Skills Ecosystem Misalignment in Emerging Technology Sectors

DOI: 10.12776/qip.v30i1.2342

Iveta Orbánová, Nataša Urbančíková

Received: 19-02-2026 Accepted: 20-03-2026 Published: 30-04-2026

ABSTRACT

Purpose: This research investigates the misalignment between educational supply and industrial demand across emerging technology sectors in five European moderate innovator countries, aiming to understand why universities and firms struggle to co-produce the hybrid talent required for the digital transition.

Methodology/Approach: A mixed-methods comparative case study design was employed, combining desk research, focus groups, and semi-structured interviews across 35 country-sector cases in five countries and seven technology domains.

Findings: The analysis reveals a Coordination Failure Equilibrium where widespread awareness of gaps coexists with systemic inaction, highlighting severe deficits in soft skills and a critical theory-practice divide driven by a temporal mismatch between agile technology and rigid academic cycles.

Research Limitation/Implication: The findings imply that traditional degree structures are insufficient for the digital transition, necessitating a paradigm shift toward knowledge co-creation through Regional Centres of Vocational Excellence (CoVEs) and industry-validated micro-credentials.

Originality/Value of paper: This paper contributes a unique comparative analysis challenging linear human capital models by applying the Quintuple Innovation Helix framework to identify structural coordination failures rather than simple quantitative shortages.

Category: Research paper

Keywords: skills ecosystem; advanced technology skills gap; quintuple innovation helix; centres of vocational excellence

Research Areas: Management of Technology and Innovation; Quality 4.0

1 INTRODUCTION: MOTIVATION AND RESEARCH CONTEXT

The global economy is currently undergoing a structural transformation driven by the rapid convergence of digital and physical systems, often referred to as Industry 5.0 (Breque, De Nul, & Petridis, 2021). In this context, Advanced Technologies (ATIs), such as Artificial Intelligence (AI), Quantum Computing, and Blockchain, are no longer futuristic concepts but immediate drivers of industrial competitiveness and national security. However, the speed of these technological advancements has far outpaced the capacity of traditional educational systems to adapt. This creates a critical speed problem where the 3–5 year cycle of a university degree is rendered partially obsolete by the 6–12 month evolution cycles of the technologies themselves.

To understand and address this temporal mismatch, this study argues for a fundamental paradigm shift: moving from a linear lens to a systems lens. Traditional workforce development has long relied on linear human capital models, viewing education as a sequential pipeline that simply delivers graduates to the labour market (Becker, 1964). However, the complexity of the Twin Transition reveals the inadequacy of this approach. Instead, we adopt a skills ecosystem perspective (Finegold, 1999; Buchanan, Anderson, & Power, 2017), which conceptualises skill formation not as a linear output but as an emergent property of the interactions between educational institutions, industry, and policy frameworks. By applying the Quintuple Innovation Helix framework (Carayannis, Barth, & Campbell, 2012), we can analyse how the breakdown of feedback loops between these actors creates the coordination failure observed in the region.

This scientific study is empirically grounded in the extensive data collection conducted under the Erasmus+ project INVESTech (*Innovation Vocational Excellence and Sustainability in Tech*). While the primary project report (INVESTech Project, 2025) focused on a descriptive inventory of skill gaps to guide local curriculum development, this article seeks to transcend those immediate project objectives. We aim to place these empirical findings within the broader systems theoretical framework, analysing the systemic causes of misalignment rather than merely listing missing competencies. By synthesising data from the INVESTech project, this study aims to uncover the deeper coordination failures that prevent ecosystem self-correction. The primary motivation stems from a persistent disconnect observed across European moderate innovator countries: despite near-universal stakeholder awareness of skill gaps, a systemic inability to bridge them remains. Traditional perspectives often treat these gaps as simple quantitative shortages defined as too few graduates for too many jobs. This paper argues that the problem is far more insidious: it is a structural dysfunction rooted in how education, industry, and policy fail to effectively interact within a regional ecosystem. By focusing on Bulgaria, Cyprus, Greece, Lithuania, and Slovakia, this research addresses a significant but under-studied region facing unique challenges in catching up with Western European technological leaders.

Furthermore, this analysis extends the theoretical discourse by incorporating Quality Management (QM) as a critical bridging competence. In the context of Industry 5.0, QM evolves into Quality 4.0, a paradigm of data-driven quality that shifts from post-production inspection to predictive quality assurance using AI and real-time sensor data. This evolution aligns with the identified skill gaps in real-time analytics and process optimisation, effectively bridging the divide between technical data engineering and managerial oversight. This study emphasises that the goal of advanced technology adoption is not merely efficiency, but the resilience and excellence of the final output; a core tenet of the Industry 5.0 framework often missed in purely technical curricula.

2 THEORETICAL FRAMEWORK: SKILLS ECOSYSTEM

To understand the persistence of skill gaps in small open economies, it is necessary to move beyond traditional, linear models of workforce development. This study adopts a multi-layered theoretical approach, integrating Skills Ecosystem Theory with the emerging literature on Regional Innovation Systems (RIS) and the transformative role of Centres of Vocational Excellence (CoVEs).

Traditional policy interventions often rely on linear human capital models (Becker, 1964), which view education as a sequential pipeline: the state invests in universities, universities produce graduates, and the labour market absorbs them. This model assumes that skill mismatches are merely market frictions. However, this linear model fails in the context of rapid technological change. It fails to account for the complexity of skill formation, where the value of a competence is determined not just by its existence, but by its deployment within a network of firms, regulations, and social institutions.

In contrast, Skills Ecosystem Theory (Finegold, 1999; Buchanan et al., 2017) conceptualises workforce development as an interconnected, organic system. An ecosystem is defined by the interdependency of actors: education providers, employers, regional governments, and workers interact to produce, demand, and regulate skills. As Uyarra (2010) argues, regional development is not just about the stock of knowledge but about the flow of knowledge between these actors. A shortcoming within the ecosystem is rarely rooted in a single institution but stems from a disruption in connectivity and feedback loops. A healthy skills ecosystem is defined by three fundamental characteristics that ensure its resilience and effectiveness (Finegold, 1999; Buchanan et al., 2017). First, it relies on coordination, ensuring that educational outputs are precisely aligned with employer requirements in terms of content, volume, and timing. Simultaneously, the system should exhibit responsiveness, demonstrating the agility to adapt curricula to technological disruptions, such as the sudden rise of Generative AI, within a timeframe of months rather than years (Capsada-Munsech & Valiente, 2020). Finally, it is anchored by inclusiveness, ensuring that multiple, overlapping pathways exist for skill acquisition, which validate diverse learning trajectories beyond the limitations of the traditional three-year degree.

Conversely, ecosystem dysfunction manifests as a low-skills equilibrium (Finegold & Soskice, 1988), where rational behaviour by individual actors leads to suboptimal collective outcomes. For example, universities may hesitate to launch niche high-tech programs due to uncertain local demand, while local firms hesitate to adopt high-tech strategies due to a lack of local talent. This chicken-and-egg deadlock is a classic example of a lack of coordination failure that linear policies cannot solve.

To break these deadlocks, the European Union has advocated Centres of Vocational Excellence (CoVEs) as institutional intermediaries. Theoretically, CoVEs represent a shift from Government to Governance. They are not mere training providers but active knowledge hubs that orchestrate the regional ecosystem (Uyarra, 2010). In the CoVE framework, the university or VET provider is no longer a monopoly educator but a network orchestrator. Their role shifts from delivering static content to facilitating a dynamic network of co-educators and trainers, including industry experts, cluster managers, and research institutes. This aligns with the Quintuple Innovation Helix model, where knowledge creation is a social process involving academia, industry, government, civil society, and the environment.

The speed problem of Industry 5.0 necessitates a move toward flexible and personalised education. Theoretical support for this shift is found in the concept of just-in-time learning and stackable credentials (OECD, 2021). The rigid, one-size-fits-all degree is increasingly viewed as an artefact of the industrial age. In a responsive ecosystem, education requires a modular structure. Micro-credentials serve as the currency of this new system, allowing learners to acquire specific, industry-validated competencies without committing to a full multi-year program. This shift redefines the university's function. It becomes a platform for lifelong learning, validating skills acquired through diverse channels – workplace training, online bootcamps, or peer-to-peer projects. As Uyarra et al. (2017) note, universities in peripheral regions can act as institutional anchors, but only if they open their boundaries to co-design curricula with regional stakeholders. By validating micro-credentials, they provide the quality assurance needed to make flexible learning portable and recognised across the labour market.

3 METHODOLOGY

This study employs a mixed-methods comparative case study design (Yin, 2018) combining desk research, focus groups, and semi-structured interviews across five European moderate innovator countries (Bulgaria, Cyprus, Greece, Lithuania, Slovakia) and seven emerging technology domains (AI & Ethics, Big Data, Blockchain, Green ICT (Information and Communication Technologies), Industry 5.0, IoT (Internet of Things), Quantum Computing). This multi-perspective approach analyses the same problem from different angles, utilising a 35-case matrix to enable robust within-country and cross-case pattern analysis across five countries and seven domains (Eisenhardt, 1989). This purposive selection targets five countries that share common regional challenges, including post-socialist transitional legacies and the constraints of small open economies. However, they also exhibit diverse economic structures that range from the heavy industrial base of Slovakia to the service-oriented economy of Cyprus.

The research design follows the principles of methodological triangulation (Denzin, 1978; Flick, 2018) and is theoretically anchored in the regional skills ecosystem framework (Table 1). For clarity, RQ denotes the primary research question, SQ the sub-questions, and FG focus groups.

Table 1 – Research design overview

Research Question	Method	Respondents / Data Sources
Primary RQ: To what extent do skills ecosystems exhibit systematic misalignment between educational supply and labour market demand?	Triangulation across all three methods	35 country-sector cases; 71 FG participants; 24 interviews
SQ1: What is the nature and magnitude of skill gaps across seven domains?	Desk research (gap taxonomy per domain/country); focus group technical gap mapping; interview synthesis	12 EU-level and national reports; FG Table 6; Interview Table 10
SQ2: Do gaps reflect quantity, quality, or composition mismatches?	Expert interviews (graduate readiness); desk research (job role vs. degree comparison); focus groups (practitioner experience)	24 interviews across 5 countries; national labour market reports; all 5 FG reports
SQ3: Are dysfunctions uniform or do distinct national/sectoral patterns emerge?	Cross-case comparison (5 × 7 matrix); national FG reports; country desk research	Bulgaria n=12, Cyprus n=14, Greece n=22, Lithuania n=11, Slovakia n=12
SQ4: What coordination failures prevent self-correction despite awareness?	Focus groups (stakeholder diagnosis); interviews (expert analysis); desk research (repeated recommendations)	All 5 FG reports; 24 interviews; 7 domain reports

Desk research was conducted at EU and national levels, drawing on European Commission policy documents, CEDEFOP and Eurostat labour market data, national educational statistics, and industry reports. The primary data collection consisted of five focus groups, one per country; each designed as a one-day multi-stakeholder workshop (Krueger & Casey, 2015; Morgan, 1997). Participants were selected through purposive sampling (Patton, 2015), targeting industry representatives, educators, policymakers, and technology experts. In total, 71 participants took part (Bulgaria n=12; Cyprus n=14; Greece n=22; Lithuania n=11; Slovakia n=12), with a gender distribution of 32% female and 68% male. Sessions were conducted between August 2024 and January 2025.

These were complemented by 24 semi-structured expert interviews (Harvey, 2011; Mikecz, 2012), five per country (four in Bulgaria), lasting 60-90 minutes each. Interviewees included senior industry professionals, researchers, and educators, providing in-depth perspectives on technical skill requirements, institutional barriers, and future workforce needs across all seven technology domains. All qualitative data were analysed using reflexive thematic analysis (Braun & Clarke, 2019). Ecosystem alignment was assessed across three dimensions: supply-demand match, skill composition gaps (following Becker, 1964; Acemoglu & Autor, 2011), and institutional response capacity. The combination of 35 country-sector cases, 71 focus group participants, and 24 expert interviews provides robust triangulated evidence of systemic skills ecosystem dysfunction across the region.

4 EMPIRICAL FINDINGS

The assessment focused on three critical axes. First, the Supply-Demand Match was evaluated by contrasting educational program outputs against employer-stated requirements, distinguishing between quantitative shortages (insufficient graduate numbers) and qualitative gaps (inadequate preparation). Second, the study analysed Skill Composition Gaps by categorising competencies into four distinct strata: domain-specific technical skills (e.g., AI, blockchain), regulatory and policy knowledge (e.g., GDPR – General Data Protection Regulation, ethics), soft skills (communication, adaptability), and the increasingly critical hybrid skills that span multiple domains, such as the intersection of ICT and sustainability. Finally, the institutional response capacity was evaluated by examining the speed and efficacy of the educational system's reaction to market signals, specifically looking for evidence of curriculum adaptation, the development of new programs in frontier technologies, and the robustness of industry-academia partnership mechanisms.

4.1 Critical Technical Gaps

The most immediate finding is the universality of functional deficiency. Across all 35 country-sector cases examined, not a single technology domain in any country shows adequate ecosystem alignment. This is not a matter of degree; it is categorical across all five countries and seven technology domains:

1. AI & Ethics: hybrid & regulatory gap – lack of professionals who combine technical machine learning expertise with knowledge of legal compliance (EU AI Act) and ethical frameworks.
2. Industry 5.0: human-centric gap – critical shortage of socio-technical skills, specifically human-robot collaboration, emotional intelligence, and user-centric design.
3. Big Data: specialisation deficit – abundance of general data analysts but a severe lack of architects for complex, real-time cloud infrastructure and data governance.
4. Green ICT: transdisciplinary mismatch – separation of engineering and environmental sciences prevents the training of experts in ICT-sustainability integration (ESG reporting – Environmental, Social, and Governance, energy-efficient coding).

5. IoT: theory-practice divide – graduates possess theoretical knowledge of protocols but lack applied skills in embedded systems, hardware-software integration, and operational security.

Focus groups and interviews corroborate this picture. All five national focus group reports independently identified education-industry misalignment as their primary concern, and all 24 expert interviews confirmed persistent gaps across their respective domains. The convergence across three independent methods (desk research, focus groups, and interviews), conducted separately by five national research teams, represents a strong form of triangulated evidence available in qualitative comparative research.

Table 2 – Critical technical skill gaps by country (Focus Group Data)

Domain	Bulgaria	Cyprus	Greece	Lithuania	Slovakia
AI & Ethics	Machine learning, Regulatory frameworks, Ethical AI	Machine learning, AI ethics, AI regulation	Machine learning, Regulatory frameworks	AI engineering, Deep learning, Data ethics	Coding, Machine learning, Containers
Big Data	Data governance, AI-driven insights	Data governance, Predictive modelling	Cloud computing, Big data frameworks	Data sourcing, ML, Cybersecurity	Server engineering, Real-time analytics
Blockchain	Blockchain integration, Smart contracts	Blockchain integration, Smart contracts	Smart contract development, Cryptographic security	Blockchain for traceability, Digital identity	Blockchain implementation, Encryption, Compliance
IoT	IoT architecture, Cybersecurity	IoT for sustainability, Cybersecurity	IoT security, Data analysis	IoT network management, Edge computing	IoT development, Network security

The core inference emerging from all data sources is that awareness of gaps does not generate correction. All five countries, all seven domains, and all three methods document the same dysfunction. Methodological triangulation confirms that the universal mechanism of dysfunction arises from a systemic disconnect between rapid technological change and inflexible educational cycles, yet its specific manifestation is strictly path dependent on national economic structures. As Table 2 illustrates, the specific character of these gaps mirrors local industrial specialisation, diverging from Slovakia's acute demand for hard operational engineering to Cyprus's focus on regulatory compliance and service-oriented ethics. Analysis across all data sources reveals four interrelated misalignments. These are not isolated failures, but structural features of how regional education systems relate to emerging labour markets.

1. Disciplinary Silo Mismatch: The labour market demands transdisciplinary competencies such as AI combined with law or Green ICT, which mono-disciplinary education systems are structurally unable to produce. Cyprus focus group participants noted that existing frameworks fail to align with

evolving needs, while interviewees identified a universal difficulty in uniting tech and business stakeholders. This creates a self-reinforcing cycle where departmental silos prevent the creation of the cross-functional graduates employers require.

2. Theory-Practice Divide: A consistent gap exists between theoretical knowledge and applied practice, particularly in Quantum Computing and IoT. Lithuanian participants emphasised that "technology alone is insufficient" without business integration. The structural cause lies in misaligned incentives: academic systems prioritise research over employability, and 3–5 year curriculum cycles cannot keep pace with technological changes measured in months.
3. Specialisation Deficit: While generalist IT skills are common, deep expertise (e.g., Rust smart contracts, quantum error correction) is rare. Small national markets create a chicken-and-egg deadlock: students avoid specialisation without guaranteed jobs, and employers do not create specialist roles without available talent, causing both sides to wait.
4. Hybrid Skills as Highest Scarcity: The most problematic gap involves combining distinct domains, such as Green ICT (energy plus tech) or AI & Ethics. Research indicates professionals with these dual competencies are virtually non-existent. These gaps cannot be filled by short courses; they require a fundamental redesign of qualifications, as current career pathways actively push these disciplines apart rather than together.

4.2 Soft Skill Deficits

A critical methodological strength of this study is the convergence of findings across three independent data sources: desk research, focus groups, and expert interviews. The single most consistent finding in the entire study is the universal deficit in soft skills (Table 3). This is not a minor observation buried in sector-specific reports. It appears in all seven technology domains in the desk research, in all five national focus group reports, and is confirmed by all 24 expert interviews. The consistency of both the finding and the language used to describe it constitutes the strongest evidence in the study – across independent research teams, in five countries, using three different methods.

Table 3 – Soft skill gaps confirmed across all data sources

Soft Skill	Desk Research (domains)	Focus Groups (countries)	Interviews
Communication/stakeholder engagement	7/7	5/5	All
Collaboration/teamwork	7/7	5/5	All
Adaptability/continuous learning	7/7	5/5	All
Critical thinking / problem-solving	6/7	5/5	All
Leadership/project management	6/7	4/5	All
Emotional intelligence	5/7	5/5	Majority

Focus group discussions were explicit about both the gap and its consequences. Slovakia participants noted that "non-technical skills should be more in focus as Industry 5.0 human centricity brings the strong demand for higher emotional and social intelligence". Greek participants called for "greater emphasis on soft skills, including adaptability and interdisciplinary collaboration". Interview synthesis described the practical damage: "ICT experts struggle to explain technical concepts to non-technical colleagues, leading to misunderstandings and slowed decision-making" (Interview Synthesis, 2024). What makes this structural unawareness rather than simply a gap is the combination of universal recognition and persistent inaction. Soft skill deficits have been documented, discussed, and recommended against in every domain and every country. Yet they remain. This points not to unfamiliarity but to a structural assumption embedded in technical education: that communication, collaboration, and adaptability are personal attributes rather than teachable competencies, and therefore not the university's responsibility to develop formally.

4.3 National Patterns: Uniform Dysfunction, Emerging Differentiation

At the level of core dysfunction, the five countries are strikingly similar. The same four misalignment types appear in each; the same soft skill gaps are named; the same recommendations emerge from independently conducted focus groups and interviews (Table 4). This similarity is itself evidence that the problem is structural rather than country-specific, rooted in shared features of how education-industry interfaces are organised across the region rather than in any national policy failure.

Table 4 – Country-specific skill focus and emerging specialisation signals

Country	Distinctive National Focus	Emerging Specialisation Signal	Evidence
Bulgaria	Circular economy, sustainable robotics	Environmental ICT applications	Desk research emphasis
Cyprus	Blockchain governance, green energy	Fintech / digital finance hub	Master's in digital currency
Greece	AI ethics research, public sector digitalisation	Research-intensive data roles	FG emphasis on academic collaboration
Lithuania	IoT for smart agriculture, cybersecurity in manufacturing	IoT hardware / embedded systems	Teltonika Academy
Slovakia	Smart cities, Industry 5.0, digital twin technologies	Advanced manufacturing / urban ICT	FG explicit Industry 5.0 framing

These specialisation signals are emergent rather than established. In no country has a genuine comparative advantage in any frontier technology yet consolidated. The risk is that five small markets, each attempting to develop all seven technology domains simultaneously, will produce thin, fragmented capabilities everywhere rather than deep, competitive expertise anywhere. Slovakia's focus group articulated the systemic challenge most explicitly, invoking the Quintuple Innovation Helix: the coordination of academia, industry, government, civil society, and environment as both necessary and currently underdeveloped.

4.4 Why Self-Correction Fails: Coordination Failure Analysis

The most important question raised by this study is not what the gaps are, as they are thoroughly documented, but why they persist despite being universally known. The answer lies in four interlocking coordination failures that prevent the ecosystem from self-correcting even when all actors are aware of the problem.

The first is *disciplinary lock-in.* Universities cannot reorganise across departmental lines without dismantling faculty incentive structures tied to disciplinary research. Individual departments cannot create hybrid programs; individual faculty lack cross-boundary expertise; individual students cannot assemble transdisciplinary profiles from mono-disciplinary course menus. Simultaneously, private firms remain passive, preferring to hire "ready-made" graduates rather than investing the time and resources required to co-design curricula or co-produce talent. This is further compounded by government policy, which favours short-term, measurable project outputs over the long-term funding cycles necessary for structural reform. Together, these forces create a self-reinforcing cycle that prevents the evolution of a collaborative educational ecosystem.

The second is *the temporal mismatch.* Technology evolution now operates on a cycle of months; curriculum development and approval operate on a cycle of three to five years. By the time a new program addressing a recognised gap reaches graduating students, the specific skill needs have often already moved on. Bulgarian participants put this directly: "the education system is lagging a lot, and the market is very underdeveloped. The pace of change must be slow and systematic in the case of study programs, fast and flexible in the case of skills provision – these two levels should be seen as two distinct but complementary paths", a contradiction that captures the impossible position education systems face.

The third is *market fragmentation.* Five small national markets cannot individually support the specialist training programs that deep technical expertise requires. A country with ten annual job openings for quantum hardware engineers cannot justify a dedicated master's program in that domain. Aggregating demand across the region through specialisation and cooperation could solve this, but no coordination mechanism currently exists to negotiate or enforce such an arrangement.

The fourth and most revealing coordination failure is *institutional inertia* evidenced by the repetition of recommendations. Every domain report recommends "strengthen industry-academia collaboration" and "integrate soft skills into technical curricula." These recommendations appear identically in desk research, focus groups, and interviews, conducted independently. This is not researchers discovering new solutions; it is researchers rediscovering solutions that have already been recommended, presumably before, without implementation. The recurrence of the same advice across independent sources is itself the strongest evidence that the ecosystem cannot self-correct: the knowledge of what to do is not the barrier. The ability to coordinate action across institutional boundaries is.

"We know what skills are needed. The lists are everywhere. But changing our programs takes years, and by then the technology has moved on again." — Slovakia Focus Group participant, 2024. The barrier is not a lack of knowledge regarding necessary actions but rather the incapacity to coordinate action across institutional boundaries.

4.5 Slovakia as a Case Study of Structural Tension

Slovakia serves as a revealing case within a regional innovation system context, reflecting broader regional dynamics while also exhibiting distinctive national features that help illuminate the mechanisms of ecosystem dysfunction. To assess the functioning of the Slovak skills ecosystem, we return to the three core characteristics defined in the theoretical framework – coordination, responsiveness, and inclusiveness (Finegold, 1999; Buchanan et al., 2017). The empirical evidence indicates that although Slovakia demonstrates a well-developed conceptual awareness of these requirements, it faces persistent difficulties in operationalising them through existing institutional arrangements.

The *Coordination mechanism*, **which ensures educational outputs align with employer requirements,** is currently obstructed by rigid disciplinary silos. Desk research indicates that while Green IT requires a synthesis of ICT and sustainability knowledge, academic programs remain largely compartmentalised. Similarly, the transition to Industry 5.0 demands a convergence of engineering, human factors, and ethics, yet curricula are described as still evolving rather than actively adapting. This misalignment is further evidenced by the *Theory-Practice Divide*, particularly in emerging fields like Quantum Computing, which remains limited to academic research, and Blockchain, where theoretical knowledge lacks the practical smart contract experience demanded by the labour market. These patterns are consistent with earlier findings on the Slovak ICT sector, where the gap between industrial knowledge needs and educational provision has historically been shaped by path-dependent institutional arrangements that privilege traditional engineering disciplines over emerging hybrid competencies (Šebová & Hudec, 2012; Rehák, Hudec, & Buček, 2013).

Focus group participants were acutely aware of this deficit and explicitly identified the need for systemic collaboration. One participant noted: "*The cooperation of Quintuple Innovation Helix entities is crucial and inevitable to meet the needs of experts in ATIs in various training.*" The invocation of the Quintuple Innovation Helix (linking academia, industry, government, civil society, and the environment) demonstrates a high level of theoretical sophistication among Slovak stakeholders. However, the persistence of gaps suggests that while the *concept* of coordination is understood, the *mechanism* to enforce it across institutional boundaries is absent. This observation aligns with previous empirical studies on the Slovak ecosystem, which found that university-industry interactions are often driven by individual researcher initiative rather than robust, systemic transfer mechanisms (Klasová, Korobaničová, & Hudec, 2019).

Regarding *Responsiveness,* the system struggles to match the temporal pace of technological change. Interviewed experts emphasised that the acceleration of Industry 4.0 and 5.0 has created a speed problem that traditional degree cycles cannot solve. As the interview summary states: *"All participants agreed that the influence of Industry 4.0 as well as 5.0 has brought not only requests for new technical skills, but also much stronger need of fast reaction from all types of educators: new courses are needed fast even for the new graduates and of course for the experienced experts."*

The domain-specific skill gaps identified in the focus group data make this institutional tension concrete. The gaps listed in Table 5 are not isolated deficiencies; they are the observable outcome of the coordination failures and path-dependent rigidities described above. Advanced machine learning, real-time analytics, smart contract development, and quantum algorithms all require applied, specialised training that the current program structure does not deliver.

Table 5 – Slovakia — Critical skill gaps by technology domain (Focus group data, Slovakia, n=12, 2024)

ATI	Slovakia-Specific Gaps
AI & Ethics	Coding, Containers (Docker), Machine learning
Big Data	Server engineering, Data pipeline design, Real-time analytics, Predictive/prescriptive analytics
Blockchain	Blockchain implementation, Encryption, Compliance
IoT	IoT development, Network security, System interoperability
ICT for Sustainability	ICT for sustainability standards, Renewable energy integration
Quantum	Quantum encryption, Quantum algorithms

When reading through the skills ecosystem framework, these domain-specific gaps reveal a consistent pattern across all three theoretical dimensions. Table 6 maps Slovakia's performance against each dimension, distinguishing between the level of conceptual awareness demonstrated by stakeholders and the actual operational capacity of existing institutional arrangements. The divergence between these two columns is the central finding of this case study and arguably the most precise formulation of what ecosystem dysfunction looks like in practice.

Table 6 – Slovakia's skills ecosystem — awareness vs. operational capacity (Synthesis of desk research, focus group n=12, and interview n=5 data, Slovakia, 2024)

Ecosystem Indicator	Slovakia	Regional Average	Interpretation
Awareness of Coordination Problem	High (Explicit use of Quintuple Helix model)	Medium (Implicit recognition of gaps)	Slovakia is more articulate about ecosystem dynamics and theoretical complexity.
Soft Skills Emphasis	Very High (Specific Industry 5.0 human-centric focus)	High (Universal broad demand)	Slovakia is leading the theoretical transition to Human-Centric industry requirements.
Innovation in Solutions	Medium (Advocacy for micro-credentials)	Low (Repetition of traditional policy recommendations)	Slovakia is actively experimenting with flexible formats like micro-credentials.

Ecosystem Indicator	Slovakia	Regional Average	Interpretation
Implementation Capacity	Low (Gaps persist despite high awareness)	Low (Universal stagnation)	Higher awareness has not translated into better implementation (Awareness ≠ Action).

The pattern across both tables points to the same conclusion: Slovakia's skills ecosystem is not unsuccessful due to ignorance of what is needed. It is inefficient because awareness, however sophisticated, cannot substitute for the institutional mechanisms that would translate it into coordinated action. This gap between knowing and doing (between conceptual clarity and operational capacity) is what Rehák et al. (2013) describe as the tension between path dependency and path plasticity: the system recognises the need to adapt but remains constrained by the accumulated weight of existing structures. Unlocking path plasticity in the Slovak context will require not more recommendations, but deliberate institutional redesign targeting the coordination mechanisms that currently do not exist.

5 CONCLUSIONS

This study set out to examine the extent and nature of skills ecosystem misalignment across seven advanced technology domains. Through the triangulation of 35 country-sector cases, 71 focus group participants, and 24 expert interviews, the research addresses the primary question and four sub-questions, confirming that misalignment is not a peripheral issue but a defining structural feature of the regional economy.

The investigation into the extent of ecosystem misalignment yields consistent evidence that the vast majority of cases analysed across all five countries and seven domains demonstrate a significant disconnect between educational supply and labour market demands. This prevalence points to a systemic challenge rather than incidental policy failures. This universality points to a systemic dysfunction rather than incidental policy failures. Theoretically, this challenges the assumption that skill gaps are merely temporary market frictions that self-correct over time. Instead, the persistent misalignment across diverse economies suggests a low-skills equilibrium where the feedback loops between education and industry are inhibited. This decoupling is bilateral: universities often remain trapped in disciplinary silos, unable to produce hybrid talent, while firms mostly remain trapped in a posture of passive expectation, waiting for "perfect" graduates to emerge rather than actively co-investing in the educational infrastructure required to produce them. This mutual inertia prevents the ecosystem from adapting to rapid technological shifts, leaving both sectors waiting for the other to move first.

Regarding the nature and magnitude of gaps (SQ1), the analysis identifies four distinct categories of deficiency that recur across all domains: technical specialisation deficits, absent interdisciplinary hybrids, missing soft skills, and a lack of applied experience. The most severe and theoretically significant gaps are the interdisciplinary hybrids (e.g., AI combined with Ethics, Green ICT).

Crucially, these gaps persist despite a visible layer of bottom-up activity. While the region hosts a vibrant ecosystem of hackathons, startup accelerators, and NGO-led digital initiatives, these act primarily as islands of agility. They successfully prototype solutions but lack the scale and continuity to resolve the Theory-Practice Divide at a systemic level. Consequently, the Quintuple Helix exhibits limited cohesion: the agility of the startup/NGO sector remains largely disconnected from the scale of the formal education system and the regulatory power of regional administration. The result is a fragmented landscape where pockets of excellence do not translate into a broadly skilled workforce capable of deploying technologies in production settings.

The study reveals (SQ2) that the dominant mismatch is one of composition, not quantity. While the region produces a reasonable volume of graduates in core disciplines like computer science, it fails to generate the specific types of talent required; specifically, those who combine technical depth with regulatory knowledge or applied skills. This finding has profound implications for human capital theory in the region. The dysfunction cannot be solved simply by pumping more graduates through the linear pipeline. The crisis is qualitative; the ecosystem produces mono-disciplinary specialists for a labour market that demands multi-disciplinary integrators. These findings are broadly consistent with evidence from Western European and other advanced economies, where research highlights that skill mismatches extend beyond simple quantitative shortages to include imbalances in skill utilisation, demand-side constraints, and the growing importance of soft skills (e.g., OECD, 2021; Capsada-Munsech & Valiente, 2020). However, while such patterns are also observed in more developed innovation systems, this study further demonstrates that the most critical gaps are increasingly compositional in nature, particularly the scarcity of hybrid profiles that integrate technical, regulatory, and applied competencies. In moderate innovator countries, these mismatches are amplified by weaker coordination mechanisms and slower institutional responsiveness.

The analysis of national patterns (SQ3) indicates that misalignment is strikingly uniform across Bulgaria, Cyprus, Greece, Lithuania, and Slovakia, suggesting that the problem is rooted in shared institutional features rather than specific national policies. However, signals of emerging specialisation are visible: Lithuania in deep-tech IoT, Cyprus in regulatory frameworks, and Slovakia in Industry 5.0 manufacturing. Theoretically, this highlights an implementation gap of Smart Specialisation (RIS3) strategies, which often struggle to materialise beyond formal strategic documentation. Regional administrations and national agencies have successfully drafted specialisation strategies, but have not been successful in orchestrating the ecosystem to achieve them. This lack of strategic coordination prevents any single ecosystem from achieving the critical mass needed to compete with larger Western European technological leaders.

Finally, the persistence of these gaps is explained by four specific coordination failures (SQ4): disciplinary lock-in, temporal mismatch, market fragmentation, and institutional inertia. The recurrence of the same recommendations across independent sources confirms that the ecosystem's challenge is not diagnostic but operational. The region suffers from "projectification", an over-reliance on short-term pilots that create activity without leaving behind permanent institutional structures.

To escape this equilibrium, the regions require a transition from ad-hoc, project-based interventions to permanent institutional translation mechanisms, whether manifest as regional innovation hubs, cluster alliances, or centres of vocational excellence. These stable intermediaries operationalise the Quintuple Helix by converting abstract industry signals into concrete pedagogical action through shared governance structures, ensuring that employer needs are not merely advisory but structurally embedded in curriculum design. Furthermore, they resolve the critical temporal mismatch between rigid academic cycles and rapid technological change by implementing a two-speed architecture, where universities provide foundational depth while the agile intermediary layer facilitates industry-validated micro-credentials for immediate market responsiveness. More specifically, responsibilities should be differentiated across actors: universities should lead curriculum redesign and integration of hybrid skills; employers should co-design programs and provide work-based learning opportunities; regional authorities should coordinate ecosystem-level partnerships and specialisation strategies; and national governments should create enabling regulatory frameworks and provide long-term funding mechanisms.

REFERENCES

Acemoglu, D., & Autor, D. (2011). Skills, tasks and technologies: Implications for employment and earnings. In D. Card & O. Ashenfelter (Eds.), *Handbook of labor economics* (Vol. 4, pp. 1043–1171). Amsterdam, The Netherlands: Elsevier.

Becker, G. S. (1964). *Human capital: A theoretical and empirical analysis*. Chicago, IL: University of Chicago Press.

Braun, V., & Clarke, V. (2019). Reflecting on reflexive thematic analysis. *Qualitative Research in Sport, Exercise and Health, 11*(4), 589–597. https://doi.org/10.1080/2159676X.2019.1628806

Breque, M., De Nul, L., & Petridis, A. (2021). *Industry 5.0: Towards a sustainable, human-centric and resilient European industry*. Luxembourg: Publications Office of the European Union. https://doi.org/10.2777/308407

Buchanan, J., Anderson, P., & Power, G. (2017). Skills ecosystems. In C. Warhurst, K. Mayhew, & D. Finegold (Eds.), *The Oxford handbook of skills and training* (pp. 444–465). Oxford, England: Oxford University Press. https://doi.org/10.1093/oxfordhb/9780199655366.013.21

Capsada-Munsech, Q., & Valiente, O. (2020). Sub-national variation of skill formation regimes: a comparative analysis of skill mismatch across 18 European regions. *European Education*, *52*(2), 166–179. https://doi.org/10.1080/10564934.2020.1723421

Carayannis, E. G., Barth, T. D., & Campbell, D. F. (2012). The Quintuple Helix innovation model: Global warming as a challenge and driver for innovation. *Journal of Innovation and Entrepreneurship, 1*(1), 2. https://doi.org/10.1186/2192-5372-1-2

Denzin, N. K. (1978). *The research act: A theoretical introduction to sociological methods*. New York, NY: McGraw-Hill.

Eisenhardt, K. M. (1989). Building theories from case study research. *Academy of Management Review, 14*(4), 532–550. https://doi.org/10.5465/amr.1989.4308385

Finegold, D. (1999). Creating self-sustaining, high-skill ecosystems. *Oxford Review of Economic Policy, 15*(1), 60–81. https://doi.org/10.1093/oxrep/15.1.60

Finegold, D., & Soskice, D. (1988). The failure of training in Britain: analysis and prescription. *Oxford review of economic policy*, *4*(3), 21–53. https://doi.org/10.1093/oxrep/4.3.21

Flick, U. (2018). Triangulation in data collection. In U. Flick (Ed.), *The SAGE handbook of qualitative data collection* (pp. 527–544). London, England: SAGE. https://doi.org/10.4135/9781526416070.n34

Harvey, W. S. (2011). Strategies for conducting elite interviews. *Qualitative Research, 11*(4), 431–441. https://doi.org/10.1177/1468794111404329

INVESTech Project. (2025). *Report on the identified skill gaps in advanced technologies in industry (Deliverable 4.1)*. Erasmus+ Centres of Vocational Excellence. Retrieved from https://investech-cove.eu.

Klasová, S., Korobaničová, I., & Hudec, O. (2019). University-industry links in Slovakia: What are the factors underlying the number of interactions with industry? *Quality Innovation Prosperity, 23*(1), 102–118. https://doi.org/10.12776/qip.v23i1.1137

Krueger, R. A., & Casey, M. A. (2015). *Focus groups: A practical guide for applied research* (5th ed.). Thousand Oaks, CA: SAGE.

Mikecz, R. (2012). Interviewing elites: Addressing methodological issues. *Qualitative Inquiry, 18*(6), 482–493. https://doi.org/10.1177/1077800412442818

Morgan, D. L. (1997). *Focus groups as qualitative research* (2nd ed.). Thousand Oaks, CA: SAGE.

OECD. (2021). *Micro-credential innovations in higher education: Who, what and why?* (OECD Education Policy Perspectives No. 39). Paris, France: OECD Publishing. https://doi.org/10.1787/f14ef041-en

Patton, M. Q. (2015). *Qualitative research & evaluation methods* (4th ed.). Thousand Oaks, CA: SAGE.

Rehák, Š., Hudec, O., & Buček, M. (2013). Path dependency and path plasticity in emerging industries: Two cases from Slovakia. *Zeitschrift für Wirtschaftsgeographie, 57*(1-2), 52–66. https://doi.org/10.1515/zfw.2013.0005

Šebová, M., & Hudec, O. (2012). The ICT sector evolution in an industrial region of Slovakia. *Journal of Economics, 60*(1), 65–82.

Uyarra, E. (2010). Conceptualizing the regional roles of universities, implications and contradictions. *European Planning Studies, 18*(8), 1227–1246. https://doi.org/10.1080/09654311003791275

Uyarra, E., Flanagan, K., Magro, E., Wilson, J. R., & Sotarauta, M. (2017). Understanding regional innovation policy dynamics: Actors, agency and learning. *Environment and Planning C: Politics and Space, 35*(4), 559–568. https://doi.org/10.1177/2399654417705914

Yin, R. K. (2018). *Case study research and applications: Design and methods* (6th ed.). Thousand Oaks, CA: SAGE.

ACKNOWLEDGEMENTS

This research was supported by the Erasmus+ Programme of the European Union under the project "Innovation Vocational Excellence and Sustainability in Tech" (INVESTech) [Project No. 101103554]. The authors acknowledge the collaborative efforts of all project partners in Bulgaria, Cyprus, Greece, Lithuania, and Slovakia for their contribution to the data collection process.

ABOUT AUTHORS

Iveta Orbánová (I.O.) – Lead Researcher / Project Coordinator in ASTRA – Association for Innovation and Development, Košice, Slovak Republic. She is specialising in HRD, upskilling and social innovation. She bridges the gap between academic research and practical implementation, e-mail: iveta.orbanova@gmail.com.

Nataša Urbančíková ORCID: 0000-0002-2158-5517 (N.U.) – Associate Professor at the Department of Regional Science and Management, Faculty of Economics, Technical University of Košice. Her research focuses on regional science, social and human capital, and project management, e-mail: natasa.urbancikova@tuke.sk.

AUTHOR CONTRIBUTIONS

Conceptualisation, N.U., I.O.; Methodology, N.U.; Validation, I.O.; Formal analysis, N.U.; Investigation, I.O., N.U.; Resources, N.U., I.O.; Data curation, I.O.;

Original draft preparation, N.U.; Review and editing, N.U., I.O.; Supervision, N.U.; Project administration, I.O.; Funding acquisition, N.U., I.O.

CONFLICTS OF INTEREST

The authors declare that they have no conflict of interest. The funders had no role in the design of the study, in the collection, analysis, or interpretation of data, in the writing of the manuscript, or in the decision to publish the results.

DISCLOSURE OF ARTIFICIAL INTELLIGENCE ASSISTANCE

The authors acknowledge the use of artificial intelligence tools in the preparation of this manuscript. Specifically, DeepL and ChatGPT were utilised for proofreading. All AI-assisted content was carefully reviewed, edited, and validated by the authors to ensure scholarly integrity, originality, and compliance with ethical standards. The authors affirm full responsibility for the content of the manuscript, including any material generated or supported by artificial intelligence.