott, 2022; Selvaratnam et al., 2024). In particular, there is still limited research on how universities in such contexts translate national policy mandates into credible and sustainable practices, how multiple stakeholders align around these reforms, and how the tension between regulatory control and educational flexibility shapes the institutionalization of micro-credentials (Kato, Galán-Muros, & Weko, 2020; Varadarajan et al., 2023).

This gap is especially consequential in the case of Kazakhstan, where micro-credentials are being introduced through a formally regulated, policy-driven model that differs substantially from the market-led approaches dominant in the existing international literature. The Concept of Development of Higher Education and Science for 2023–2029 explicitly promotes lifelong learning, minor programs, and micro-credentials, while the updated State Compulsory Standard of Higher Education institutionalizes stackable degrees, nano-credits, and micro-credentials at the regulatory level (Government of the Republic of Kazakhstan, 2023; Ministry of Science and Higher Education of the Republic of Kazakhstan, 2022). Alongside this policy architecture, the Law on Professional Qualifications and the Rules for Recognizing Outcomes of Non-Formal Learning establish legal pathways through which universities may evaluate and convert non-formally acquired learning into academic credit (Law of the Republic of Kazakhstan, 2023; Ministry of Education of the Republic of Kazakhstan, 2023). Despite this formally advanced architecture, the dynamics of Kazakhstan's emerging model – including its institutional implementation, governance tensions, and position within comparative international trajectories – have not yet been systematically analyzed in the international academic literature.

This article addresses three research questions. RQ1: How are micro-credentials conceptualized internationally, and what major institutional trajectories can be identified in their development across higher education and lifelong learning contexts? RQ2: How is the concept of micro-credentials being adapted and institutionally integrated into a transitional and regulated higher education system, with particular reference to Kazakhstan? RQ3: What institutional, policy, and pedagogical challenges must be addressed to support the credible and sustainable implementation of micro-credentials in such contexts? To address these questions, the article combines a narrative literature review with comparative policy analysis, proposes a Macro-Meso-Micro conceptual framework for transitional higher education systems, and draws on a dedicated national corpus of Kazakhstani regulatory, institutional, and empirical materials.

Methodology

This study adopts a qualitative design combining a narrative literature review with comparative policy analysis. The methodological purpose is to identify major conceptual approaches to micro-credentials, examine international patterns of institutionalization, and analyze how micro-credentials are being integrated into higher education systems and qualification frameworks, with particular attention to transitional and regulated contexts.

A narrative literature review was selected because micro-credentials represent an emerging and conceptually heterogeneous field shaped by both academic debate and policy development. In educational research, review-based approaches are widely used to synthesize developing bodies of knowledge, identify recurring themes, and clarify conceptual and institutional trends (Grant & Booth, 2009; Snyder, 2019). This approach is especially appropriate here because the field remains marked by definitional variation, uneven

institutionalization, and divergent policy interpretations across national settings (Brown & Nic Giolla Mhichíl, 2022; Varadarajan et al., 2023). The study does not follow the full procedure of a formal systematic review and does not claim exhaustive coverage. Rather, it applies a transparent, question-driven review logic designed to support conceptual synthesis and comparative analysis – an approach well-established for fields in which the research objective is analytically grounded interpretation rather than exhaustive retrieval (Snyder, 2019).

The analysis included academic publications, policy reports, and analytical documents published between 2015 and 2026, identified through Scopus, Web of Science, and EBSCOhost using keyword combinations including "micro-credentials," "alternative credentials," "digital badges," and "higher education." Sources were selected on the basis of their relevance to the research questions and their contribution to at least one of the following analytical dimensions: conceptual definitions, institutional models of implementation, higher education integration, qualification-framework alignment, stakeholder expectations, and implementation challenges. In addition to peer-reviewed literature, the source base included policy and analytical documents produced by the European Commission, OECD, UNESCO, and Cedefop, treated as primary evidence for formal definitions, governance arrangements, and recognition mechanisms. Academic studies were used primarily to interpret conceptual debates, implementation challenges, and comparative trajectories.

To address the Kazakhstan case, the study incorporated a focused national corpus comprising legal and regulatory documents, state standards, qualifications-framework materials, institutional regulations, monitoring reports, and recent empirical studies – including Sovetkanova et al. (2026) and Borgekova et al. (2026) as the most substantive peer-reviewed contributions currently available on the Kazakhstani context. These materials were used to examine how international micro-credentials discourse is being adapted within a regulated national context and to distinguish between policy intent, formal legal architecture, and actual institutional implementation. The use of grey and institutional sources – including university regulations, conference presentations, and national monitoring reports – is acknowledged as a limitation inherent to the analysis of an emerging policy field where peer-reviewed empirical evidence remains limited.

The analytical procedure combined thematic synthesis, interpretive analysis, and comparative policy interpretation. First, the literature was reviewed to identify recurring conceptual and policy themes, major patterns, and unresolved tensions, including definitions, scenarios of development, typologies, and models of integration. Second, these themes were interpreted comparatively to examine how different national and supranational contexts position micro-credentials in relation to higher education, lifelong learning, labor-market demand, and formal recognition. Third, the Kazakhstan case was analyzed as a policy-oriented example of a regulated and institutionally embedded model, situating national developments within the broader international discussion.

Literature Review

Interest in micro-credentials has grown significantly over the past decade as education systems and labor markets have undergone rapid transformation. Recent scholarship increasingly suggests that micro-credentials should not be understood as a single stable category, but rather as part of a broader and evolving credential ecology shaped by educational, economic, and policy change (Brown & Nic Giolla Mhichíl, 2022). Rather than representing a linear progression from digital badges to formalized short credentials, the literature reveals a set of unresolved tensions between flexibility and regulation, employability and academic coherence, stackability and standalone signaling, and innovation and recognition architecture. These tensions suggest that micro-credentials are not simply a new educational product, but a contested institutional form whose meaning varies across higher education systems.

One of the earliest strands of research emerged in the context of digital badges and alternative credentialing systems, where early studies highlighted the possibility of recognizing smaller and more granular forms of learning outside traditional degree structures (Gibson et al., 2016; Kato et al., 2020; Varadarajan et al., 2023). Over time, the concept expanded beyond digital badges to include a broader range of short learning programs offered by universities, training providers, and online platforms, reinforcing conceptual ambiguity as terms such as digital badges, alternative credentials, nanodegrees, and micro-credentials were used inconsistently or interchangeably. More recent literature has shifted attention toward

the institutional role of micro-credentials in higher education, where they are increasingly presented as a means of complementing traditional degrees by enabling learners to acquire more targeted professional competencies, strengthen employability, and participate in more flexible forms of lifelong learning (Wheelahan & Moodie, 2022; Bruguera et al., 2024; Pirkkalainen et al., 2023). Universities are correspondingly discussed as active actors in the design and delivery of micro-credentials, attempting to align academic provision with emerging policy agendas and labor-market demand, though institutional implementation depends heavily on governance, standards, resourcing, staff capacity, and assessment design (Selvaratnam & Sankey, 2021; Selvaratnam et al., 2024; Reed et al., 2024).

The literature contains a substantial critical strand that must not be overlooked. Wheelahan and Moodie (2022) argue that the expansion of micro-credentials may weaken the broader knowledge-based and developmental functions of higher education, particularly when short-form credentials are shaped primarily by immediate labor-market demand. Ralston (2021) similarly criticizes the growing commodification of higher education and warns against reducing education to short-cycle, market-oriented training detached from broader intellectual and civic purposes. Pollard and Vincent (2022) further suggest that micro-credentials risk becoming embedded in neoliberal policy narratives that reframe higher education primarily through employability and market responsiveness. These critical perspectives are analytically important because they establish the normative stakes of micro-credentials development: the question is not only what micro-credentials certify, but what kind of higher education system their expansion gradually normalizes.

Three further debates structure the field. First, whether micro-credentials can remain flexible while being integrated into systems of formal recognition. The more short-form learning is brought into formal qualifications systems, the greater the pressure to standardize it; the more it remains open and demand-responsive, the greater the risk of fragmentation and weak trust (Cedefop, 2022, 2023; Council of the European Union, 2022). Second, whether stackability – frequently presented as one of the defining strengths of micro-credentials – can be operationalized in practice. McGreal and Olcott (2022) caution that stackability may look persuasive in policy rhetoric while remaining highly difficult to implement across institutions and systems, a concern supported by recent evidence showing that credit transfer and accumulation remain contested and context-dependent (Parsons et al., 2025; Selvaratnam et al., 2024). Third, whether the value of micro-credentials depends primarily on employer signaling or on academic recognition, since learners, universities, employers, and governments often attach different and sometimes incompatible expectations to the same credential (Varadarajan et al., 2023; Oliver, 2019; Kalabuki & Uzorka, 2026).

The literature identifies three interrelated conditions for successful institutionalization. Higher education institutions require sufficient implementation capacity, including governance arrangements, standards, technological infrastructure, staffing, and assessment design. Micro-credentials depend on alignment among multiple stakeholders, since divergent expectations among learners, universities, employers, and governments must be actively managed rather than assumed away. And their long-term credibility is strengthened when they are linked to qualification frameworks and formal recognition mechanisms (Varadarajan et al., 2023; Selvaratnam et al., 2024; Brown et al., 2021). These conditions are especially important in more regulated and transitional systems, where formal recognition and quality assurance are expected to generate the institutional trust that fragmented credential markets struggle to produce (Kalabuki & Uzorka, 2026). Taken together, the literature indicates that micro-credentials are best understood as contested and context-dependent institutional arrangements rather than as a single stable educational form – a conclusion that makes comparative analysis of different national trajectories both necessary and analytically productive.

Results

The Global Credential Ecology: Definitions and Analytical Dimensions

The international development of micro-credentials has produced not a single stable concept, but a broader credential ecology marked by terminological expansion, policy experimentation, and increasing institutional differentiation. Early discussions often used micro-credentials interchangeably with digital badges, alternative credentials, MOOCs, and nanodegrees, reflecting the absence of a clear boundary between technological formats, short learning experiences, and formal recognition mechanisms (Brown et al., 2021; Kato et al., 2020; Varadarajan et al., 2023). Over time, the discussion shifted toward understanding

micro-credentials as more structured forms of certified learning with potential relevance for higher education, employability, and qualification systems. Despite this shift, no universally accepted definition has emerged. Instead, international organizations and academic authors frame micro-credentials in overlapping but analytically distinct ways, differing in their emphasis on assessment, stackability, qualification-framework integration, labor-market relevance, and higher education use.

Table 1 summarizes the main international framings and highlights their differences in emphasis and implications for higher education.

Table 1
International Framings of Micro-Credentials

Source	Core framing	Main emphasis	Implication for higher education
Council of the European Union (2022)	Record of learning outcomes acquired through a small volume of learning and assessed against transparent criteria	Learning outcomes, assessment, transparency, portability	Supports formal recognition and integration into qualification frameworks and higher education pathways
OECD (2023)	Smaller, more targeted, and more flexible credentials linked to organized learning activities	Lifelong learning, labor-market responsiveness, flexibility	Highlights institutional innovation and responsiveness, while also pointing to tensions with rigid quality assurance systems
UNESCO (2022)	Record of focused learning achievement awarded by a trusted provider after assessment against defined standards	Inclusion, lifelong learning, standalone value, stackability	Emphasizes flexible progression, recognition of prior learning, and broader access
Cedefop (2023)	Framework-oriented application of micro-credentials in labor-market and vocational contexts	Qualification frameworks, modularization, recognition, trust	Strengthens formal readability and employer trust through framework integration
Oliver (2019)	Certification of assessed learning that may be additional, alternative, complementary to, or a formal component of a qualification	Assessed learning, employer relevance, exchange value	Links micro-credentials to employability, recognition, and institutional credibility
Brown et al. (2021)	Unbundled, credit-bearing, and potentially stackable credentials within a broader and unsettled credential ecology	Conceptual heterogeneity, institutional diversity, system change	Frames micro-credentials as part of wider transformation in higher education and credential systems

Note. The table summarizes major international framings of micro-credentials across policy and academic sources.

As Table 1 shows, the European policy approach has been particularly influential in stabilizing the concept through learning outcomes, transparent assessment, portability, and links to qualification frameworks (Council of the European Union, 2022). OECD publications frame micro-credentials more strongly in relation to flexibility, lifelong learning, and workforce responsiveness (OECD, 2023). UNESCO emphasizes focused learning achievement, inclusion, and the possibility of both standalone value and cumulative potential (UNESCO, 2022). Cedefop places stronger emphasis on qualification frameworks, modularization, recognition, and trust within labor-market and vocational contexts (Cedefop, 2023). In academic literature, Oliver (2019) emphasizes assessed learning and exchange value in relation to employers, whereas Brown et al. (2021) highlight the broader and still unsettled credential ecology in which

micro-credentials operate.

For analytical purposes, the most important differences across these framings can be grouped into four dimensions. The first concerns learning outcomes and assessment – whether micro-credentials are understood primarily as records of rigorously assessed achievement or as more flexible forms of certified learning. The second concerns stackability and progression – whether micro-credentials are expected to accumulate into larger qualifications or retain value as standalone signals of competence. The third concerns qualification-framework integration, which varies from strong alignment with formal frameworks to more open and decentralized forms of recognition. The fourth concerns labor-market relevance and higher education use – whether micro-credentials are framed primarily as instruments of employability and rapid upskilling or as components of formal university provision. These dimensions show that micro-credentials occupy a variable position between formal and non-formal learning, between institutional curriculum and external provision, and between short-cycle skill signaling and regulated qualification structures. This analytical framing shifts attention from definitional disagreement alone to the more consequential question of institutional positioning – how different systems institutionalize micro-credentials in practice – which the following section examines comparatively.

Trajectories of Institutionalization: A Comparative International Analysis

Comparative analysis shows that micro-credentials do not follow a single pathway of institutionalization. Across international contexts, they are being embedded in higher education through different balances of policy steering, market demand, qualification-framework integration, and institutional initiative. The reviewed literature points not to one dominant model, but to several recurring trajectories shaped by different governance arrangements, educational traditions, and quality-assurance logics (Brown et al., 2021; Kato et al., 2020; Orr et al., 2020; Cedefop, 2022, 2023). Table 2 summarizes these trajectories and compares them in terms of governance, framework integration, stackability, institutional drivers, and implications for higher education.

Table 2

Comparative Trajectories of Micro-Credentials Institutionalization in Higher Education

Trajectory / model	Illustrative systems	Governance and regulatory logic	Integration with qualification frameworks	Stackability / credit architecture	Primary drivers and institutional actors	Implications for higher education
Top-down regulated and integrated	New Zealand, Malaysia, partly Australia	Strong statutory or agency-led regulation; centralized approval and quality assurance	Strong or explicit integration into national frameworks; formal listing and recognition	More formalized and potentially credit-bearing; progression is structured and supervised	National quality agencies, ministries, regulated providers, HEIs	Supports trust, readability, and formal recognition, but may reduce agility
Supranational collaborative	European Union / EHEA	Policy steering through recommendations, shared principles, and cross-border coordination rather than one national mandate	Strong alignment with EQF, ECTS, Bologna tools, and national frameworks	Strong emphasis on portability, accumulation, and recognition across systems	EU institutions, university alliances, member states, HEIs	Encourages comparability and mobility while preserving higher education legitimacy

Decentralized market-driven	United States, partly Canada	Minimal centralized regulation; coordination depends on market demand, employer trust, and voluntary registries	Weak or uneven integration; no single unified national architecture	Often standalone, non-credit, or provider-specific; stackability is uneven	Platforms, employers, corporate issuers, entrepreneurial universities, registries	Maximizes innovation and responsiveness, but increases fragmentation and variability in trust
Mixed / hybrid policy-supported	Australia, Ireland, Singapore, provincial Canada	Combination of state support, institutional autonomy, and targeted policy steering	Partial, selective, or negotiated framework integration	Mix of stackable and standalone forms depending on system design	HEI consortia, governments, sector initiatives, universities, employers	Balances flexibility with coordination, but often produces uneven system coherence
Note. The table summarizes major trajectories of institutionalization identified in the reviewed source set. It compares systems by governance logic, qualification-framework integration, stackability, leading actors, and implications for higher education.						

A first trajectory may be described as top-down regulated and integrated institutionalization. In this model, micro-credentials are embedded formally within national education systems through statutory rules, centralized approval processes, and explicit quality-assurance requirements. New Zealand is the clearest example: micro-credentials were incorporated into the New Zealand Qualifications and Credentials Framework, and providers must demonstrate industry or community need and undergo formal approval before a credential can be recognized (New Zealand Qualifications Authority, 2018, 2019, 2023; Parsons et al., 2025). Malaysia similarly operates through national guidance issued by the Malaysian Qualifications Agency linking credit-bearing micro-credentials to the Malaysian Qualifications Framework (MQA, 2020; Ahmat et al., 2021). Australia belongs partly to this trajectory in a more mixed form, having promoted a National Microcredentials Framework while deliberately avoiding full integration into the Australian Qualifications Framework in order to preserve institutional flexibility (Department of Education, Skills and Employment, 2021; OECD, 2023, 2024; Selvaratnam & Sankey, 2021). This trajectory prioritizes trust, formal readability, and regulatory coherence, but raises the question of how much agility can be preserved once short-form learning is tightly governed.

A second trajectory is supranational collaborative institutionalization, most clearly associated with the European Union and the broader European Higher Education Area. Here, institutionalization is driven not by one national authority, but by coordinated policy guidance, shared principles, and common recognition instruments. The 2022 Council Recommendation frames micro-credentials as complementary to existing qualifications and promotes transparency, portability, and recognition across borders (Council of the European Union, 2022), relying heavily on alignment with the European Qualifications Framework and ECTS to support comparability and stackability (European Commission, 2020, 2022; Lantero et al., 2021; Cedefop, 2023). European university alliances and consortia seek to keep micro-credentials anchored within higher education values rather than allowing the field to be shaped entirely by external providers (Orr et al., 2020; Cirlan & Loukkola, 2020; Bideau & Kearns, 2022). Compared with the top-down regulated model, this trajectory relies more on consensus and soft-law steering than on statutory control, yet still seeks strong framework alignment and formal recognition. Finland and Poland further illustrate that some European systems emphasize consensus-based coordination without collapsing into a single institutional formula (Trepule et al., 2021; Dybaś-Stronkowska & Pieńkosz, 2019; Cedefop, 2022).

A third trajectory is decentralized market-driven development, most strongly associated with the

United States and, in a more mixed form, Canada. Micro-credentials circulate in a fragmented landscape shaped by employers, digital platforms, technology companies, and independent institutional initiatives rather than by a unified national qualifications architecture (Kato et al., 2020; McGreal & Olcott, 2022; OECD, 2021, 2023). In the United States, universities act as entrepreneurial actors within an open marketplace, frequently partnering with MOOC platforms and corporate issuers to offer standalone badges, certificates, and short-cycle credentials whose value depends heavily on market signaling and employer trust rather than statutory recognition (Brown et al., 2021; Fong et al., 2016; Credential Engine, 2021; Shah, 2021; Kumar et al., 2022). Canada presents a more hybrid case: Ontario and British Columbia have moved toward stronger policy support through provincial portals, funding mechanisms, and targeted upskilling initiatives, but without creating a single national model (McGreal & Olcott, 2022; Government of Ontario, 2020; eCampusOntario, 2023; OECD, 2024). This trajectory maximizes responsiveness and innovation, but produces the strongest concerns about fragmentation, uneven quality assurance, and weak comparability across providers.

The comparative material also points to mixed and hybrid models that do not fit neatly into a single category. Ireland combines university-led development with state support and framework alignment through the MicroCreds initiative, government funding, and ECTS-bearing, quality-assured provision linked to the National Framework of Qualifications (Irish Universities Association, 2020; Nic Giolla Mhichíl et al., 2020; McCoshan, 2023; OECD, 2024). Singapore represents another hybrid configuration in which state steering and labor-market alignment are combined through SkillsFuture, producing a system that is simultaneously government-steered and highly responsive to industry demand (Government of Singapore, 2023; OECD, 2023). These mixed cases show analytically that institutionalization is not simply a matter of choosing between regulation and market responsiveness – in practice, many systems combine elements of both, with different outcomes for coherence, trust, and portability (Pouliou, 2024; Brown, McGreal, & Peters, 2023).

Taken together, the international evidence suggests that micro-credentials are institutionalized through different balances of state control, supranational coordination, institutional autonomy, and market dynamics. What varies across systems is not simply whether micro-credentials exist, but how they are governed, recognized, stacked, funded, and trusted. This comparative pattern is especially important for the present study because it establishes that Kazakhstan does not fit a purely market-driven or loosely coordinated model. Rather, as the following section demonstrates, Kazakhstan is best interpreted as an emerging hybrid trajectory that combines top-down framework integration with decentralized university implementation and labor-market-oriented content making it especially relevant for understanding micro-credentials institutionalization in transitional systems.

The Kazakhstan Case: A Hybrid, Multi-Tiered Model of Regulated Institutionalization

In comparative terms, Kazakhstan is best understood as a hybrid, multi-tiered model of micro-credentials institutionalization. At the macro level, the system is state-framed and framework-oriented: the government defines the relevant units in official regulatory documents, links short-form learning to the National Qualifications System, and embeds reform in strategic policy. At the meso level, implementation is decentralized and university-led, since higher education institutions are formally empowered to recognize non-formal learning, approve micro-credential programs, and convert them into formal academic value. At the content level, the model is strongly labor-market-oriented, because micro-credentials are explicitly tied to labor functions, professional standards, and employer participation. This configuration differs from Malaysia, where national framework integration preceded and shaped institutional implementation through centralized agency guidance (MQA, 2020; Ahmat et al., 2021), and from Ireland, where university-led development preceded formal state coordination (Nic Giolla Mhichíl et al., 2020; McCoshan, 2023). In Kazakhstan, by contrast, regulatory architecture and institutional experimentation have developed simultaneously and interactively, producing a model that is neither purely top-down nor purely bottom-up but genuinely hybrid in its governance logic (Borgekova et al., 2026; Government of the Republic of Kazakhstan, 2023; Kato et al., 2020).

The formal regulatory architecture is the first distinguishing feature of the Kazakhstani model. The State Compulsory Standard of Higher Education defines a micro-credential as a volume of knowledge, skills, and competencies sufficient to perform one distinct labor function acquired during short-term training; a nano-credit as a unified unit of measurement for a small and self-contained volume of learning; and

stackable degrees as an accumulation of skills and competencies obtained through formal and non-formal education (Ministry of Science and Higher Education of the Republic of Kazakhstan, 2025). Unlike many international framings that begin with small units of assessed learning, the Kazakhstani model defines short-form credentials through their sufficiency for one distinct labor function and their place within a larger accumulation logic. The Concept of Development of Higher Education and Science for 2023–2029 further mandates that micro-credentials and nano-learning outcomes be recognized across educational levels and that certificates and credits obtained through short-term courses be translated into stackable degrees, while also calling for a unified system of academic and non-credit learning and an updated National Qualifications Framework (Government of the Republic of Kazakhstan, 2023). The Law on Professional Qualifications and the Rules for Recognizing Outcomes of Non-Formal Learning provide the legal pathway through which universities may evaluate non-formally acquired learning and convert it into formal academic credit (Law of the Republic of Kazakhstan, 2023; Ministry of Education of the Republic of Kazakhstan, 2023). This legal architecture is closely tied to the qualifications framework and professional standards system: the updated National Qualifications Framework supports transitions between levels through recognition of formal, non-formal, and informal learning, while professional standards define the labor requirements to which micro-credentials must correspond (National Qualifications Framework of the Republic of Kazakhstan, 2025; Atameken, 2016; Cedefop, ETF, UNESCO, & UIL, 2019).

Importantly, the Kazakhstan case can no longer be described only in terms of policy intent – there is now clear evidence of actual institutional implementation across multiple universities and fields. Almaty Technological University has developed 25 micro-credential programs in cooperation with industry (Nurakhmetov, 2023). Satbayev University has formalized internal regulations governing the development and recognition of micro-credentials, including the issuance of microcertificates and open badges (Satbayev University, 2025). Astana IT University and IITU have implemented technology-focused micro-credentials such as Python Developer and ML Specialist, including a documented 16-credit, 480-hour certificate. Toraighyrov University has embedded engineering-oriented micro-credentials into bachelor's programs linked to regional industrial demand, while other institutions have launched targeted programs in STEM pedagogy, speech therapy, and economic-crime investigation (Sadykov et al., 2023). The national monitoring data further indicate that implementation extends beyond isolated pilots: 64,451 learners studied on Coursera within educational programs across 37 higher education institutions practicing credit transfer, while 187,104 learners completed Huawei ICT courses with 95,873 certificates issued across 33 universities (National Center for Higher Education Development, 2025). These data show that the recognition of externally acquired platform-based learning is already an operational feature of the system, not merely a policy aspiration.

The most substantive empirical evidence currently available is provided by Sovetkanova et al. (2026), whose study of a Stackable Degree pilot in graduate teacher education documents five implemented micro-credential programs and identifies the conditions required for portability and stackability in the Kazakhstani context. The authors demonstrate that practical portability depends on alignment of learning outcomes with the NQF, clear rules for credit transfer and stackability, established recognition-of-prior-learning procedures, enforceable quality assurance requirements, and verifiable digital credentials – thereby bridging the gap between macro-level policy and meso-level implementation and showing that state mandates alone are insufficient without interoperable recognition procedures and credible digital verification (Sovetkanova et al., 2026; McGreal & Olcott, 2022).

At the same time, the evidence points to important systemic tensions. Despite visible institutional uptake, Kazakhstan still lacks a unified national registry of micro-credentials, and the source base indicates heterogeneity of approaches across universities, the absence of a single republican accreditation standard, and persistent reluctance among some institutions to integrate micro-credentials into traditional programs (Jomartova, 2025; Borgekova et al., 2026). Two limitations must be stated explicitly. First, employer recognition remains insufficiently documented at the system level: although many programs are designed around labor-market demand and employer participation, the evidence does not yet establish how consistently employers interpret, trust, and reward these credentials. Second, learner-outcome evidence remains partial: beyond the teacher-education pilot and selected survey results, longitudinal evidence on wage returns, career mobility, or inclusion effects is still limited (Varadarajan et al., 2023; McGreal &

Olcott, 2022; Wheelahan & Moodie, 2022).

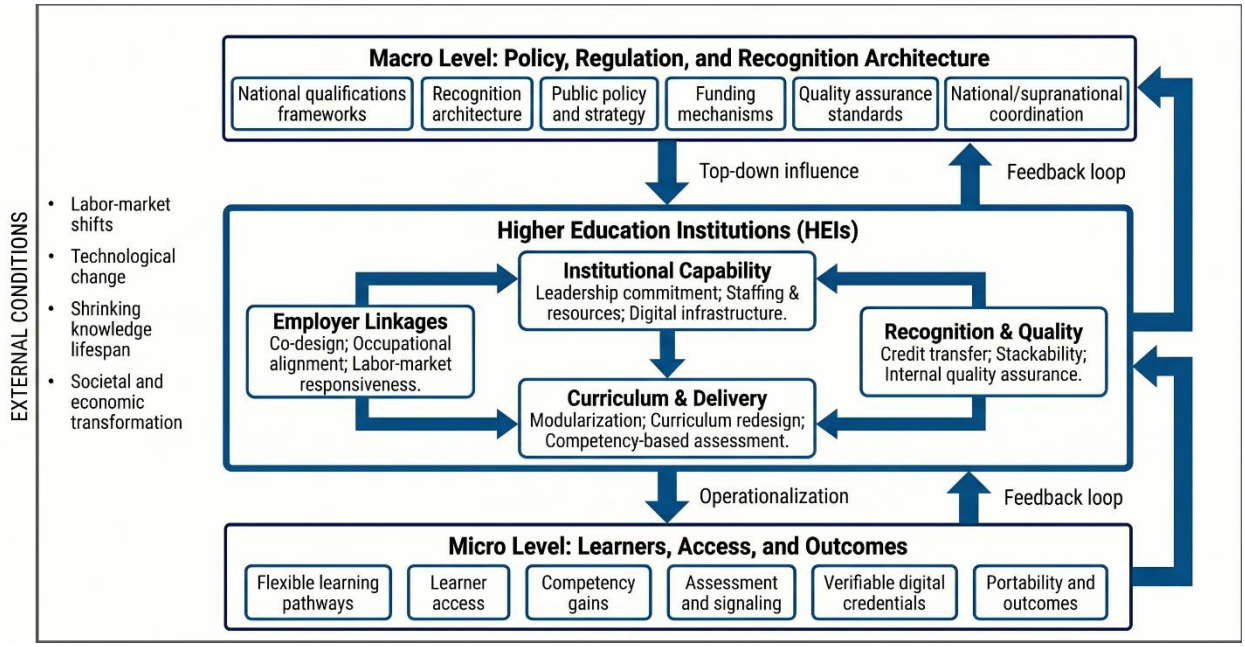
Taken together, Kazakhstan illustrates a distinctive pathway in which official definitions, qualification frameworks, university autonomy, and labor-market alignment are being assembled into a hybrid governance model. Its main strength lies in the existence of a formal legal basis, a clear state strategy, and already visible institutional uptake across multiple universities and recognition channels. Its main weakness lies in uneven implementation, fragmented institutional practice, the absence of unified accreditation and registry infrastructure, and still limited evidence on employer trust and long-term outcomes. Kazakhstan is therefore best interpreted not as a completed model, but as an emerging regulated and institutionally mediated trajectory at a critical juncture: the macro-level architecture is largely in place, the meso-level implementation is underway but uneven, and the micro-level outcomes remain insufficiently documented. This three-level unevenness is precisely what the Macro-Meso-Micro framework proposed in the following section is designed to capture – and what makes Kazakhstan an analytically productive case for understanding the conditions under which transitional higher education systems can move from regulatory ambition to credible and sustainable micro-credentials integration.

A Conceptual Framework for Micro-Credentials Integration in Transitional Higher Education Systems

The preceding analysis suggests that the integration of micro-credentials in transitional higher education systems cannot be explained adequately through definitions or country cases alone. What is required is a framework that captures the vertical interdependence between state regulation, institutional implementation, and individual learning outcomes. For the purposes of this article, a Macro-Meso-Micro (MMM) framework is the most analytically appropriate because it captures both hierarchy and interaction: macro-level policy settings shape meso-level institutional possibilities, which in turn structure micro-level learner pathways and outcomes (Varadarajan et al., 2023; Brown et al., 2021). This multi-level logic is well-established in educational research, where systemic change is understood as inherently cross-level – neither reducible to policy design alone nor to individual institutional choices (Ehlers, 2018; Selvaratnam et al., 2024). Figure 1 visualizes the framework and shows how the three levels interact within a transitional higher education system under external pressures of labor-market change, technological shifts, and shrinking knowledge lifespans.

Figure 1

Conceptual Framework for Micro-Credentials Integration in Transitional Higher Education Systems



Note. *The figure presents micro-credentials integration as a Macro-Meso-Micro ecosystem. The Macro level includes regulation, qualifications frameworks, recognition architecture, and public policy conditions. The Meso level places higher education institutions at the center of implementation and shows their interaction with employers, institutional capability, curriculum redesign, quality assurance, and recognition procedures. The Micro level captures learner access, assessment,*

portability, digital credentials, and individual outcomes. The framework also acknowledges external conditions, including labor-market change, technological shifts, and the shrinking lifespan of knowledge, as cross-cutting pressures on all three levels. This structure is supported by the literature on stakeholder ecosystems, institutional readiness, and multi-level educational change, and is especially relevant for transitional systems where state regulation, institutional mediation, and learner-facing mechanisms must develop in coordination (Brown et al., 2021; Varadarajan et al., 2023; Selvaratnam et al., 2024; Cedefop, 2022, 2023).

At the Macro level, micro-credentials integration depends on state policy, qualifications governance, and national or supranational regulatory architecture. This level establishes the legal and systemic conditions under which short-form learning can become credible, portable, and recognized. The literature consistently highlights the role of National Qualifications Frameworks, standardized credit architectures, public funding mechanisms, and formal recognition systems in creating order within an otherwise fragmented credential ecology (Council of the European Union, 2022; Cedefop, 2022, 2023; OECD, 2021). In transitional systems, the macro level is especially consequential because rapid labor-market change and skills mismatches create simultaneous pressure for flexible learning and for regulatory coherence. Excessive rigidity may suppress innovation, so macro-level integration must balance quality assurance and comparability with sufficient space for institutional adaptation (OECD, 2021; Cedefop, 2022, 2023).

At the Meso level, the core issue is institutional and organizational capacity. Universities occupy the central mediating position in the ecosystem because they translate regulatory frameworks into actual curricula, assessment procedures, recognition systems, digital infrastructure, and employer partnerships (Varadarajan et al., 2023; Selvaratnam et al., 2024). Successful institutionalization at this level depends on leadership commitment, sustainable financial and staffing models, curriculum redesign, interoperable technological infrastructure, and the capacity to align micro-credentials with quality assurance and credit-transfer systems (Selvaratnam & Sankey, 2021; Brown, McGreal, & Peters, 2023). This is also the level where most operational friction appears – faculty resistance, workload pressures, weak digital capacity, and uncertainty about business models and institutional incentives – and where the tension between academic legitimacy and labor-market responsiveness must be actively managed rather than assumed away (McGreal & Olcott, 2022; Varadarajan et al., 2023).

At the Micro level, the framework focuses on learners, assessment design, and individual educational trajectories. Micro-credentials function here as flexible units that can support upskilling, reskilling, personalized pathways, and alternative routes into or through higher education (Tamoliune et al., 2023; Pirkkalainen et al., 2023; West & Cheng, 2023). The literature provides reasonably strong support for short-term learner motivations and competency gains, especially where learners value flexibility, targeted skill acquisition, and transparent signaling of specific competencies (Thi Ngoc Ha et al., 2024). However, long-term claims – seamless stackability, durable labor-market returns, democratizing effects – remain context-dependent and unevenly evidenced. The micro level should therefore be conceptualized not as a zone of guaranteed outcomes, but as the point where institutional and regulatory arrangements are experienced by individuals, often with unequal results depending on affordability, digital access, and employer recognition.

These three levels are not separate layers but interdependent dimensions of one transitional ecosystem. Macro-level frameworks define the legal and recognition environment. Meso-level institutions operationalize that environment through program design, partnerships, and administrative procedures. Micro-level learners encounter the resulting system through access, assessment, portability, and labor-market signaling. The framework is therefore not simply a stakeholder map but a causal model: it shows how micro-credentials move from policy architecture through institutional practice to individual educational and professional trajectories, and – critically – how failure at any one level destabilizes the others. Regulatory architecture without institutional capability produces formalism without delivery; institutional experimentation without recognition architecture produces fragmentation without legitimacy; and robust policy and institutional systems without learner-facing trust mechanisms produce credentials that are formally valid but practically inert.

The Kazakhstan case confirms the analytical value of this framework. At the Macro level, Kazakhstan already has state-defined terminology, qualifications-framework integration, and legal recognition of non-formal learning. At the Meso level, universities have begun implementing internal regulations, employer-linked programs, and credit-recognition procedures, but unevenly across institutions. At the Micro level, learners already receive microcertificates, digital badges, and recognized short-form credits, yet employer

trust, long-term outcomes, and equitable access remain unresolved. The MMM framework thus explains why transitional systems can simultaneously display regulatory advancement, institutional experimentation, and persistent gaps in system coherence – and why coordinated development across all three levels, rather than sequential progress through them, is the defining condition for sustainable micro-credentials integration (Sovetkanova et al., 2026; Government of the Republic of Kazakhstan, 2023; National Center for Higher Education Development, 2025).

Systemic Risks, Implementation Barriers, and Policy Implications

The preceding sections show that the institutionalization of micro-credentials in transitional systems is no longer merely a conceptual issue. However, expansion alone does not guarantee system coherence, public trust, or long-term sustainability. Across international practice, micro-credentials often grow faster than the recognition, quality assurance, and governance structures needed to stabilize them (Brown et al., 2021; Cedefop, 2022, 2023). In transitional systems, this risk is more pronounced because reform is expected to satisfy several objectives simultaneously – labor-market responsiveness, qualification-framework integration, institutional modernization, and learner flexibility – without the institutional maturity that more established systems have developed incrementally (Varadarajan et al., 2023; Selvaratnam et al., 2024).

At the Macro level, the central barrier is the structural tension between flexibility and regulation. Under-regulation produces fragmentation, inconsistent signaling, and weak public trust, whereas over-regulation reduces institutional responsiveness and undermines the agility that makes micro-credentials attractive in the first place (Cedefop, 2022, 2023; OECD, 2021). Kazakhstan reflects this tension clearly. On one hand, the country already has a legal and regulatory basis for micro-credentials, recognition of non-formal learning, and qualifications-framework integration – formal definitions in the State Compulsory Standard of Higher Education, recognition procedures, and policy commitments to stackability (Government of the Republic of Kazakhstan, 2023; Ministry of Science and Higher Education of the Republic of Kazakhstan, 2022). On the other hand, the system still lacks full coherence in critical areas: unified accreditation standards, a functioning national registry, and consistent recognition architecture across institutions remain incomplete (Borgekova et al., 2026; Jomartova, 2025). Kazakhstan has therefore moved beyond the purely declarative stage, but its macro-level architecture remains only partially consolidated.

At the Meso level, the most serious barriers concern uneven institutional readiness. Universities need more than policy authorization to implement micro-credentials effectively – they also require leadership commitment, internal regulations, sustainable staffing and funding models, interoperable digital systems, workable modularization strategies, and credible procedures for assessment, stackability, and credit recognition (Varadarajan et al., 2023; Selvaratnam & Sankey, 2021; Selvaratnam et al., 2024). This is also the level where operational friction is most visible: faculty resistance, workload pressures, uncertainty about business models, and tensions between academic rigor and labor-market responsiveness (McGreal & Olcott, 2022; Brown, McGreal, & Peters, 2023). The Kazakhstan evidence confirms these barriers in concrete form. Universities have developed internal regulations, employer-linked programs, credit-recognition practices, and digital badging mechanisms, as documented at Satbayev University, Almaty Technological University, Astana IT University, IITU, and Toraighyrov University (Satbayev University, 2025; Sadykov et al., 2023; National Center for Higher Education Development, 2025; Nurakhmetov, 2023). Yet the evidence also points to heterogeneity of approaches, the absence of a common standard, and persistent reluctance among some universities to integrate micro-credentials into traditional programs (Jomartova, 2025). In transitional systems, this produces a recurring risk of institutional fragmentation, where similar forms of short-form learning are designed, weighted, and recognized differently depending on the institution.

At the Micro level, the key risks concern trust, access, and the limits of current evidence. The literature provides reasonably strong support for short-term learner motivations and competency gains, especially where micro-credentials offer flexibility and targeted skill acquisition (Tamoliune et al., 2023; West & Cheng, 2023). However, long-term outcomes – wage returns, sustained employability, durable mobility – remain weakly evidenced across most contexts (McGreal & Olcott, 2022; Varadarajan et al., 2023). In Kazakhstan, learners are already receiving microcertificates, digital badges, and recognized short-form credits, and national monitoring data show large-scale participation through Coursera and Huawei ICT modules (National Center for Higher Education Development, 2025). Yet employer acceptance remains uneven, especially in regulated fields where the traditional diploma still functions as the dominant hiring

filter (Jomartova, 2025). Possible equity risks also arise if micro-credential programs become predominantly fee-based, and infrastructural barriers persist in regions with weaker digital connectivity (Jomartova, 2025).

A further systemic challenge is the gap between formal commitments and actual implementation. In Kazakhstan, policy and law have already introduced the language of micro-credentials, nano-learning, stackability, and non-formal recognition (Government of the Republic of Kazakhstan, 2023; Ministry of Science and Higher Education of the Republic of Kazakhstan, 2025). Yet the evidence still points to fragmented recognition, incomplete accreditation architecture, and unresolved interoperability issues across institutions (Borgekova et al., 2026; Jomartova, 2025). Where state steering, university autonomy, and labor-market alignment remain weakly synchronized, the result is not a coherent ecosystem but a partially connected system marked by variable portability, uneven trust, and incomplete quality assurance.

One major policy implication that follows directly from the MMM framework is the need for a dedicated registry mechanism for university micro-credential programs within Kazakhstan's national register of higher and postgraduate education programs. Comparative evidence confirms that registry-like mechanisms play a central role in strengthening transparency, verification, and public trust. New Zealand's public register of NZQA-approved micro-credentials standardizes title, framework level, credit volume, provider, and review dates, thereby supporting formal recognition (OECD, 2021, 2023; Kato et al., 2020). In Europe, the Europass and European Digital Credentials for Learning infrastructure supports authenticity, metadata standardization, and cross-border portability (PPMI Group, 2020). In the United States, Credential Engine seeks to improve transparency in a fragmented market by standardizing credential descriptions (Credential Engine, 2021; OECD, 2021, 2023). Analogous functions are visible in Australia's MicroCred Seeker, Ireland's MicroCreds.ie, Germany's hoch & weit portal, and Poland's Odznaka+ system (OECD, 2023; Cedefop, 2023). For Kazakhstan, a dedicated registry module could require standardized information on program code and title, implementation format, partner organization, professional standard, labor function, learning outcomes, final assessment, and the document confirming results – directly addressing the fragmentation identified at both macro and meso levels of the MMM framework.

Discussion

This study contributes to the literature on micro-credentials in three main ways. First, it demonstrates that micro-credentials are best understood as a heterogeneous and evolving field shaped by different governance logics, institutional traditions, and recognition architectures rather than as a single stable educational format (Brown et al., 2021; Kato et al., 2020). Second, it shows that cross-national variation is not merely terminological but reflects deeper differences in how short-form learning is embedded in qualifications systems, linked to labor-market needs, and mediated by higher education institutions (Council of the European Union, 2022; Cedefop, 2022, 2023). Third, it highlights the analytical importance of transitional systems such as Kazakhstan, where the tensions between flexibility and regulation, policy ambition and institutional readiness, and labor-market responsiveness and academic legitimacy become especially visible and consequential (Varadarajan et al., 2023; McGreal & Olcott, 2022).

With regard to RQ1, the findings confirm that international trajectories of micro-credentials institutionalization are patterned rather than random. The comparative analysis identified four distinct trajectories – top-down regulated, supranational collaborative, decentralized market-driven, and hybrid – that differ systematically in governance, framework integration, stackability, and institutional drivers. This supports an analytical shift away from definitional debates alone and toward recognition architecture, provider roles, and relations to formal qualifications systems as the more consequential dimensions of comparison (Brown et al., 2021; Kato et al., 2020; McGreal & Olcott, 2022). The trajectory typology proposed here extends existing comparative work by Orr et al. (2020) and Cedefop (2022, 2023) by incorporating non-Western and transitional contexts alongside the more commonly studied European and Anglophone systems.

With regard to RQ2, the Kazakhstan case shows how global micro-credentials discourse is adapted within a more regulated national context in ways that existing literature has not yet systematically captured. Kazakhstan is neither a purely market-driven case nor a purely institution-led one. Rather, it is a hybrid, multi-tiered arrangement in which state-defined categories, qualifications frameworks, legal recognition of non-formal learning, university autonomy in implementation, and labor-market-oriented content are

assembled into a distinctive governance model (Government of the Republic of Kazakhstan, 2023; Ministry of Science and Higher Education of the Republic of Kazakhstan, 2025; Borgekova et al., 2026). This extends the literature by moving the discussion beyond mature systems in the Global North and toward contexts where state steering remains strong and qualifications reform is closely tied to occupational standards and national development priorities (Muravyeva & Oleynikova, 2024; Kato et al., 2020).

The Kazakhstan evidence also complicates any simplistic reading of regulated systems. Formal legal definitions, qualifications-framework integration, and policy mandates may coexist with uneven implementation, fragmented institutional practice, incomplete accreditation architecture, and uncertain employer recognition (Borgekova et al., 2026; Jomartova, 2025). This is precisely why the MMM framework is analytically useful: it demonstrates that successful integration depends on coordinated development across policy, institutional, and learner-facing levels rather than on regulatory ambition alone (Sovetkanova et al., 2026; Selvaratnam et al., 2024). In this sense, the study supports and extends the argument of McGreal and Olcott (2022) that state mandates are necessary but insufficient conditions for sustainable micro-credentials ecosystems.

With regard to RQ3, the findings point to three interdependent conditions for credible implementation in transitional systems. At the macro level, regulatory frameworks must balance quality assurance with sufficient flexibility for institutional adaptation. At the meso level, universities require not only authorization but genuine organizational capacity – governance, digital infrastructure, employer partnerships, and workable assessment models. At the micro level, learner-facing mechanisms of trust, portability, and digital verification must be developed in parallel with, not after, regulatory and institutional structures. These conditions align with and reinforce recent empirical findings on institutional readiness and maturity in Australasian contexts (Selvaratnam et al., 2024) and with employer-oriented evidence showing that credential value depends heavily on how consistently it is interpreted and rewarded in labor markets (Gauthier, 2020; Oliver, 2019).

This study also has clear limitations. The evidence across countries remains uneven, and the Kazakhstan-specific corpus, while substantially stronger than in earlier literature, still combines regulatory texts, institutional materials, monitoring reports, and a limited number of peer-reviewed empirical studies (Sovetkanova et al., 2026; Borgekova et al., 2026). The available evidence is stronger on policy architecture and institutional arrangements than on long-term learner outcomes and employer behavior (Varadarajan et al., 2023; McGreal & Olcott, 2022). The article is based on a narrative and comparative design rather than on systematic review methods or original stakeholder fieldwork, so its contribution lies in conceptual synthesis and policy analysis rather than causal measurement of effects (Grant & Booth, 2009; Snyder, 2019).

Future research should focus more directly on employer recognition, digital verification, institutional capability, and learner outcomes in transitional systems. Kazakhstan in particular would benefit from longitudinal studies on labor-market mobility, wage returns, and access to further education, as well as from comparative institutional research on how universities operationalize recognition, stackability, and partnership models (Sovetkanova et al., 2026; National Center for Higher Education Development, 2025). More broadly, regulated and transitional systems deserve much closer scholarly attention because they expose the governance conditions under which micro-credentials either become integrated into qualifications ecosystems or remain fragmented at the margins of higher education (Muravyeva & Oleynikova, 2024; Borgekova et al., 2026).

Conclusion

This article examined how micro-credentials are conceptualized internationally, how they are institutionalized across different higher education systems, and how these processes are unfolding in Kazakhstan. Three findings stand out.

With regard to RQ1, international trajectories of micro-credentials institutionalization vary systematically – not randomly – in governance logic, recognition architecture, stackability, and the role of higher education institutions. No single global model has emerged, and the variation is structurally grounded in different educational traditions, regulatory environments, and stakeholder configurations (Brown et al., 2021; Kato et al., 2020; Council of the European Union, 2022; Cedefop, 2022, 2023).

With regard to RQ2, Kazakhstan emerges as an analytically distinctive case of an emerging hybrid,

multi-tiered model in which state steering, university implementation, and labor-market-oriented content are being assembled into a regulated but institutionally mediated system. This model differs from both market-driven and consensus-based trajectories and illustrates how global micro-credentials discourse is adapted under conditions of strong state regulation and occupational framework alignment (Government of the Republic of Kazakhstan, 2023; Ministry of Science and Higher Education of the Republic of Kazakhstan, 2025; Borgekova et al., 2026; Sovetkanova et al., 2026).

With regard to RQ3, the principal risks arise when regulatory architecture, institutional capability, and learner-facing recognition mechanisms do not develop in coordination. The Macro-Meso-Micro framework proposed in this article captures this interdependence and shows that credible integration requires simultaneous progress across all three levels – not sequential development through them (Varadarajan et al., 2023; Selvaratnam et al., 2024; McGreal & Olcott, 2022).

A central practical implication is that transitional systems require stronger public infrastructures of transparency, recognition, and verification if micro-credentials are to move beyond fragmented experimentation. For Kazakhstan, this includes the need for a dedicated registry mechanism for university micro-credential programs as a foundational step toward a transparent, interoperable, and trusted national ecosystem. More broadly, this article argues that the future value of micro-credentials in transitional higher education systems will depend less on the speed of proliferation than on whether regulatory ambition, institutional capacity, and learner-facing trust mechanisms can be developed as a coordinated whole rather than as disconnected parts.

Declaration of Generative AI and AI-assisted Technologies in the Writing Process

During the preparation of this work, the authors used ChatGPT (OpenAI) to improve language clarity, refine academic phrasing, and support structural editing of author-written text. After using this tool, the authors reviewed, revised, and verified the content as needed and take full responsibility for the content of the publication.

Conflict of Interest Statement

The authors declare no potential conflicts of interest regarding the research, authorship, or publication of this article.

Author Contributions

AN: Conceptualization, Methodology, Validation, Supervision, Writing – Original Draft, Writing – Review and Editing. RB: Conceptualization, Methodology, Investigation, Formal Analysis, Resources, Writing – Original Draft, Writing – Review and Editing, Project Administration. AM: Resources, Project Administration, Writing – Review and Editing. BR: Resources, Writing – Review and Editing. KT: Resources, Writing – Review and Editing. KB: Resources, Validation, Writing – Review and Editing. All authors have read and approved the final version of the manuscript.

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