

Article

Systems Thinking in Higher Education: A Conceptual Model of the Micro-Credentials Ecosystem

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Highlights

Please indicate how your work links to systems science via your contributions to systems practice, theory, and/or methodology.

- This study interprets the micro-credential ecosystem as a complex adaptive system in which learner need, program supply, employer recognition, and credential accumulation jointly shape the signal value of a credential through coupled reinforcing and balancing loops.
- For systems practice in higher education, it develops the resulting causal loop diagram as a curriculum artifact, specifying how feedback structure, boundary judgment, and system-as-cause reasoning can be sequenced across a degree program rather than delivered in a single elective.

What are the main findings and/or the implications of the main findings?

- The findings identify credential inflation as a balancing loop that erodes signal value as supply accumulates, framing it as a transferable sub-form of the Overshoot and Collapse archetype in a social signaling domain.
- Because systems thinking pedagogy has drawn mainly on STEM and sustainability cases, the study offers higher education's own credentialing system as a teaching case, with implications for curriculum sequencing, faculty development, and the assessment of systems reasoning.

Abstract

Micro-credentials are reshaping higher education credentialing, yet existing models mostly link their components through one-way causality, while systems thinking pedagogy has developed largely around STEM and sustainability rather than higher education policy itself. This conceptual paper reframes the micro-credential ecosystem as a complex adaptive system governed by feedback loops, addressing both gaps at once. Following theory synthesis and model-building approaches and Sterman's system dynamics modeling steps, a four-stage process integrates system dynamics, institutional theory, signaling theory, and adult learning theories. The study yields four testable propositions and one balancing loop, formalized in a single integrated causal loop diagram with defined polarities and delays: the bidirectional need–program link (P1), certification–design feedback (P2), demand–standardization network effect (P3), an ecosystem-level reinforcing loop (P4), and credential inflation as a balancing loop (B1). The coupling of the reinforcing and balancing loops frames credential inflation as a transferable sub-form of the Overshoot and Collapse archetype. The core loop is operationalized as a stock-flow structure, a three-level moderator architecture links the model to variable-based designs, and the framework maps



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onto SDGs 4, 8, and 10. Analysis of Meadows's leverage points and a step-by-step design guide translate the model into policy and curriculum practice and into a teaching case for systems thinking.

Keywords: micro-credentials; systems thinking; complex adaptive systems; higher education; adult learning; lifelong learning; sustainable development goals

1. Introduction

Digitalization, globalization, and the rise of the knowledge economy are reshaping labor markets. They also make individuals' knowledge and skills obsolete at a faster pace [1–3]. The spread of automation and artificial intelligence turns learning into a continuous process. It can no longer be confined to one stage of life [4,5]. Under these conditions, lifelong learning has moved to the center of education policy. It is now seen as the main safeguard that helps individuals adapt to changing social and economic conditions [3,6,7]. The lifelong learning approach stresses that learning is not limited to formal institutions. It is a multidimensional process that continues across different life stages and settings [8,9].

In current policy frameworks, lifelong learning is positioned as a core component of sustainable development. Sustainable Development Goal 4 defines inclusive and equitable learning opportunities as a global target [10,11]. Sustainable Development Goals (SDG) 8 frames upskilling and reskilling as key mechanisms for sustainable employment [5,12]. In this context, the digital and green transitions require flexible and accessible learning responses to sit at the center of lifelong learning systems [13]. The design of lifelong learning ecosystems thus emerges as a structural component of sustainable social and economic transformation.

This study does not treat the sustainable development framework as a surface-level reference. It treats it as an analytical whole, mapped onto SDG 4, 8, and 10 through the model's structural components.

Adult education literature offers an important theoretical basis for understanding this multidimensional learning process. Adult learners differ clearly from traditional student profiles. They are self-directed, they tend to link new knowledge to life experience, and they show transformative learning orientations [14,15]. This difference makes it necessary to develop flexible, accessible, and experience-based learning models that meet adult learners' needs [16,17].

Yet traditional higher education systems cannot fully meet these needs. Their structure rests on long-term degree programs. This structure has clear limits when it comes to responding quickly to changing skill demands and supporting individual learning paths [18,19]. These limits have paved the way for micro-credentials to emerge as an alternative learning approach in recent years. Micro-credentials are short, modular certification programs. They document that specific knowledge and skills have been acquired [20,21]. Offered by universities, online platforms, and industry organizations, these programs let individuals acquire the skills they need in a flexible and rapid way [22,23].

Notably, generating additional income is among the reasons higher education institutions offer micro-credentials, alongside enhancing visibility, experimenting with new pedagogies, and responding to labor-market demand [24]. In the United States in particular, where the further-education function is largely integrated within higher education, institutions increasingly retain micro-credentials within their own systems, with over half of surveyed institutions viewing them as a supplementary source of income [24].

Such incentives are not pedagogically neutral: they shape which components are unbundled from existing curricula and how programs are designed and packaged [23], thereby influencing program-design and instructional decisions rather than remaining a purely financial matter.

This potential becomes more meaningful as learning grows more distributed and multi-actor. Learning is no longer confined to university campuses. It happens at the same time across digital platforms, workplaces, and open learning networks. The literature calls this structure a learning ecosystem. It refers to a multilayered environment where different institutional and digital actors operate in mutual dependence [25–27]. This mutual dependence, however, coexists with competition among providers for learners and recognition; such rivalry is not external to the ecosystem but part of its dynamics, and it bears directly on program design and the standards to which learning outcomes are held [23]. Within this structure, micro-credentials are not the product of a single institution. They emerge as a system that works through interactions among universities, online platforms, certification bodies, employers, and policymakers. This system also carries self-limiting dynamics. Credential inflation acts as a structural feedback mechanism that curbs the system's unlimited growth [28,29]. These features mean micro-credentials should not be addressed through linear causality. They call for a complex adaptive systems perspective, in which feedback loops among actors produce macro-level behavior [30,31]. The systems-thinking tradition provides a suitable basis for analyzing such ecosystems. Through causal loop diagrams, reinforcing-balancing loop hierarchies, and system boundary analysis, it makes visible the delayed feedback dynamics and self-limiting saturation mechanisms in ecosystems [32–35].

When the current literature is examined, however, micro-credential research is found to concentrate on specific areas. These include higher education policy, digital certification systems, and labor-market outcomes [19,22,36]. These studies offer valuable contributions. But they mostly treat micro-credentials as independent tools. They do not systematically conceptualize the mutual determination among components or the feedback dynamics that emerge at the system level. Indeed, systematic reviews in this area also point to the lack of an integrated approach. They note that the field's multidimensional structure needs to be addressed holistically [37–39].

From the perspective of the systems thinking education literature, a complementary gap stands out. The body of systems thinking pedagogy has matured over the past two decades [40–42]. It has developed mainly in STEM disciplines, engineering education, and sustainability science. Conceptual work that treats higher education's own policy domain—credentialing, quality assurance, recognition regimes—as a field for teaching systems thinking is relatively scarce. There are also a few pedagogical frameworks that present the reinforcing—balancing loop tension through a concrete public policy example grounded in polarity. This suggests that a model explaining the role of micro-credentials within lifelong learning ecosystems—one that uses adult learning theories and system-theoretic tools together—has not yet been sufficiently addressed in the literature.

This study makes contributions at four levels to address this theoretical gap. The first is to the systems thinking literature. Higher education credentialing is treated as a case from a complex adaptive systems perspective [30]. Credential inflation is discussed within a balancing loop framework, and the reinforcing–balancing loop interaction is analyzed through the concept of signal value. In addition, credential inflation is framed as a transferable sub-form of the Overshoot and Collapse archetype, specific to social signaling systems. The second is to systems thinking pedagogy. Teaching examples have primarily focused on engineering, STEM, and sustainability science cases [41,42]. This study widens the pedagogical repertoire by offering a concrete case from the higher education policy

domain. The third is to micro-credential research. The field's one-way causality view [22,43] is reframed in the language of system dynamics, as reinforcing and balancing feedback loops. The fourth is theoretical integration. Education sciences, system dynamics, labor economics, and institutional theory [44] are brought together on a common analytical ground. Capital theories [45] are linked not to the model's endogenous core but to its moderator layer. They serve as a theoretical lens that explains why outcomes are unequally distributed across social groups.

Taken together, these two gaps establish the rationale for this study. Micro-credential research lacks an integrated, feedback-based account of how the system's components shape one another, and systems thinking pedagogy lacks concrete cases drawn from higher education's own policy domain. A model that addresses both gaps at once is therefore needed.

The aim of this study is to develop a conceptual model that reframes the micro-credential ecosystem as a complex adaptive system governed by feedback loops and to show how this model can serve both as an analytical tool and as a concrete teaching case for systems thinking in higher education policy.

To pursue this aim, the study addresses three research questions:

- RQ1. How can the relationships among the components of the micro-credential ecosystem be conceptualized as reinforcing and balancing feedback loops rather than one-way causal chains?
- RQ2. What does this system-dynamics account offer as a pedagogical case for teaching systems thinking within the higher education policy domain?
- RQ3. How can the model guide the design of micro-credential programs in practice?

2. Methodological Approach

This study is conceptual in nature. Rather than testing hypotheses with empirical data, it develops an integrated model by synthesizing established theoretical perspectives from the existing literature. Whetten [46] defines four elements as the minimum condition for a theoretical contribution: stating the building blocks clearly (what), defining the relationships among them (how), giving the theoretical rationale for why the relationships work as they do (why), and setting out the conditions under which the proposed structure holds (who, where, when). Jaakkola [47] divides conceptual papers into four basic design approaches: theory synthesis, theory adaptation, typology development, and model building. This study combines two of them—theory synthesis and model building. Theoretical knowledge from different disciplines (adult learning theories, system dynamics, institutional theory) is synthesized within an integrated conceptual model. The relationships among components are then formalized as propositions.

Conceptualizing the model as a system rest on the model-building stages of system dynamics methodology. The study follows, in order, the steps Sterman [35] defines for the modeling process: problem definition, dynamic hypothesis formation, and mapping the structure with a causal loop diagram. First, the systemic problem is defined—the inadequacy of explaining the role of micro-credentials in the lifelong learning system through one-way causality. Next, a dynamic hypothesis is developed that expresses the relationships among components as feedback loops. This hypothesis is then formalized as a causal loop diagram. To secure the model's testability, the propositions are linked to observable indicators and data sources. The main feedback loop is operationalized through a stock-flow conceptualization. In this way, the study remains grounded in qualitative systems thinking. At the same time, it offers a clear methodological bridge to future quantitative system dynamics research.

The model was developed through a four-stage process. In the first stage, theoretical models and frameworks in the micro-credential field were reviewed. Three frameworks were selected for detailed comparative analysis based on two criteria: being among the most cited or referenced in international policy documents and representing different analytical levels. On these grounds, the study examined the 3M Model [43], the Credential Ecology Framework [22] and the Universal Micro-credential Framework [48].

In the second stage, the model's theoretical foundations were established. Three core traditions in the adult learning literature—*andragogy* [14], *transformative learning* [15] and *experiential learning* [49]—were linked to the micro-credential components. In addition, Bronfenbrenner [50], Bandura [51], Siemens [27], DiMaggio and Powell [44], Spence [52], Sen [53] and Bourdieu [45] provided theoretical support for different components of the model.

In the third stage, the model components and their relationships were defined. The literature typically represents these relationships as one-way causal chains. Guided by Whetten's [46] framework, the study instead reconceptualizes them as bidirectional interactions. This reframing is a theoretical requirement of the ecological perspective and the connectivist learning view that underpin the model [26,27,50]. Both directions were developed separately for each relationship. The theoretical mechanism behind each direction—institutional isomorphism, signaling, network effect and supply-driven demand—was justified explicitly. The model thus covers not only the relationships among the four core components, but also the ecological framework in which they operate—universities, online platforms, industry, policymakers, and professional networks—as a structural element.

In the fourth stage, the developed relationships were formulated as four theoretical propositions (P1–P4). Each proposition was structured around three components: a proposition statement defining the direction and nature of the relationship, the theoretical rationale supporting the first direction, and the mechanisms explaining the second (reverse) direction. The propositions were framed as testable hypothetical statements for future empirical research.

Finally, moderator variables operating at the individual, institutional, and contextual levels were defined to ensure the model's sensitivity to context. This three-level structure matches the micro–meso–macro distinction in Bronfenbrenner's ecological systems theory [50]. It shows that the model makes no claim to universality and may take different forms in different contexts.

3. Theoretical Framework

3.1. Lifelong Learning

Lifelong learning refers to the learning activities individuals carry out at every stage of life to sustain their personal, social, and professional development [8,54]. Such activities are distributed across formal, non-formal, and informal settings [9,55]. These processes, described through the concepts of *upskilling* and *reskilling*, help individuals adapt to changing labor-market conditions and support economic competitiveness [3–5]. Lifelong learning is more than an individual process. It operates as a distributed structure spanning multiple actors and learning environments.

The role of lifelong learning within the sustainable development framework can be examined on a deeper theoretical basis through Sen's capability approach [53]. For Sen, development should not be understood only as economic growth or higher income. It is the expansion of real freedoms that let individuals lead the lives they value. In this framework, education and learning opportunities are key mechanisms. They expand an individual's capabilities and enable people to act as effective agents [56]. This approach forms the theoretical background of the inclusive and equitable lifelong learning target

under SDG 4. It positions access to learning opportunities as an ethical requirement of sustainable development [10,11].

3.2. Learning Ecosystems

A learning ecosystem is a multidimensional, dynamic structure in which learning occurs across different institutions, technologies, and social networks [26]. This approach stresses that learning processes are not limited to activities run by universities. They are also shaped by digital platforms, industry, and individual learning networks [25,57]. Siemens's [27] connectivism supports this view. It emphasizes that learning is a social and cognitive process that occurs within digital networks. Still, digital learning environments do not serve all actors equally. They tend to reinforce existing inequalities [19,58].

This multi-actor and distributed structure requires the learning ecosystem to be treated not as a mere descriptive metaphor, but as a complex adaptive system. Hecht and Crowley [30] note that the education literature often uses the ecosystem framework at a descriptive level—as “a complex but deterministic structure of interconnected components.” Yet education is emergent, nonlinear, and feedback-driven by nature. It should be conceptualized as a genuinely complex system. Complex adaptive systems are structures in which unpredictable behavior emerges at the whole-system level from the local interactions of many heterogeneous actors. Actors adapt their behavior to feedback, and the system reproduces itself through this adaptation [31,59]. The micro-credential ecosystem meets these criteria. The local interactions of heterogeneous actors (learners, program providers, certification bodies, employers, policymakers) produce holistic patterns at the system level without central control. Actors adapt their strategies to one another's signals. This adaptation is mutual, and it unfolds over time. Employers signal which skills they value. Course and program designers respond by adjusting what they offer. As these programs grow and their credentials become more standardized, employers rethink how much weight to give them in hiring. Universities, online platforms, and policymakers take part in the same back-and-forth. No single actor changes on its own. Each one responds to the others. These adjustments build up across repeated cycles of provision, recognition, and revision. This is a process of coevolution. Over time, the actors and their relationships reshape one another rather than staying in fixed roles [31]. The delays in the model make this coevolution visible. Each actor responds to the others' earlier signals only after a lag, not at once. The ecosystem also learns as a whole, not only through its individual learners. When many actors adjust to the same signals, useful practices spread and become shared expectations. A quality standard that proves credible at one institution is taken up by others. A credential type that employers come to trust shapes how later programs are designed. In this way, knowledge that begins in one part of the system accumulates and becomes part of how the whole system operates. This is collective learning. Work in complexity-based education theory has shown that learning need not be located solely in individual agents: a collective can itself function as a learning system whose capacity is not reducible to the sum of its members' understandings [60]. The same logic applies at the level of the ecosystem, which retains and builds on what its actors discover, so that the system's capacity grows beyond what any single actor learns on its own [30]. For this reason, the study conceptualizes the learning ecosystem as a complex adaptive system that self-regulates through feedback loops among its components [32,34,61].

The complex adaptive systems (CAS) and system dynamics (SD) frameworks are positioned here not as rivals, but as complementary approaches at two different levels of abstraction. The CAS perspective describes the ontological nature of the micro-credential ecosystem: the local, uncoordinated actions of individual actors. System dynamics provides its analytical representation: the aggregate pattern those actions produce. The proposed

causal loop diagram does not explain how the system's behavior arises from the interaction of individual actors. Instead, it makes visible the patterns that emerge across the whole system because of these interactions: tendencies toward growth, saturation, and self-correction.

A concrete example makes this level shift clearer. Consider a single learner who decides whether to enrol in a credential, and later whether to complete it. Thousands of other learners make the same choice on their own, and no one coordinates these decisions. When credential supply keeps rising in this way, each credential signals less to employers. This system-level outcome -credential inflation- is something no single learner intends or controls. It emerges only from the many separate decisions taken together [31]. The diagram does not track these decisions one by one; it captures what they add up to.

In other words, the model justifies treating the micro-credential ecosystem as a feedback-driven and adaptive system, but it maps the aggregate-level outcome of these behaviors, not their detailed process of formation. The diagram is not a simulation of individual behavior. It is an abstraction. Modeling the micro-to-macro transition itself—how individual actions produce these aggregate patterns— would require agent-based simulation and is left for future research.

3.3. Adult Education Theories

Adult education forms an important dimension of lifelong learning [17,61]. Knowles's andragogy approach [14,62] stresses that adults give priority to self-directed learning and link learning experiences to their prior life experiences. Mezirow's transformative learning theory [15,63] defines adult learning as a critical process. In it, individuals question their existing frames of thinking and develop new perspectives. Kolb's experiential learning theory [49,64] holds that learning takes place within a cyclical structure of experience, reflection, conceptualization, and application. Illeris [16] combines these theories into a holistic perspective that also covers the emotional and social dimensions of learning. These theories are presented as the micro-mechanisms that explain how the model's R1 reinforcing loop operates at the individual level.

3.4. Micro-Credentials

Micro-credentials are defined as short, modular certification programs based on learning experiences that document the acquisition of specific knowledge or skills [20,21]. The European Commission [13] defines the concept as the certification of knowledge, skills, and competencies gained through specific learning outcomes. Milligan and Kennedy [65] treat micro-credentials as digitally verifiable and portable learning records.

In the literature, micro-credentials are classified in different forms, such as digital badges, nanodegree programs, stackable certificates, and MicroMasters programs [21,24]. These types differ in duration, content structure, certification format, and scope. Their common feature is that they allow learning to take place in a modular, flexible, and individualized structure [28,66]. International organizations such as the European Union, OECD, and UNESCO stress that micro-credentials play a critical role in strengthening lifelong learning systems and responding quickly to changing skill needs. The European Commission recommends aligning micro-credentials with the European Qualifications Framework, in line with the principles of quality assurance, recognition, transparency, and portability [4,8,67].

Criticisms of micro-credentials cannot be ignored, however. Wheelahan and Moodie [19] argue that the labor-market-driven structure of micro-credentials shapes education in line with market logic. The spread of many small-scale certificates also brings the risk of credential inflation. This can weaken their credibility in the eyes of employers [28].

From a lifelong learning standpoint, micro-credentials offer individuals flexible learning opportunities. They support a skills-focused learning approach, allow for personalized learning processes, and make it easier to recognize skills gained across different learning settings [21,65,67]. These features show that micro-credentials are not an independent certification tool. They should be treated as a holistic structure that operates within lifelong learning ecosystems, in line with adult learning principles.

3.5. Existing Micro-Credential Models

In recent years, different theoretical models and frameworks have been developed to explain the role of micro-credentials within education and labor-market systems. Since this study is not a systematic literature review but a conceptual model-building effort [47], a purposive selection was made for comparison. Three frameworks were chosen based on two criteria: (i) being among the most cited in the field or referenced in international policy documents, and (ii) representing different analytical levels of micro-credentials-multilevel impact (3M), credential typology (Credential Ecology), and the education–employment interface (Universal Framework). The three frameworks compared in Section 2 are examined in detail below. The aim is not to cover all models in the field, but to analyze representative frameworks that most clearly show the theoretical gap the proposed model addresses. As each model is introduced, the main differences from the conceptual model proposed here are also noted. A comparative summary of the models is presented in Table 1.

Table 1. Comparative evaluation of existing micro-credential models.

Model	Analytical Focus	Core Component	Theoretical Basis	Sustainability Dimension	Key Limitation
3M Model	Multilevel impact analysis	Micro, meso, and macro levels	Zawacki-Richter's [68] open and distance education framework	Implicit through lifelong learning; SDG link not explicitly established	Interaction mechanisms across levels not systematically conceptualized
Credential Ecology Framework	Credential typology mapping	Two axes (bundled/unbundled × credit-bearing/non-credit-bearing) and four quadrants	Typology approach based on a synthesis of the existing literature	Central role within the lifelong learning framework; equity discussion included; no SDG link	Interaction processes among components and the role of the adult learner not theorized
Universal Micro-credential Framework	Skills matching at the education–employment interface	Skill profiling, micro-credential pathways, badge catalogs, and design patterns	Capacity–competency gap concept, skills-based hiring approaches, 21st-century skills discussion	Not explicitly addressed	Developed in the context of computer science education; motivational patterns of the adult learner and contextual conditions not systematically addressed

3M Model [43] is adapted from Zawacki-Richter's [68] open and distance education framework. It addresses the effects of open micro-credentials on learning at three levels: the micro level, focused on learners and instructors; the meso level, covering institutions; and

the macro level, operating at the societal level. The model's main contribution is bringing individual learning, institutional transformation, and societal certification systems together in a common analytical framework. Yet the 3M Model is an analytical framework that maps research gaps. It does not systematically conceptualize the mechanisms of mutual interaction across levels or the relationship of these interactions to adult learning theories.

Credential Ecology Framework [22] offers a map that positions the micro-credential field along two axes: bundled or unbundled credentials, and credit-bearing or non-credit-bearing credentials. These axes produce a four-quadrant typology. They position micro-credentials as unbundled, credit-bearing, and stackable credentials. The framework's main contribution is treating micro-credentials not as independent tools but as part of a broader credentialing ecology. Yet the framework serves as a typological mapping. It does not systematically theorize the interaction processes among its components or the role of the adult learner within this ecology.

Universal Micro-credential Framework [48] is a skills-profiling-based framework. It aims to address the structural mismatch between the capacities gained in education and the competencies expected in the labor market—a gap the authors call the capacity—competency gap. The framework offers a mechanism for integrating into traditional qualification structures through micro-credential pathways, badge catalogs and design patterns. It supports the acquisition of 21st-century skills. Its main contribution is conceptualizing micro-credentials as a structure that can be operationalized within the learning-acquisition ecosystem through concrete skill profiles and design patterns. Still, the framework was developed mainly in the context of computer science education. It does not systematically address the motivational patterns of the adult learner, the transformative dimensions of learning, or the ecosystem's contextual conditions.

In addition to these three theoretical frameworks, reports from organizations such as Bideau and Kearns [20], the OECD [12] and the European Commission [13] offer important policy and practice discussions. These reports address the alignment of micro-credentials with the European Qualifications Framework (EQF) and the European Credit Transfer System (ECTS), as well as quality assurance and credential recognition. But these works are largely policy guides in nature. They do not put forward a theoretical model.

Other studies in the field serve to complement these three frameworks. Some map the field through systematic reviews [38,39,69]. Others address the rationale, value, and student/practice perspectives of micro-credentials [70–72]. These studies were not included in the detailed comparison because they do not propose the kind of integrated structural model that the three conceptual models compared here offer.

When the three theoretical models are assessed together, they show three common limitations. First, each model addresses micro-credentials through a specific level or dimension. None formalizes component interactions systematically as reinforcing/balancing feedback loops with defined polarity, loop type, and delay points. Second, the existing models do not systematically link micro-credentials to adult learning theories—the andragogy, transformative learning and experiential learning traditions. Third, no model explicitly links micro-credentials to the Sustainable Development Goals framework. At most, the SDG connection is assumed implicitly through lifelong learning (Table 1, Sustainability Dimension column). The conceptual model proposed in this study addresses these three gaps together. It aims to position micro-credentials within a lifelong learning ecosystem, linked to adult learning theories, explicitly connected to the SDG framework, and building bidirectional interactions among its components in a holistic framework.

3.6. Frameworks in the Field of Systems Thinking Education

In parallel with micro-credential research, different conceptual frameworks have been developed in the field of systems thinking education over the past two decades. These frameworks offer pedagogical tools to help students gain systems thinking skills. But most of them focus on specific application areas, such as STEM disciplines, engineering education, and sustainability science. Four prominent frameworks in the field are discussed below, and a comparative summary is presented in Table 2.

Table 2. Comparative evaluation of frameworks in the field of systems thinking education.

Framework	Analytical Focus	Core Component	Context of Development	Key Limitation
Systems Thinking Inventory	Student assessment	Bathtub dynamic; stock-flow understanding	STEM and engineering education	Assessment tool; no pedagogical application
DSRP Framework	Cognitive competency	Distinction, system, relationship, and perspective competencies	Transferable cross-disciplinary skills	General cognitive model; no contextual application
The Fifth Discipline	Organizational learning	System archetypes; learning organization	Management and organizational governance	Not adapted to the higher education policy context
Systems Thinking Competency Definition	Competency definition	The eight core skills that make up systems thinking	Higher education in general	Definition-focused; no pedagogical application framework

Systems thinking inventory: Sweeney and Sterman [42] developed an assessment tool that measures students' understanding of basic stock-flow concepts and feedback dynamics. At the center of the framework is the bathtub dynamic. The amount of water flowing into and out of a bathtub is used to test students' grasp of cumulative system behavior. Sweeney and Sterman [40] extended this line of research and documented students' and teachers' understanding of natural and social systems. The framework's main contribution is defining systems thinking skills as a measurable learning outcome. Yet it is a tool focused on student assessment. It does not offer a holistic teaching framework built around a concrete policy case.

DSRP framework: Cabrera, Colosi, and Lobdell [41] define systems thinking through four core cognitive competencies: making distinctions, recognizing systems, identifying relationships, and taking perspectives. These competencies are positioned as transferable core skills across disciplines. The framework's main contribution is to abstract systems thinking from a specific application area and define it as a general set of cognitive competencies. Yet the framework remains an abstract model. It does not develop a contextual teaching framework for how these competencies can be applied in a concrete policy field.

The fifth discipline tradition: Senge [34] positioned systems thinking as a core component of organizational learning. He defined it as one of the core disciplines of learning organizations, alongside shared vision, team learning, personal mastery, and mental models. The concept of system archetypes offers managers and educators a practical tool for recognizing feedback dynamics. This approach played a decisive role in spreading systems thinking within the management field. But it developed mainly in the context of organizational management. It did not develop models that address the structural dynamics

of fields such as education policy and higher education credentialing in the language of systems thinking.

Systems thinking competency definition: Arnold and Wade [73] propose an integrated competency definition to resolve the conceptual ambiguity that arises from the different ways systems thinking is defined in the literature. In this framework, systems thinking consists of eight core skills: recognizing systems, identifying relationships, distinguishing feedback loops, understanding dynamic behavior, seeing the structure-behavior relationship, grasping nonlinear effects, recognizing delays, and making decisions under complexity. The framework's main contribution is structuring systems thinking as a functional set of competencies for teaching and assessment. Yet the definition does not propose a contextual pedagogical application for how the eight competencies can be taught through a concrete policy case.

Arnold and Wade's framework [73] offers a widely used taxonomy of systems thinking competencies. A more recent line of empirical work asks a different question: how do students in higher education conceptualize systems thinking? Sreenivasulu and Subramaniam [74] examined this in a multidisciplinary undergraduate cohort using a single open-ended question, administered before and after a course on systems thinking. Seven attributes recurred in the responses: interconnectedness/interdependence, feedback, causality, systems boundary, mapping, emergent behavior over time, and synthesis. Their distribution was strikingly uneven. Two attributes dominated—interconnectedness and mapping—while feedback and systems boundary were rare, and emergent behavior and synthesis fell in between. The authors therefore treat feedback, boundary judgment, emergence, synthesis, and nonlinear causality as threshold concepts, and propose an “attributes continuum” running from inadequate to canonical understanding. What this suggests is that the competencies specified in systems thinking frameworks are not acquired evenly. Students grasp what a system contains and how its parts connect long before they grasp how feedback generates behavior, or how a boundary is drawn in the first place. This matters for the present study. The reinforcing and balancing loops of the micro-credential ecosystem rest on exactly the attributes that learners find hardest to internalize. The model developed here is thus both an analytical device and a pedagogical artifact for making these concepts explicit.

When these four frameworks are assessed together, they show two common limitations. First, the contexts in which they were developed are mainly STEM disciplines, engineering education, and organizational management. Higher education policy itself—especially credentialing, quality assurance, and recognition regimes—has been studied relatively little as a direct case for teaching systems thinking [38,39]. Second, although these frameworks offer general conceptual tools, they do not develop pedagogical cases that present the reinforcing and balancing loop tension in a concrete policy field on the grounds of polarity. The conceptual model proposed in this study aims to contribute to these two gaps. The micro-credential ecosystem is treated as a concrete case from the higher education policy field, and the reinforcing–balancing loop tension is discussed through the example of credential inflation.

4. Development of the Conceptual Model

Holistic theoretical models that explain the role of micro-credential systems within the lifelong learning ecosystem remain limited in the literature. Existing studies mostly treat micro-credentials as independent certification tools in the context of higher education transformation and the labor market. They do not systematically conceptualize the bidirectional, dynamic relationships these systems establish with ecosystem components [19,23].

The model proposed in this study aims to close this gap. It offers an integrated framework that includes bidirectional interactions among components and four feedback loops.

The section is structured as follows. Section 4.1 defines the model's general structure and the system boundary. Section 4.2 outlines the model's two-level theoretical foundations (systems theory and adult learning theories). Section 4.3 develops the four theoretical propositions (P1–P4) and the balancing loop (B1) around a single integrated causal loop diagram (Figure 1). Section 4.4 explains the moderator variables and the model's structural alignment with the Sustainable Development Goals. Section 4.5 offers a research roadmap for operationalizing and testing the model.

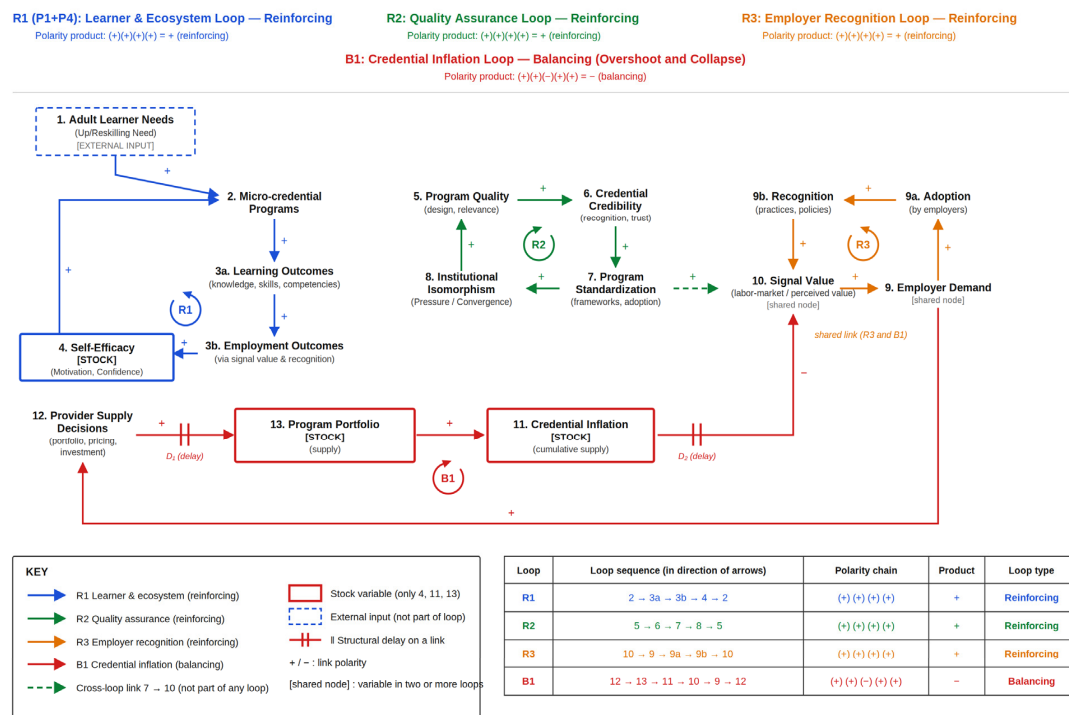


Figure 1. Integrated causal loop diagram of the micro-credential ecosystem. Notes: (1) Each loop is closed and drawn in a single color for visual traceability: R1 blue, R2 green, R3 orange, B1 red. (2) Rectangles denote stock variables; the model contains three stocks (4, 11, 13). All other variables are unboxed. Node 1 is an exogenous input and is shown with a dashed outline; it lies outside every loop. (3) Shared causal links are drawn only once but may belong to more than one loop: the link 10 → 9 belongs to both R3 and B1, and nodes 9 and 10 are therefore shared between them. Nodes 9a and 9b are internal to R3 only. (4) Double hash marks on links 12 → 13 and 11 → 10 denote the two structurally consequential delays, labeled D₁ and D₂; delays implied by stock accumulation are not separately marked. (5) The dashed green arrow (7 → 10) is a cross-loop link carrying the output of R2 into the signal-value node. (6) Loop sequences reported in the legend table correspond exactly to the direction of the arrows in the diagram; polarity products confirm loop type (reinforcing = +, balancing = -).

4.1. Model Structure and System Boundary

The model is built on four core endogenous components: adult learners' upskilling/reskilling needs, micro-credential programs, digital certification mechanisms, and outcomes, which are distinguished as learning and employment outcomes. We treat learning outcomes and employment outcomes as distinct endogenous variables, because a learning outcome does not guarantee an employment outcome: the two are linked only through intermediate mechanisms -signal value and employer recognition- and the transfer of learning gains to labor-market returns is context-dependent [17]. These components op-

erate within an ecosystem comprising four actor categories: universities, online platforms, industry and policymakers [26,27].

The unit of analysis is therefore not the individual institution but the multi-actor learning ecosystem, whose actors share a common pool of learning-outcome standards and a common recognition regime. Within this scope, institutions are not isolated: the quality and legitimacy of one provider's credentials affect the signal value available to others, since all draw on the same recognition regime.

The model differs from approaches in the existing literature in two ways. First, the relationships among components are conceptualized not as a one-way causal chain, but as mutually reinforcing feedback loops. Second, contextual variables (policy regime, digital infrastructure, macro labor market) are positioned as exogenous drivers. These shape the system's behavior but are not determined by the system. Together, these two features make the model a complex adaptive system that regulates itself through feedback loops, rather than a static schema.

For a system model to be interpretable, its boundary must be defined clearly [33,35]. Table 3 summarizes the model's endogenous core, the exogenous drivers that enter the boundary, and the areas left out of scope, under three categories. This classification clarifies what the model explains and what it does not. It also makes visible that contextual conditions work from two frames at once: as system boundary parameters and as moderator variables. Among these exogenous drivers, funding includes institutional revenue incentives that motivate providers to offer micro-credentials, which in turn enter the system as boundary parameters.

Table 3. The model's system boundary and variable classification.

Endogenous Variables (System Core)	Exogenous Drivers (Entering the Boundary)	Out of Scope (Outside the System)
• Learner needs • Program scope and quality • Certification recognition • Learning outcomes • Employment outcomes • Self-efficacy • Employer demand • Standardization • Credential inflation	• Labor-market conditions • Policy regime • Digital infrastructure • Funding • Pace of technological change	• Subjective learning experience • In-institution pedagogy • Informal learning outcomes

4.2. Theoretical Foundations: A Two-Level Architecture

The model's theoretical foundation works at two different analytical levels. The first level is the adult learning theories that explain the individual mechanisms within components (andragogy, transformative learning and experiential learning). The second level is systems theory, which explains the dynamics among components and the system's behavior at the whole level. Adult learning theories explain why and how learners learn. But on their own, they cannot explain the mutual determination among components or the system's self-reproducing dynamic. Systems theory takes on this second function [32,33,35]. In this framework, adult learning theories serve as the model's micro-level mechanism providers, and systems theory serves as the macro-level explainer of behavior.

The micro-credential ecosystem can be viewed through different theoretical approaches. Network analysis maps the relationship structures among stakeholders [75]. Institutional economics examines the regulatory infrastructure of the credential market [76]. Organization theory analyzes the institutional behavior of program providers [44]. Each

one sheds light on a specific dimension of the ecosystem. Yet the ecosystem has three distinctive features: reinforcing growth and balancing saturation work together; the erosion of credential value produces a delayed feedback dynamic; and the interaction among actors is bidirectional and adaptive. These features become visible through feedback loops, delay structures, and polarity analysis, rather than linear causality or static institutional analysis. For this reason, the study adopts systems thinking not to exclude alternative approaches, but as a framework that can capture these three features analytically.

The adult learning theoretical backbone draws on three traditions. Andragogy [14] defines the model's first component. Since adult learners are self-directed and problem-centered, their needs are not an abstract notion of demand but a concrete set of needs. Transformative learning theory [15] positions the second component not as mere content delivery, but as a process that transforms an individual's meaning frames. Micro-credentials do not only impart technical skills; they restructure professional identities. Experiential learning theory [49] grounds the transitions among components in a cyclical learning logic. Each completed module closes one learning cycle and starts the next. This forms the individual-level theoretical counterpart of the ecosystem-level feedback loop in P4.

A second consideration concerns the actors themselves. The four actor categories (universities, online platforms, industry, and policymakers) are not interchangeable functional slots. They enter the ecosystem with unequal power and distinct sources of legitimacy. As a result, the same feedback structure can produce different outcomes across settings. Following Suchman [77] legitimacy takes three forms. Pragmatic legitimacy rests on self-interest. Moral legitimacy rests on normative approval. Cognitive legitimacy rests on taken-for-grantedness. The actors draw on different grounds. Universities rest on academic authority and accreditation. Their recognition is durable but slow to adapt. Universities are also driven by economic incentives, since micro-credentials offer a supplementary source of income [24]; this incentive functions as an exogenous driver shaping program scope and quality rather than as a neutral input. Platforms rest on scale and infrastructure. They expand supply rapidly, yet their credentials initially lack the recognition universities command. Employers act as arbiters of labor-market value. They confer or withhold signal value through hiring. Policymakers hold regulatory authority. They set the recognition rules within which the others operate. These sources are not commensurable, and no single actor controls the others. This makes the ecosystem a site of negotiation rather than hierarchical coordination.

From this perspective, micro-credentials are not merely an educational innovation. They are an institutional negotiation arena where economic, regulatory, and social interests intersect. Wheelahan and Moodie [19] make a related point. They argue that the market-driven structure of micro-credentials shapes education along market logic. Reading the actors relationally, through institutional isomorphism [44] and signaling [52], shows how these asymmetries are contested and provisionally settled.

Institutional isomorphism refers to the process by which organizations in the same field grow more alike over time [44]. DiMaggio and Powell [44] distinguish three forms: coercive isomorphism, driven by external pressures such as regulation and accreditation; mimetic isomorphism, in which organizations imitate peers seen as successful; and normative isomorphism, arising from shared professional and disciplinary standards. In the micro-credential field, these forces make program designs converge. Accreditation requirements push providers toward common structures (coercive); providers copy programs that have gained recognition (mimetic); and shared professional and pedagogical norms shape how learning outcomes are defined (normative).

The positive polarity assigned to the link from institutional isomorphism pressure (8) to program quality (5) in R2 rests specifically on the normative mechanism.

Where accreditation agencies, professional associations, and shared qualification frameworks define the reference standard, convergence pulls programs toward a codified quality benchmark rather than merely toward one another. Where mimetic pressure dominates—that is, where providers imitate visible competitors in the absence of an authoritative standard—convergence produces homogenization without quality gain, and the polarity of this link weakens or vanishes. R2 is therefore conditional on the presence of an institutionalized normative reference point, a condition that is not uniformly met across the contexts discussed below.

This reading also helps explain why some systems take root while others do not. Micro-credentials gain recognition and value when they are embedded in national qualification frameworks and aligned with public policy. Fragmented, market-driven approaches tend to produce credentials with uncertain legitimacy [78]. Where short programs are not incorporated into national frameworks and quality assurance systems, their value is difficult to recognize [79]. A system becomes embedded when employer recognition, regulatory endorsement, and institutional accreditation reinforce one another. Where these claims diverge, the credential's signal value erodes regardless of its instructional quality.

Competition among providers shapes this process in two directions. Where providers compete on quality, competitive pressure can raise program standards through isomorphism [44] toward the strongest offerings; but where they compete on speed and volume, rapid and shallow program proliferation drives the credential oversupply that activates the B1 balancing loop, diluting the value of learning outcomes and accelerating the erosion of signal value.

4.3. Integrated Causal Loop Diagram and Theoretical Propositions

This section forms the core of the model. First, the four theoretical propositions (P1-P4) and one balancing loop (B1) are formalized in line with Whetten's [46] what/how/why framework. These propositions are then visualized in a single integrated causal loop diagram (Figure 1) using the system dynamics convention [35]. Finally, it explains how the R3-B1 coupling reveals the model's central theoretical contribution.

4.3.1. Four Propositions and the Balancing Loop

Models in the existing literature mostly present component interactions as a linear causal chain: need determines the program, the program produces the credential and the credential affects employment. The propositions developed in this study instead formalize each relationship as a feedback link with defined direction, polarity, and delay. This choice is a necessary requirement of the ecological framework on which the model rests. For Bronfenbrenner [50], relationships in systems are bidirectional, and the same logic holds for learning ecosystems [26,27]. Without the reverse direction, the concept of "ecosystem" is reduced to an empty metaphor. With the reverse direction, the model works as a genuinely interdependent and self-renewing system.

Table 4 presents the full statements of the four propositions, their systems-thinking counterparts, and their pedagogy/policy application areas.

The reverse-direction mechanism of each proposition forms the study's original contribution to the existing literature, and each draws on more than one of the model's three theoretical traditions. The reverse direction of P1 works through three mechanisms: the visibility effect [80], grounded in signaling theory; the transformative reframing of professional identity [15], grounded in adult learning theory; and supply-driven demand [67]. The reverse direction of P2 draws on two institutional-theory mechanisms: isomorphism pressure [44] and quality assurance feedback [28]. The reverse direction of P3 turns the labor market into an active force that shapes the certification system, combining signal-

ing theory [52] with the network effect [19]. P4 differs structurally from the other three propositions. It is not a dyadic relationship, but a loop formed by individual-level [50] and ecosystem-level [34,35] mechanisms that operate across the whole ecosystem; here adult learning theory supplies the individual mechanism through self-efficacy, while systems-level theory supplies the ecosystem mechanism. Each proposition thus combines more than one tradition -adult learning on the demand side, signaling in the credential's market value, and institutional theory in supply and recognition- and none is reducible to a single lens. A boundary case for P2 arises when several institutions of differing quality issue a single joint credential. These providers may not share the same instructional quality or learning-outcome standards. When this happens, the meaning and value of the shared credential become blurred. Its signal value is pulled toward the average of the issuers. Stronger providers are discounted, and weaker ones are lifted. This averaging weakens the P2 feedback between learning outcomes and recognition, because recognition can no longer be tied to a clear standard of instruction. A joint credential preserves this feedback only under quality assurance in joint program design and aligned learning outcomes across providers.

Table 4. Theoretical propositions of the conceptual model and the balancing loop.

	Proposition Statement	Systems Thinking Counterpart	Pedagogy/Policy Application
P1	Adult learners' upskilling and reskilling needs shape the content and structure of micro-credential programs. In turn, the scope and accessibility of programs enable learners to discover needs they were previously unaware of and to develop new career orientations.	Bidirectional causality between supply and demand	Curriculum analysis; supply-driven demand dynamic
P2	The quality and credibility of micro-credential programs shape the labor-market recognition of digital certification mechanisms. In turn, the recognition and portability of certification systems shape the design standards of programs.	Institutional isomorphism and quality feedback	Accreditation and recognition policy analysis
P3	The labor-market recognition of digital certification mechanisms enhances individuals' employment opportunities and career mobility. In turn, the value and demand the labor market attaches to credentials shape the development direction and standardization processes of certification systems.	Network effect and signaling	Education–employment interface analysis
P4	Positive learning outcomes and, through them, employment outcomes from micro-credentials form a systematic feedback loop. This loop raises learners' motivation to join new learning cycles and expands the capacity of ecosystem actors to develop programs.	Reinforcing feedback loop (ecosystem level)	Ecosystem growth and institutional capacity analysis
B1	As reinforcing loops raise credential supply, credential inflation occurs once a threshold is crossed. Inflation erodes the signal value of each credential, lowers employer demand, and pushes program providers to cut supply-thus breaking the reinforcing loops.	Balancing feedback loop (self-limitation)	Credential inflation and signal value policy

P1, P2, and P3 are link-level propositions. They assert the bidirectionality of single connections between pairs of components. P4 works at a different level of analysis. It asserts not a single relationship, but that the loop formed by the connections closes at the ecosystem level and feeds itself. For this reason, P4 is not a link proposition but a system-level proposition. This distinction also clarifies how the propositions map onto the loops in the diagram below. P1, P2, and P3 each correspond to a single bidirectional link, whereas the reinforcing loop labeled R1 is not the diagrammatic form of P1 alone: it is the closed four-node circuit that emerges when the forward link of P1 (need $\rightarrow$ program) is combined with the ecosystem-level return path asserted by P4 (outcomes $\rightarrow$ self-efficacy $\rightarrow$ renewed need). In other words, P1 supplies the entry link and P4 supplies the closure of the loop; R1 is their joint instantiation, not a relabeling of either proposition.

The B1 balancing loop is the structural mechanism that prevents the reinforcing loops from predicting unlimited growth [33,35]. As reinforcing loops raise credential supply, credential inflation occurs once a threshold is crossed, eroding the signal value of each credential [28,29]. The drop in signal value lowers employer demand. Program providers perceive this signal (with a delay) and adjust their supply decisions. This institutional inertia-sunk costs, prestige investments, accreditation commitments-structurally explains why B1's corrective effect is time-spread rather than instant [44]. B1 is a balancing loop, but a delayed one, and it requires intervention before the system approaches the inflation threshold.

Signal-value erosion is not driven by oversupply alone. It also depends on whether the legitimacy claims of ecosystem actors remain aligned. When employer recognition, regulatory endorsement, and institutional accreditation reinforce one another, a credential retains its signal value even as supply grows. When these claims diverge, signal value erodes faster, and B1 tightens sooner. The B1 threshold is therefore not fixed. It shifts with the degree of legitimacy alignment among actors, since legitimacy that is conferred consistently across audiences is more durable and self-reinforcing [77], whereas fragmented recognition leaves credentials vulnerable to value erosion [78,79].

4.3.2. The Integrated Diagram: Reading Four Loops in a Single System

The four propositions defined above and the B1 balancing loop are visualized as a single integrated causal loop diagram in Figure 1.

The diagram follows standard system dynamics conventions, established in the field since Forrester's *Industrial Dynamics* [32] and codified in later treatments [35]: nodes represent variables, arrows represent causal links, "+" and "-" signs indicate polarity, rectangles denote stocks, and the labels D_1 and D_2 mark the two structurally consequential delays. Delays that are implied by stock accumulation are not separately marked, in line with the convention that only delays generating oscillation or materially altering system behavior warrant explicit notation. The four feedback loops are distinguished by color coding: R1 (P1 + P4—Learner & Ecosystem Feedback Loop) in blue, R2 (Quality Assurance Loop) in green, R3 (Employer Recognition Loop) in orange, and B1 (Credential Inflation Loop) in red.

Adult learner needs (1) is treated as an exogenous input: upskilling and reskilling need arises from labor-market conditions that lie outside the model boundary. Self-efficacy, therefore, closes R1 not by generating need but by raising willingness to act on it, through renewed enrollment in micro-credential programs (4 $\rightarrow$ 2). This formulation preserves the reinforcing character of the loop while locating the origin of need where it belongs, in labor-market structure rather than in individual disposition.

The separation of learning outcomes (3a) from employment outcomes (3b) has a direct consequence for B1. Where employment outcomes are tracked, credential inflation weakens

the loop directly, since inflation erodes the signal value on which labor-market returns depend. Where only learning outcomes are tracked, that erosion remains invisible: learners continue to acquire the intended competencies and the system appears to perform, even as its labor-market function degrades. The divergence between the two outcome measures is therefore itself a diagnostic indicator of credential inflation, and a monitoring regime that reports only completion and learning gains will register saturation late.

Table 5 documents the link chain, polarities, number of negative links, and main delay points of each loop in Figure 1, in the formalism of system dynamics. The type of a feedback loop is determined by the parity of the number of negative links in the loop: an even number of negative links produces a reinforcing loop, and an odd number produces a balancing loop [35]. R1, R2, and R3 are classified as reinforcing, with zero negative links. B1 is classified as balancing, with a single negative link (credential inflation → signal value, 11 → 10).

Table 5. Loop structure, polarities, and delay points of the propositions.

Proposition/Loop	Loop Type	Link Chain and Polarities (Node No.)	Number of Negative Links	Main Delay Point
P1 + P4 (R1)	Reinforcing (R)	Micro-credential programs (2) → (+) learning outcomes (3a) → (+) employment outcomes (3b) → (+) self-efficacy (4) → (+) micro-credential programs (2)	0 (even)	No separately marked delay; accumulation delay is implied by the self-efficacy stock (4).
P2 (R2)	Reinforcing (R)	Program quality (5) → (+) credential credibility (6) → (+) standardization (7) → (+) institutional isomorphism pressure (8) → (+) program quality (5)	0 (even)	No separately marked delay; standard diffusion operates on a slower timescale than the loop's other links.
P3 (R3)	Reinforcing (R)	Signal value (10) → (+) employer demand (9) → (+) employer adoption (9a) → (+) employer recognition (9b) → (+) signal value (10)	0 (even)	No separately marked delay; adoption and recognition lags are implied by the sequence 9 → 9a → 9b.
B1	Balancing (B)	Provider supply decisions (12) → (+) program portfolio (13) → (+) credential inflation (11) → (−) signal value (10) → (+) employer demand (9) → (+) provider supply decisions (12)	1 (odd; credential inflation → signal value, 11 → 10)	D ₁ —supply decision → realised portfolio; D ₂ —credential accumulation → signal-value erosion

4.3.3. Link-by-Link Theoretical Justification

The propositions establish the model's four core relationships, but Figure 1 contains eighteen individual causal links. This section justifies each one. Table 6 gives the mechanism and source for every arrow in the diagram. Three links require further discussion and are treated after the table.

Table 6. Link-by-link theoretical justification of the causal links in Figure 1.

	Link	Loop	Polarity	Theoretical Rationale	Refs.
1	1 → 2	R1 (entry)	+	Labor-market upskilling and reskilling needs generate demand to which providers respond in program content and structure; this is the forward direction of P1.	[15,67]
2	2 → 3a	R1	+	Program participation produces the intended knowledge, skills, and competencies; the standard input–output relation of instructional provision.	[15]
3	3a → 3b	R1	+	Learning gains translate into labor-market returns only through the intermediate mechanisms of signal value and employer recognition; the transfer is real but conditional.	[17,52]
4	3b → 4	R1	+	Mastery experience and observed labor-market return raise learner self-efficacy and motivation; the individual-level mechanism supplied by adult learning theory.	[50]
5	4 → 2	R1 (closure)	+	Self-efficacy raises willingness to act on need through renewed enrollment. Need itself is exogenous; self-efficacy closes the loop by converting latent need into participation.	[50]
6	5 → 6	R2	+	Program design quality and relevance are the basis on which credentials acquire credibility with external audiences.	[28]
7	6 → 7	R2	+	Credible credentials become the reference points around which frameworks and common descriptors are formalized.	[28]
8	7 → 8	R2	+	Established standards create coercive and normative pressure on providers to conform to a common template.	[44]
9	8 → 5	R2 (closure)	+	Where the reference standard is set by accreditation bodies and professional associations, normative convergence raises programs toward a codified benchmark. Under predominantly mimetic pressure this polarity weakens (see Section 4.2).	[44]
10	10 → 9	R3,B1	+	Perceived labor-market value raises employers' articulated demand for credentialed candidates; the entry step of the network effect and the link through which B1's inflation effect propagates.	[19,52]

Table 6. Cont.

	Link	Loop	Polarity	Theoretical Rationale	Refs.
11	9 → 9a	R3	+	Where demand for credentialed candidates is present, employers begin to incorporate micro-credentials into hiring and screening practice.	[19,44]
12	9a → 9b	R3	+	Repeated adoption consolidates into codified recognition in job specifications, promotion criteria, and procurement policy.	[19,44]
13	9b → 10	R3 (closure)	+	Formal employer recognition raises the perceived signal value of the credential; the return arm of the network effect and the reverse direction of P3.	[19,52]
14	12 → 13 (D ₁)	B1	+	Provider investment and approval decisions translate into a realized program portfolio after an institutional lag arising from sunk costs and accreditation commitments.	[44]
15	13 → 11	B1	+	Cumulative program supply accumulates into credential stock; inflation is a stock, not a flow.	[29,35]
16	11 → 10 (D ₂)	B1	−	Credential proliferation dilutes the distinguishing information a credential carries, eroding signal value. This is the single negative link in the diagram and the source of the system's self-limitation.	[28,29,52]
17	9 → 12	B1 (closure)	+	Providers read employer demand as a market signal and adjust supply decisions accordingly.	[44,67]
18	7 → 10	Cross-loop	+	Standardization raises the interpretability of a credential to external audiences, coupling R2's output into the signal-value node shared by R3 and B1.	[28,52]

Note. Polarity indicates the direction of a link: variables move in the same direction across a positive (+) link and in opposite directions across a negative (−) link. Loops whose polarity product is positive are reinforcing (R); those with a negative product are balancing (B). B1 is balancing by virtue of its single negative link, 11 → 10 in Figure 1, whereby cumulative supply erodes signal value (see Section 4.2).

Three links carry theoretical weight. The closure of R1 (4 → 2) locates the loop's return path in willingness to act rather than in need formation, since upskilling need originates in labor-market structure that lies outside the model boundary. The isomorphism–quality link in R2 (8 → 5) is conditional on a normative reference point and does not hold uniformly where mimetic imitation dominates. The inflation–signal link in B1 (11 → 10) is the only negative-polarity link in the diagram and, together with the D₂ delay, gives the system its capacity for overshoot.

4.3.4. The Central Theoretical Contribution: The R3–B1 Coupling

The reinforcing loop R3 and the balancing loop B1 are not independent. They are coupled at two nodes: signal value (10) and employer demand (9), marked as shared nodes in Figure 1. R3 is not a direct two-node loop: the return path from employer demand back to signal value operates through two intermediate steps that are themselves observable ecosystem behaviors. High signal value first raises aggregate employer demand

for credentialed candidates (9); demand in turn leads employers to adopt micro-credentials in hiring and screening practice (9a); and adoption then consolidates into formal recognition in job specifications, promotion criteria, and procurement policies (9b), which feeds back into signal value. Specifying these intermediate nodes makes the network-effect mechanism explicit rather than assumed: the loop gains strength only where adoption translates into codified recognition, which is precisely what distinguishes ecosystems with mature employer engagement from those where employer interest remains informal.

R3 is internally self-reinforcing, but a cross-loop link connects it to the wider system. As standardization (7) increases, signal value (10) rises (Figure 1, green dashed arrow). This link matters because it carries the output of the R2 Quality Assurance Loop—standardization—into the signal value node shared by R3 and B1. Three loops (R2, R3, and B1) thus converge on a single variable. This point of convergence forms the structural basis for the R3–B1 tension discussed below.

The critical tension arises at the signal value node. Here, two forces meet. One is the positive pathway that feeds R3 (the positive link from standardization). The other is the negative contribution of B1 (credential inflation → signal value, the single negative-polarity link in the diagram). This polarity conflict is the structural source of the system's capacity for saturation and self-correction. Once credential supply passes a certain threshold, the negative effect of B1 dominates through the shared signal value → employer demand link. It slows R3's network-effect loop. The system's long-run trajectory is then set by the relative strength of the two loops.

This coupling structure also adds pedagogical value to the model. In systems-thinking pedagogy, few frameworks show the reinforcing–balancing tension in a concrete public-policy case and justify it on the grounds of polarity. The R3–B1 coupling fills this gap with a concrete case from higher education policy. The polarity-parity analysis in Table 5 can be read through a real policy case. This lets systems thinking be taught not as an abstract set of cognitive competencies [41], but as the capacity to analyze the structural dynamics of the higher education system in which students are embedded.

All loops involve delayed relationships, and delays are the main source of oscillation in system dynamics [35]. Delays do not by themselves imply that a system cannot reach equilibrium: a dynamic model with delays may still converge. What delays do is shape the path to equilibrium and, in balancing loops, create the potential for overshoot and oscillation. The two retained delays, D_1 and D_2 , are structurally consequential in precisely this sense: D_1 separates provider supply decisions from realized program supply, and D_2 separates credential accumulation from the erosion of perceived signal value. Together they allow supply to overshoot the level the labor market can absorb before the corrective feedback registers. This sensitivity reveals that the model contains leverage points open to intervention.

The R3–B1 coupling instantiates the Overshoot and Collapse archetype [34,35,81] rather than Limits to Growth. The distinction is consequential. In Limits to Growth, a reinforcing loop encounters an exogenous ceiling and growth stabilizes at that ceiling. In Overshoot and Collapse, the growth process itself depletes the resource on which its own continuation depends, and the system passes beyond the sustainable level before corrective feedback registers. The micro-credential ecosystem exhibits the latter structure: credential proliferation does not meet an external constraint but consumes signal value, the very resource that makes credentials worth issuing. The D_2 delay between credential accumulation and perceived signal-value erosion is what permits overshoot; without it the system would adjust smoothly. This mechanism of growth, undermined by signal-value erosion, is not specific to credentialing. It can also apply to other systems whose value depends on the signal they carry, such as degrees, professional titles, and certificate markets.

The model's contribution to the systems literature becomes clear here. The study does not propose a new archetype. It instantiates a transferable sub-form of a known archetype—one specific to social signaling systems—in the context of higher education policy.

4.4. Moderator Variables and Sustainability Mapping

4.4.1. The Three-Level Moderator Architecture

The relationships among components in Figure 1 do not have a universal, fixed strength. Their direction and strength vary with individual, institutional, and contextual conditions. The model's practical applicability requires these conditions to be defined systematically through moderator variables [46]. In Section 4.1, contextual conditions were defined as exogenous drivers entering the system boundary. In this section, the same variables are treated as moderator variables that condition the endogenous loop structure from the outside. In system-theoretic language, these variables are exogenous parameters that feed the endogenous structure [35]. In the language of empirical testing, they are operationalized through interaction terms in regression models [82]. The two frames do not conflict. The system boundary concept expresses the model's theoretical architecture, and the moderator concept expresses the model's empirical-testing logic [83].

Moderator variables are addressed at three levels: individual, institutional, and contextual. This framework draws on Bronfenbrenner's ecological systems theory [50] and is structurally consistent with the model's multi-actor ecosystem nature. Contextual-level moderators can be analyzed on a deeper theoretical basis through Bourdieu's theory [45] of forms of capital. Digital infrastructure and credential recognition policies work as structural conditions. They determine whether different social groups can benefit equally from micro-credential systems [58]. This theoretical depth makes visible the model's link to the goal of reducing inequalities defined under SDG 10. Table 7 summarizes the moderator variables at each of the three levels together with their theoretical basis.

Table 7. Moderator variables in the conceptual model.

Level	Moderator Variable	Theoretical Basis
Individual	Self-regulation skill, digital literacy, prior learning experience, motivation type (intrinsic/extrinsic)	[14,16,50]
Institutional	Program quality assurance, the teaching staff's technology competence, capacity for inter-institutional collaboration	[18,50,84]
Contextual	National qualification frameworks, credential recognition policies, labor-market structure, digital infrastructure	[20,50,57]

The effect of moderator variables on the propositions differs by level. Individual-level variables shape the P1 relationship. When a self-directed learner with high digital literacy encounters micro-credential programs, this creates a more favorable basis for new needs to emerge [14,16]. Institutional-level variables mainly affect the P2 relationship. In institutions with strong program quality assurance, the mutual interaction with certification systems works more functionally [18,84]. Contextual-level variables shape the P3-P4 relationships

decisively. In a policy environment aligned with national qualification frameworks, the labor-market recognition of digital credentials increases, and the feedback loop works more effectively [20,57].

4.4.2. SDG Mapping: A Structural Architecture

The model treats the Sustainable Development Goals (SDGs) not as surface-level policy discourse, but as an architecture systematically mapped onto structural components. SDG 4, SDG 8, and SDG 10 are linked to three different components of the model through separate mechanisms. This mapping derives from the system-theoretic design.

- SDG 4 and the model's endogenous core. The goal of inclusive and quality lifelong learning (SDG 4) becomes functional through the bidirectional relationships among the model's four core components. Micro-credential programs that meet learner needs (P1), meet quality certification standards (P2), and lead to employment outcomes (P3) form a cyclical counterpart to SDG 4 [10]. This articulation does not occur at the level of policy discourse. It occurs through structural features such as program accessibility, modular structure, and recognition of skills gained across different learning settings.
- SDG 8 and the R1–B1 tension. The goal of decent work and sustainable employment (SDG 8) works through the dynamic tension between the model's reinforcing R1 loop and balancing B1 loop. The R1 loop grows the employment return of micro-credentials through successful learning outcomes and supports the sustainable employment goal. The B1 loop, in turn, erodes this return through credential inflation and threatens the same goal. The “sustainable” dimension of SDG 8 depends on policy design that secures R1 against collapse by B1—a certification regime that preserves signal value and is quality-assured and standardized.
- SDG 10 and the moderator layer. The goal of reducing inequalities (SDG 10) becomes directly visible in the model's moderator variable layer—especially in individual-level cultural capital [45] and in the distribution of digital infrastructure and recognition policies at the contextual level. The same micro-credential program produces different outcomes under different individual and social conditions. This makes it necessary to embed the distributional sensitivity that SDG 10 requires structurally into the model [56,58]. In this respect, moderator variables are not only a methodological tool for contextualization. They are the main channel through which the SDG 10 goal is embedded in the model at the theoretical level.

4.5. Operationalization and Testability

For Whetten [46], the contribution of a theoretical model is assessed not only by its internal consistency, but also by its capacity to produce testable propositions for future empirical research. This section offers an operationalization framework (Table 8) that links propositions P1–P4 and the B1 balancing loop to observable indicators, possible data sources, and suitable research methods. It also provides a stock-flow mapping (Table 9) for testing P4 using system dynamics simulation. Joint credentials issued by institutions of differing quality provide a further test of P2. The more instructional quality varies across co-issuers, the weaker the joint credential's signal value and its P2 feedback should be. This can be operationalized by measuring the extent to which learning-outcome standards diverge across co-issuing institutions.

An important epistemic point: since this study is a conceptual model proposal, the empirical data points cited throughout the text should be interpreted not as evidence confirming the loop mechanisms the model predicts, but rather as descriptive patterns consistent with those mechanisms. The causal support of a loop hypothesis requires longitudinal research designs in which concurrent exogenous drivers are controlled, delay

structures are modelled, and the loop holds under counterfactual conditions as well [35]. The operational framework in Table 8 and the stock-flow conceptualization in Table 9 form the roadmap for this empirical agenda.

Table 8. Operationalization of the propositions: variable, indicator, data source, and method.

Proposition/Loop	Key Variable	Observable Indicator/Proxy	Possible Data Source	Suitable Method
P1 (R1)	Learner need; program scope	Change in program enrollment demand; rate of new program launches; need-program fit index	Platform enrollment statistics; national skills/labor surveys	Longitudinal panel data analysis; learner survey
P2 (R2)	Program quality; credential credibility	Quality assurance compliance score; EQF/ECTS alignment rate; employer trust index	Institutional quality assurance reports; accreditation records; employer surveys	Case study; comparative cross-institutional analysis
P3 (R3)	Credential recognition; employer demand	Frequency of credential demand in job postings; rate of integration into hiring criteria	Job posting text mining; employer panel survey	Text mining; signalling model regression
P4 (R1 feedback)	Self-efficacy; re-enrollment; portfolio growth	Re-enrollment rate; growth of the ecosystem program portfolio; self-efficacy scale score	Longitudinal platform data; self-efficacy scales; institutional program inventory	System dynamics simulation; time series analysis
B1 (balancing)	Credential inflation; signal value	Number of credentials per person; decline in the employment return of a single credential	Labor-market micro-data; wage-credential regression	Threshold analysis; system dynamics scenario simulation

Table 9. Stock-flow-feedback mapping for the P4 simulation.

System Dynamics Element	Counterpart in the Model	Theoretical Basis
Stock	Cumulative number of credential holders; total program portfolio; cumulative self-efficacy level	[51,85]
Flow	Rate of new enrollments; rate of program development; rate of credential value erosion	[66,86]
Reinforcing feedback (R1)	Self-efficacy stock → increase in new enrollment flow	[34,35]
Balancing feedback (B1)	Cumulative credential stock → acceleration of the value erosion flow	[28,29]
Delay	Recognition, isomorphism, and inflation delays (D_1 , D_2 ; Figure 1)	[35]

Table 8 shows which indicators and methods suit each proposition. But to test a feedback claim, we also need to make its causal chain visible. Each proposition moves through three steps: a starting condition, a theoretical mechanism, and an outcome we can observe. From the standpoint of P1, when a shift occurs in learners' skill requirements, the mechanisms of visibility and identity reframing are expected to become operative, manifesting as an increase in enrollment in domains learners had not previously targeted. P2 reflects the same underlying logic: the tightening of recognition requirements generates isomorphic pressure, which in turn manifests as the convergence of programs around shared design standards. In P3, the growth of employer recognition operates through the mechanism of signaling and becomes concrete through the increasing visibility of credentials in job postings. In P4, positive outcomes reinforce both self-efficacy and provider capacity, a dynamic discernible in re-enrollment rates and in the expansion of the program portfolio. In B1, oversupply erodes signal value, and this erosion surfaces, once a given threshold is crossed, as a decline in the employment return per credential.

This pattern exhibits consistency across all propositions: whereas the initial condition and the outcome are directly observable, the mechanism situated between them corresponds to a loop dynamic that can be confirmed only through longitudinal and simulation-based research designs. These causal chains align with the division of labor among the three research traditions set out in Section 4.3.1.

Among the propositions, P4 places the heaviest demand on this kind of design. It defines not a dyadic relationship, but a feedback loop that operates across the whole ecosystem. In system dynamics, feedback loops are properly tested through simulation [35] rather than static statistical methods, because cyclical causality, delays, and cumulative effects only become visible in a time-based model. Table 9 presents how P4 can be operationalized in a stock-flow framework. The R1 reinforcing loop is modelled as positive feedback, in which the self-efficacy stock raises the inflow of new enrollments. The B1 balancing loop is modelled as negative feedback, in which a rising cumulative credential stock speeds up the credential value erosion flow.

At least two scenario analyzes can be run on this stock-flow framework. The first scenario compares high policy recognition (a strong national qualification framework) with low recognition conditions. It tests how sensitive the R1 loop's growth rate is to this exogenous parameter. The second scenario varies the rate at which credential supply rises. It simulates when the system reaches the credential inflation threshold and when B1 starts to brake R1. The model's central claim—a system that renews itself but does not grow without limit—can only be confirmed through such a simulation, one that compares the relative strength of the reinforcing and balancing loops over time. P4 is thus positioned as a hypothesis that is not only conceptual but also stimutable for future empirical research.

The model also opens a qualitative research path that complements the quantitative simulation. The R1 loop rests on two individual-level mechanisms: transformative learning [15] and self-efficacy [51]. But the causal loop diagram does not show how these processes work in individual learners. It only summarizes them as an aggregate pattern. Qualitative studies can make this missing micro level visible. The return path that closes (R1-outcomes → self-efficacy → renewed need) is, at the individual level, a process in which learners redefine their professional identity after completing a credential. Several methods can trace this process. These include interpretative phenomenological analysis, longitudinal narrative interviews, and meaning-frame mapping across repeated interviews. Such methods can show how a completed learning cycle reshapes a learner's perspective. They can also show how this generates the new need that feeds the next cycle. In this way, qualitative and quantitative approaches are not alternatives. They are two complementary ways of testing the same structure. The qualitative designs reveal the micro-mechanisms

behind the loop. The simulation models the aggregate behavior these mechanisms produce. This keeps the subjective learner experience outside the model's endogenous boundary (see Table 3). At the same time, it explains how that experience can be studied as the micro-foundation of the ecosystem-level loop.

5. Discussion

The conceptual model developed in this study explains the role of micro-credentials within lifelong learning ecosystems from a systems thinking perspective. The model's core propositions (P1–P4) and the balancing loop (B1) position micro-credentials not as isolated certification tools, but as structural components that operate through bidirectional relationships and feedback loops among ecosystem actors.

The four propositions both overlap with and extend the existing literature. For P1, the literature suggests that micro-credentials can reshape individuals' career expectations. But the reverse direction that forms the proposition's original contribution—programs generating needs that were not previously recognized—has not yet been subjected to direct empirical testing. The current evidence is consistent with this mechanism but does not confirm it [86,87]. For P2, descriptive findings indicate that employers' expectations regarding verification and standardization shape program design [88]. European Union policy frameworks also acknowledge the effect of credential recognition on program standards [12]. These patterns are consistent with the quality feedback mechanism that P2 predicts. But on their own, they do not confirm the claim of bidirectional causality. For P3, it is suggested that rising employer demand can bring standardization pressures. But the OECD [12] also acknowledges that the evidence on labor-market effects remains limited. This relationship is therefore an expectation consistent with P3, but it requires empirical confirmation of the network effect and signalling mechanism. For P4, the doubling of enrollment on Coursera between 2020 and 2024, reaching 168 million [85] and the rise in the number of institutions offering alternative credentials [66] are consistent with the growth trajectory the proposed reinforcing feedback loop predicts. But this growth alone does not confirm that the loop works. The same trend can also be explained by non-loop exogenous drivers such as the pandemic-driven shift to online learning, platform marketing investments, and access pricing (see Table 3). Among these drivers, the intensity of competition among providers—and whether it is oriented toward quality or toward volume—warrants explicit operationalization as a variable in future work, since it is expected to condition both program quality and the rate at which signal value erodes. As stressed earlier, the causal support of the loop mechanism requires longitudinal and simulation-based designs in which these exogenous drivers are controlled. The way infrastructure gaps in low-income countries limit both access and demand [89] recall the importance of the contextual moderator variables that govern how P4 works.

The B1 loop also has an institutional side. Credential inflation is not only about how many micro-credentials exist. It also depends on whether the key actors in the learning ecosystem—employers, regulators, and accrediting bodies—accept a micro-credential as meaningful. When these actors recognize a system together, learners' credentials carry real weight in further study and in the labor market, and the system takes root. When this shared recognition is missing, the same credentials lose their signal value even when the learning behind them is sound. This is part of why some micro-credential systems become a lasting part of educational pathways while others stay on the margins. It also shows that universities, platforms, employers, and policymakers are not fixed roles. Their willingness to recognize micro-credentials changes over time, and that shifting recognition shapes how the system develops.

The model positions micro-credentials by linking them to adult learning theories. This forms a theoretical backbone consistent with andragogy, transformative learning, and experiential learning theories [14,15,49]. At the same time, in the context of the skills gap triggered by digital transformation, automation, and artificial intelligence [2,3], the flexible and modular structure of micro-credentials that can respond to upskilling and reskilling processes [21] stands out as a tool for alignment between the labor market and the learning ecosystem.

These findings also make visible the model's link to the Sustainable Development Agenda. Micro-credentials contribute directly to the inclusive and lifelong learning opportunities under SDG 4 and to the upskilling/reskilling agenda of SDG 8 [10,12]. Sen's capability approach [53] enables this contribution to be read not only as skills transfer but also as a process of emancipation that expands individuals' capabilities to lead the lives they value. This perspective shows that the model's feedback loop carries a social and ethical sustainability dimension [56]. The dynamic structure the model proposes overlaps with adaptivity and self-regulation—the core features of sustainable learning ecosystems. Sustaining these two capacities is becoming increasingly decisive under labor-market conditions transformed by the digital and green transitions [13].

Still, the spread of micro-credentials brings important debates with it. Some researchers argue that micro-credentials can lead to the fragmentation of the higher education system and to credential inflation [23,28]. Wheelahan and Moodie [28] deepen concerns that micro-credentials, functioning as “gig credentials for the gig economy,” can accelerate the marketization of education and shift employer training costs onto individuals. The tendency of digital learning environments to reinforce inequalities cannot be ignored either [58]. Bourdieu's theory [45] of forms of capital offers a structural explanation for this dynamic of inequality. The capacity to benefit from programs is determined by individuals' cultural capital and digital habitus. Even when technical access is equal, outcomes can still be distributed unequally. These criticisms once again show the importance of the model's contextual moderator variables. They stress the critical role of quality assurance mechanisms and international recognition frameworks [20].

5.1. International Transferability: The Model in Low-Infrastructure and Emerging-Recognition Contexts

The evidence behind this model comes largely from Europe, North America, and global platforms. This raises a question of transferability. How does the model behave where digital infrastructure is limited, qualification frameworks are still forming, and recognition regimes are at an early stage? The model does not claim universal validity. Its three-level moderator architecture (Section 4.4.1) is what lets it accommodate such variation. Global South contexts are not exceptions to the model. They are cases where the contextual moderators—qualification frameworks, recognition policies, digital infrastructure—sit at the low end of their range. As these moderators weaken, so do the P3 and P4 relationships, which depend on labor-market recognition.

Three regions illustrate this. In much of Africa, mobile penetration is high but stable connectivity is scarce, so access and demand are constrained together [88]. The response has been to build recognition architecture deliberately rather than leave it to the market: the African Continental Qualifications Framework and its Micro-Credentials Handbook, the Addis Convention, and national pilots that make short, community-based learning stackable toward formal qualifications [90]. In several Asian systems, governments have expanded provision, but short programs often remain outside national frameworks and quality assurance, so their labor-market value is hard to establish [79]. This is the stalling pattern the model predicts: supply grows while the recognition pathway stays weak, and the system does not take root. Latin America shows a third variant. Equity gaps

have made micro-credentials attractive, yet credentials developed in isolation lose value across borders—hence the regional move toward a common framework for portability and trust [91].

These cases reinforce the model rather than weaken it. The embedding mechanism from Sections 4.2 and 4.3.1—a credential takes root only when employer recognition, regulatory endorsement, and accreditation align—is not specific to Europe. Its absence is simply most visible where recognition infrastructure is still being built. The uneven geography of the evidence itself, concentrated in Europe, Australia, and North America [78], is a further reason to state transferability conditionally rather than assume it. This also gives SDG 10 concrete form: where moderators are unequally distributed across regions, the same program yields unequal returns. The model is therefore transferable, but conditionally. In low-infrastructure, emerging-recognition settings, it expects weaker reinforcing dynamics and a greater reliance on coordinated recognition policy.

These regional patterns take concrete form at the national level. In 2026, Türkiye’s Council of Higher Education issued a national framework [92]. It allows learning gained outside the formal curriculum to be converted into ECTS and recorded on transcripts and diploma supplements. Recognition decisions are made at the institutional level. This institutional discretion works as the gateway through which a credential is embedded in the academic system, but it is also open to inconsistency across institutions. The framework caps the contribution of micro-credentials at 10% of the total ECTS. This cap serves as a policy lever to offset credential inflation. Alignment with the European Education Area and the Turkish Qualifications Framework links these credentials to a national and supranational architecture. Access to the prioritized fields is unevenly distributed, so gains may be distributed unevenly as well. As the framework is not yet in force, it should be read as a design intention rather than as evidence of system behavior.

The degree of coordination among sites is itself a contextual moderator. Even where a nominal recognition framework exists—such as the Bologna Process [70] or the European approach to micro-credentials [13]—actual coordination among institutions may be absent, and a region may lack effective alignment across its sites. Where such coordination is weak, credential recognition and the transfer of learning outcomes across institutions are correspondingly weakened, even under a shared framework.

5.2. A System Intervention Perspective: Leverage Points and Sustainable Development

The policy debates discussed above—quality assurance, credential recognition, and inequality—can be reframed from a systems thinking perspective as an intervention hierarchy. Meadows [33,93] showed that the points at which a system can be intervened do not have equal impact. The hierarchy was first set out in Meadows’ Leverage Points report [93], which ranks twelve places to intervene in a system from shallow parameter adjustments to shifts in goals and paradigms; the five levels discussed below correspond to that ordering. Some interventions only adjust parameters (low leverage). Others change the system’s rules, information flows, and goals (high leverage). This framework allows policy proposals for the micro-credential ecosystem to be assessed not only through the question of “what should be done,” but through the question of “which intervention transforms the system’s behavior, and to what extent”. Building on this framework, five leverage levels for the micro-credential ecosystem are discussed below: parameters, delays, the strength of balancing loops, the system’s rules, and the system’s goal. Table 10 summarizes these interventions together with the loops they affect and their SDG connections.

Low-leverage interventions adjust system parameters without changing structural behavior. Funding or enrollment incentives for micro-credential programs accelerate the R1 loop, but they do not prevent the system from reaching the inflation threshold.

Table 10. Policy interventions by Meadows leverage level, the loops they affect, and SDG connection.

Policy Intervention	Leverage Level (Meadows)	Affected Loop and Mechanism	Related SDGs
Program funding/enrollment incentives	Low (parameter)	Raises R1 speed; does not change structural behavior	SDG 4 (access)
Delay management: real-time demand data sharing between employers and program providers, and fast accreditation processes	Low-medium (delays)	Shortens the recognition delays in R2 and R3; raises the system's speed of adaptation	SDG 8 (employment alignment)
Credential-inflation control mechanism: transparent quality assurance and recognition information infrastructure	Medium (information flow/feedback)	Makes B1 work early and correctively; prevents inflation	SDG 8 (sustainable employment)
Redesign of the national qualification framework to cover micro-credentials	High (rules/goal)	Redefines the boundary conditions of all loops; changes the direction of isomorphism pressure	SDG 4 + SDG 10 (inclusiveness, reducing inequality)
Shift of the system's goal from mere employability to inclusive capability expansion	Highest (system's goal)	Transforms the system's long-term trajectory and the orientation of all loops	SDG 4 + SDG 10 (structural equality)

Interventions aimed at delaying transform the system's speed of adaptation. Real-time demand data sharing between employers and program providers, and fast accreditation processes, shorten the delay in policy pressure penetrating program design in R2 and the delay in employer trust forming in R3. Delays are a principal source of oscillation in system dynamics, a point established since Forrester's foundational treatment [32] and elaborated in later work [35]. Shortening delays therefore speeds up the system's adaptation to new skill demands and reduces the risk of delay-driven fluctuation.

Strengthening balancing loops deepens the system's information flows and feedback structure. A quality assurance infrastructure that allows credential recognition information to circulate transparently between employers and program providers makes it possible for the B1 balancing loop to work early and correctively and for credential inflation to be prevented. This intervention turns the credential-inflation control mechanism—one of the model's original contributions—directly into a policy tool.

Redesigning the system's rules transforms the boundary conditions of all loops. A policy regime that rebuilds national qualification frameworks to cover micro-credentials changes the direction of institutional isomorphism pressure and resolves the quality–form tension in P2 at a structural level.

The highest leverage point is redefining the system's goal. Shifting the goal of the micro-credential ecosystem from mere employability to inclusive capability expansion [53] creates a paradigm shift that realigns rules, information flows, and parameters. For Meadows [33,93], the system's goal is the high-level leverage that conditions all lower-level leverage points, including the rules. This level is also where the structural equality goal under SDG 10 is embedded most deeply in the model.

As Table 10 indicates, this five-level leverage perspective shows that a sustainable micro-credential ecosystem can be built not only through more programs or funding, but

through high-leverage interventions: shortening delays, strengthening balancing loops, redesigning rules, and transforming the system’s goal.

6. Implications for Systems Thinking Teaching, Learning, and Curriculum Development in Higher Education

Meadows’s [33,93] leverage framework offers a tool that can be used directly not only for policy design, but also for the pedagogy of higher education policy. Up to this point, the model has been developed as a descriptive framework that explains the micro-credential ecosystem. The same structural logic can also be turned into a program design guide for higher education institutions. The model’s reinforcing (R1) and balancing (B1) loops, along with its system boundary logic, can serve as a concrete thinking tool in curriculum and micro-credential design. When a program is designed, not only its content and outcomes, but also how it will affect the feedback relationships among learner need, employment outcome, and credential recognition, becomes part of the design. The model thus offers a systemic design perspective. It moves institutions beyond the question of “which course to open” toward the question of “which loop of the ecosystem will this program feed, and how.”

This perspective positions systems thinking both as a design method and as a competency to be taught to students. When universities design micro-credential programs, they can embed tools such as causal loop thinking, feedback awareness, and system boundary setting at two levels: the programs themselves are designed with these tools, and these tools are taught to students as a cross-disciplinary competency. Senge’s [34] learning organization approach shows that institutions that both produce and transmit systems thinking create more adaptive learning environments.

This pedagogical integration also works as a concrete sustainability strategy. The goal of inclusive, high-quality lifelong learning under SDG 4 can be advanced not only by expanding program offerings but also by systematically designing programs. Using systemic design principles, universities can build a sustainable micro-credential portfolio that prevents credential inflation, is aligned with employment outcomes and is responsive to learner needs.

These principles are an adaptation, to the higher education policy context, of the systems thinking frameworks examined in Section 3.6 (Arnold and Wade’s [73] competency definition, the DSRP framework’s [41] four cognitive competencies and Sweeney and Sterman’s [42] feedback and stock-flow approach). Table 11 summarizes how these principles are reflected in program design and student competency.

Table 11. The reflection of systems thinking principles in program design and student competency.

Systems Thinking Principle	Reflection in Program Design	Competency Gained by the Student
Causal loop thinking [41,73]	Anticipating in the design how the program feeds the learner need–employment–recognition loop	Analyzing nonlinear cause-and-effect relationships
Feedback awareness [42]	Embedding reinforcing and balancing dynamics (R1/B1) into the curriculum update cycle	Anticipating system behavior over time
System boundary setting [41,73]	Defining clearly which actors and variables the program covers and which it treats as external	Determining the problem scope and stakeholder map

Building on this perspective, the model can be translated into a step-by-step guide that curriculum designers can follow when developing a micro-credential program. Each step

pairs an established curriculum design task with the structural element of the model that informs it, so the guide is a direct application of the framework rather than an external addition.

Step 1: Needs and stakeholder analysis. The design process should begin with a needs assessment that identifies learner needs alongside the universities, platforms, employers, and policymakers whose recognition the program will depend on (model: actor mapping and system boundary, Section 4.2). This step defines both the learner needs the program is intended to serve and the actors whose endorsement confers value on the credential.

Step 2: Alignment of learning outcomes, assessment and recognition. Following the logic of constructive alignment [94], learning outcomes should be defined at the level of curriculum and instruction, and assessment should be designed to provide evidence of their attainment. Intended employment outcomes should then be treated as a distinct result, and a recognition pathway should be designed to connect the two, since a learning outcome does not in itself guarantee an employment outcome (model: distinction between learning and employment outcomes, Section 4.1; P2, P3).

Step 3: Incorporation of quality assurance and framework alignment. The program should be aligned with institutional as well as national or regional quality assurance and qualification frameworks [13,70]. This constitutes the curriculum-level condition under which employer recognition, regulatory endorsement, and accreditation reinforce one another, so that the credential becomes recognized rather than marginal (model: embedding mechanism, Section 4.2).

Step 4: Evaluation of the program's distinct educational value. As a curriculum-level decision, it should be established whether the program adds distinct value or merely duplicates existing offerings. Designing for depth and a clear learning-outcome profile, rather than for rapid proliferation, mitigates the credential inflation that would otherwise erode the credential's value (model: balancing loop B1, Section 4.3).

Step 5: Planning for context and stackability. The contextual and implementation conditions that shape how the program will function—institutional capacity, teaching-staff readiness, digital infrastructure, and recognition policy [69]—should be taken into account, and the credential should be designed to be stackable within larger learning pathways [13] (model: moderator architecture, Section 4.4).

These steps are offered as design principles derived from the model rather than as a validated procedure. Because the model is conceptual and has not yet been tested empirically, the guide should be read as a structured way of reasoning through program design, to be refined as the model is tested in future work.

The model's pedagogical use can be read at three levels. At the first level, the model offers the classic tools of systems thinking pedagogy—stakeholder map, polarity-defined causal loop diagram, and leverage point analysis—a concrete case from the higher education policy field. At the second level, the model forms one of the few pedagogical cases that discuss the reinforcing and balancing loop tension (R1–B1) through a concrete policy example and explain this tension on the grounds of polarity (see Section 3.6). At the third level, the model positions systems thinking for students not as a set of cognitive competencies [41], but as the ability to analyze the structural dynamics of the higher education system in which they are part. These three levels make the model's position in systems thinking pedagogy concrete. They offer a theoretical basis for turning it into practice through program development processes in future research.

6.1. Teaching Practice: Making Threshold Concepts Visible

Systems thinking attributes are not acquired evenly. Undergraduates articulate interconnectedness and mapping readily but engage far less with feedback and system

boundaries, and five attributes—feedback, system boundary, emergent behavior, synthesis, and non-linear causality—function as threshold concepts, requiring conceptual transformation rather than incremental accumulation [74]. The broader case for treating a systems view as itself a threshold in education for sustainability was made earlier, with the caveat that what counts as a threshold is agent-relative [95].

That difficulty has a specific source: learners import the everyday senses of systems terms—feedback as evaluative comment, hierarchy as rank—in place of their systemic senses [96]. The obstacle is an occupied concept rather than an empty one and being linguistic rather than developmental it does not dissolve with maturity. This bears directly on the present setting, where feedback already carries a settled institutional meaning tied to assessment and quality assurance.

Boundary judgment likewise carries a technical sense: a boundary is not a fact the analyst discovers but a judgment to be defended, raised to be reviewed rather than settled [97]. Three features of the model address these difficulties. The coupling of R3 and B1 at a shared node renders feedback observable, since students can trace how one variable is driven upward by one loop and downward by another. Treating adult learner needs as exogenous surfaces a boundary judgment for questioning: what would change were need endogenized, and how would the choice be defended? The separation of learning from employment outcomes supplies a case in which a system appears to perform while its function degrades—an entry to system-as-cause thinking, in which behavior is generated by structure rather than imposed externally [98].

6.2. Curriculum Development Beyond a Single Course

Systems thinking is developmental, and the epistemic development it requires is not achieved through short didactic sessions spread across a single semester [95]. Its acquisition follows an ordered progression—components and processes, then relationships among them including dynamic ones, then cyclic reasoning and generalization, and only then inference of what the representation does not show—in which later stages are not reached before earlier ones are secured [99].

Sequencing matters for a second reason. Competent systems thinking requires several modes of reasoning to operate at once, and demanding their simultaneous coordination produces cognitive overload, so progression should develop one skill at a time [98]. Where a characteristic proves resistant, a dedicated lesson is more effective than repeated exposure alongside the others [96].

The model can therefore be opened up in stages: its variables and links in early study; the R3–B1 coupling and, separately, the exogenous treatment of need in intermediate study; and the structure–behavior distinction and, where disciplinary context permits, quantitative modeling in advanced study.

Positioning the competency at the program rather than module level has precedent: systems thinking is one of five key competencies to be developed across a degree, with required depth differing by level of study, though how it should be evaluated is left unspecified [100]. That gap is where constructive alignment becomes consequential [94], since an intended outcome that generates no assessment evidence tends to remain rhetorical. The same gap is noted in science education, where systems approaches are widely endorsed in curriculum frameworks without accompanying guidance on how to teach or assess them [101].

6.3. Academic Staff Development

The binding constraint on integration is often the readiness of teaching staff rather than the willingness of students, since pedagogical content knowledge for teaching systems

thinking is a distinct and trainable form of knowledge, not reducible to understanding the systems themselves [102]. Group model building offers a vehicle: a group drawn from a program's curriculum committee and its teaching staff produces a shared causal loop diagram of a contested institutional problem, together with a record of which concept each participant stalled on. That record is the substance of the development, since recognizing one's own impasse precedes diagnosing a student's—and institutions that practice systems thinking as well as teach it adapt more readily [34]. Two supports are decisive: a shared repository of worked diagrams, and recognition of systemic curriculum work within workload and promotion criteria.

6.4. Student Learning Experiences and Assessment

Causal loop diagrams produced by students are assessable artifacts, exposing reasoning that prose conceals: whether a loop closes, whether polarities are consistent, and whether a boundary has been argued or assumed. Because several structurally different yet defensible diagrams of the same system may exist, inter-rater reliability is fragile; scoring should therefore rest on separately inspectable structural criteria and on a short written rationale for the boundary chosen.

Where a validated instrument is preferred, a published scenario-based tool with a scoring rubric captures integrated performance on an unfamiliar scenario [101], whereas an attributes-based rubric serves the different purpose of showing which attributes a cohort has secured.

Transfer warrants attention: when undergraduates taught systems thinking in one domain were asked to model an unfamiliar one, competence varied widely across the cohort [103]. Tasks requiring students to model a structurally analogous second system therefore test something distinct from recall of the taught case.

Modeling the credentialing system in which students are themselves participants positions systems thinking as institutional agency rather than analytical technique [98]. That proximity carries risks—motivated reasoning, and academics grading criticism of arrangements to which they are party—mitigated, though not removed, by scoring criteria independent of the conclusion reached and stated openly.

6.5. Practical Implications for Institutions, Academic Leaders, and Educators

For institutions. Locate systems thinking in program-level outcomes rather than isolated modules, and assess it with instruments designed for the purpose [100,101]. Monitor learning and employment outcomes separately, since the model predicts divergence once B1 becomes dominant; because the same pattern may arise from labor-market shocks or changes in intake, divergence is an alert rather than a diagnosis [104].

For academic leaders. Apply the leverage hierarchy [93]: adding courses adjusts a parameter, altering how curriculum committees are constituted changes a rule, and redefining a program's purpose changes a goal. A single elective is a parameter-level intervention and leaves the surrounding rules untouched.

For educators. Teach feedback and boundary judgment explicitly and separately [96,98]. Where program structure cannot be changed, a minimum viable adaptation comprises a session displacing the institutional meaning of feedback, a second on boundary judgment, and an assessment task requiring a structurally analogous second system. Treat diagrams as claims to be defended, not as illustrations.

The implications developed here are advanced as reasoned extensions of a conceptual model and await empirical evaluation.

7. Limitations

This study has several main limitations. The first limitation is that the study has not been tested empirically. It offers a framework proposal at the conceptual level, and the model developed has not yet been tested with empirical data. The propositions are derived through logical inference from the existing literature and do not contain a definite judgment about causal relationships.

The second limitation is the model's sensitivity to contextual variability. The model treats policy environments and institutional structures, which may vary considerably across different national contexts, as moderator factors. This limits the model's universal validity. Data on digital certification mechanisms exhibit heterogeneous distributions across countries and sectors, which making comparative inferences difficult [66]. The model's predictions shift where infrastructure is limited and recognition systems are young, and these conditions are discussed conceptually rather than tested. A full comparative analysis across Global South settings remains future work.

The third limitation is that the learner perspective is not represented at the structural level. Andragogy and transformative learning theories explain how adult learning works. But how learners subjectively experience micro-credential processes, what meanings they construct, and how programs contribute to the transformation of professional identity remain outside the scope of this study. This gap makes qualitative research designs (in-depth interviews, lived-experience studies) a priority agenda item. It is especially needed for a deeper understanding of the reverse direction of P1—how programs generate needs that were not previously recognized.

The fourth limitation concerns the study's pedagogical claims. Section 6 sets out implications for teaching practice, curriculum sequencing, staff development, and assessment, but these are reasoned extensions of a conceptual model rather than findings from classroom research. Neither the proposed graduated sequence nor the minimum viable course adaptation has been evaluated with learners, and testing them would require instructional design studies with pre- and post-measures of the attributes the model depends on.

These limitations do not diminish the model's potential as a productive starting point for empirical research. On the contrary, observable indicators, data sources, and methods have been defined for each proposition, and how P4 can be tested through system dynamics simulation has been set out as a concrete stock-flow framework.

8. Conclusions

This study developed an integrated conceptual model by addressing the role of micro-credentials within the lifelong learning ecosystem from a systems thinking perspective. The model positions micro-credentials not as independent certification tools, but as structural components of a complex adaptive system that operates through feedback loops. Through four theoretical propositions, one balancing loop (B1), and a three-level moderator architecture, the endogenous dynamics and contextual conditions of this system are addressed together. The model thus builds an integrated conceptual bridge between the inclusive lifelong learning goal under SDG 4, the sustainable employment agenda of SDG 8, and the goal of reducing inequalities under SDG 10.

In these terms, the study answers the three research questions it set out to address. In response to RQ1, it reconceptualizes the relationships among the ecosystem's components as reinforcing and balancing feedback loops (P1–P4 and B1) rather than one-way causal chains. In response to RQ2, it offers this system-dynamics account as a concrete pedagogical case for teaching systems thinking within the higher education policy domain (Section 6). In response to RQ3, it translates the model into a step-by-step design guide that curriculum designers can follow when developing micro-credential programs (Section 6).

Assessed from a practical standpoint, the model offers concrete implications for policymakers and institutions. For micro-credential systems to work sustainably, strengthening quality assurance standards and developing policy frameworks that raise the national and international recognition of credentials are a priority requirement. Alongside traditional degree programs, universities can become effective actors in the lifelong learning ecosystem through micro-credential programs designed in collaboration with industry. Under labor-market conditions transformed by the digital and green transitions, structuring these collaborations toward green skills and learning outcomes that support sustainable development will make a critical contribution to operationalizing the model's sustainability dimension at the institutional level. A sustainable ecosystem is built not only through low-leverage funding and program growth, but through medium- and high-leverage interventions: shortening delays, strengthening balancing loops, redesigning rules, and redefining the system's goal—especially through transparent recognition regimes that strengthen the B1 balancing loop.

It is highly important for future research to test the proposed model with empirical methods in different national contexts and learner groups. The participation motivations of adult learners, their learning experiences, and the effects on career development can be examined through both quantitative and qualitative methods. A comparative analysis of micro-credential systems applied in different countries can provide critical findings on integration into lifelong learning policies. Research aimed at measuring the effect of moderator variables on the propositions will contribute to determining the model's boundary conditions. The applied dimension of the systemic pedagogy perspective presented in the study can be addressed through separate studies that include program development processes. A systematic assessment of the extent to which micro-credentials contribute to an inclusive and equitable lifelong learning ecosystem, in line with the Sustainable Development Goals, will strengthen the field's role in the sustainable development agenda.

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