

FROM SKILLS INTELLIGENCE TO TRANSFORMATION INTELLIGENCE: A FORESIGHT-DRIVEN AI FRAMEWORK FOR CURRICULUM MODERNIZATION, WORKFORCE DEVELOPMENT AND INNOVATION ECOSYSTEMS

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ABSTRACT

Artificial intelligence is accelerating transformations across labor markets, education systems, innovation ecosystems and public institutions, increasing uncertainty while amplifying capability, inclusion and governance challenges.

Building on the SKILLBRIDGE project, this paper introduces a transformation intelligence framework that integrates foresight, artificial intelligence, labor-market analytics and multi-actor engagement to support capability-based transformation across education, enterprise and ecosystem contexts. The framework draws on a multi-source evidence base comprising more than 120 stakeholder interviews, 25 best practice cases, over 140 policy, analytical and labor-market reports, real-time job vacancy intelligence, scientific literature and education program documentation from five European countries. Through a hybrid intelligence approach combining AI-supported extraction, human-in-the-loop validation and semantic alignment with ESCO, the framework identifies emerging skills, weak signals, capability needs, and transformation priorities.

A central contribution is the SKILLBRIDGE capability architecture, which organizes intelligence through top skills, capability areas and capability diamonds, together with a transformation challenge architecture synthesizing recurring challenges identified across education, labor markets, enterprises and innovation ecosystems and linking intelligence with intervention pathways. The approach is demonstrated through the analysis of more than 40 education and training programs spanning ISCED levels 3–8, generating alignment signals that support curriculum modernization and stakeholder prioritization.

The findings suggest that AI-supported observatories should evolve beyond skills monitoring towards participatory transformation intelligence infrastructures capable of linking foresight, capability development and coordinated action. The proposed framework offers a transferable model for supporting trustworthy AI ecosystems, inclusive capability development and AI for good objectives.

Keywords - Artificial intelligence, capability intelligence, curriculum modernization, foresight, multi-source evidence, skills observatories, transformation intelligence.

1. INTRODUCTION

Artificial intelligence (AI) is no longer a discrete technological domain affecting only specialized occupations or advanced digital sectors. It is becoming a pervasive force reshaping labor markets, education systems, innovation ecosystems, public institutions and regional development

trajectories. Its effects are uneven, uncertain and frequently non-linear: new capabilities emerge before they are formally recognized, existing roles are recombined, organizational routines are disrupted, and education and training systems are asked to respond to signals that are often ambiguous, fragmented or weakly institutionalized. In this context, the question is not only which AI-related skills are needed but how societies can build the anticipatory capabilities required to interpret change, prioritize action and adapt systems before gaps become structurally-embedded.

At the same time, significant investments have been made in skills intelligence systems, labor market observatories, foresight initiatives and competency frameworks. While these efforts have generated valuable insights, many remain fragmented, descriptive in nature and only weakly connected to curriculum modernization, organizational adaptation and policy implementation.

As a result, intelligence frequently stops at the identification of emerging skills without providing effective mechanisms for translating evidence into coordinated action across educational, economic and societal systems. The challenge facing AI-enabled societies is therefore no longer simply one of identifying what is changing but of understanding how diverse forms of intelligence can be transformed into capabilities, priorities, and interventions that support adaptation, innovation, and sustainable transformation.

1.1 AI, uncertainty, and transformation

AI-driven transformation unfolds under conditions of deep uncertainty. Technological acceleration, generative AI adoption, data-driven automation, cybersecurity risks, sustainability transitions, and new regulatory environments are not developing as isolated trends. They interact with demographic change, regional inequality, institutional inertia, labor market shortages, and changing expectations about work and learning. These interactions create systemic conditions in which small signals may become major disruptions, and where delayed responses can reinforce digital, social, and territorial divides.

Recent foresight research and innovation activities have argued that such transformations require models capable of capturing weak signals, disruptive dynamics and adaptive resilience across multiple levels of change [1, 2]. This is particularly relevant for AI-related skills and capabilities. Emerging AI practices often appear first as experimental behaviors in workplaces, start-ups, research communities or informal “bring-your-own-AI” settings, before becoming visible in occupational taxonomies, formal curricula or policy frameworks. By the time they are codified, the system may already be facing a new cycle of change.

This paper therefore starts from the premise that AI skills' development cannot be addressed through static inventories alone. The challenge is evolutionary and systemic: skills emerge, combine, stabilize and sometimes disappear within broader socio-technical ecosystems. Responding effectively requires not only better data but better interpretative and organizational capacities for translating uncertain signals into coordinated action.

This suggests that the challenge facing AI-enabled societies is not simply one of skills anticipation but of developing intelligence systems capable of connecting evidence, capability development and transformation action.

1.2 Limitations of current skills intelligence

Skills intelligence systems have expanded significantly in recent years, supported by online vacancy analytics, occupational taxonomies, labor market forecasting, curriculum analytics and AI-based extraction tools. These systems have improved the ability of policymakers, educators and employers to detect trends and describe changing demand. However, they often remain limited in three important ways.

- First, many approaches remain primarily descriptive. They identify skills, trends or gaps, but provide limited support for understanding how these signals should be translated into curriculum redesign, workforce development, enterprise transformation or ecosystem-level interventions.
- Second, skills intelligence is often fragmented across data sources, institutional mandates and analytical traditions. Labor market evidence, education data, stakeholder knowledge, foresight outputs, and innovation-system intelligence are frequently analyzed separately, even though transformation challenges cut across all of them.
- Third, existing systems often struggle to connect granular skills evidence with higher-order capabilities. As a result, they risk producing long lists of skills without a sufficiently robust architecture for prioritization, interpretation and action.

The SKILLBRIDGE Handbook: Skills Intelligence, Capability Architecture and Transformation Framework [3] responds to this limitation by positioning skills as components of broader capability systems rather than isolated units of competence. This shift is important because AI-enabled transformation requires hybrid capabilities that combine technical knowledge, ethical judgement, organizational awareness, foresight, collaboration, sustainability literacy, and innovation capacity. In other words, the core challenge is not merely to detect skills gaps but to build capability systems able to anticipate, absorb and shape transformation. More fundamentally, the challenge facing contemporary societies is not simply a skills gap but a transformation gap. While technological, environmental, economic, and societal changes continue to accelerate, the ability of institutions to interpret emerging signals and convert intelligence into coordinated action frequently lags behind. Skills intelligence therefore needs to evolve from a monitoring function into a strategic capability capable of supporting adaptation across education systems, enterprises, innovation ecosystems, and policy domains.

1.3 Research objective and contributions

This paper introduces and discusses the SKILLBRIDGE transformation intelligence framework, a foresight-driven, AI-supported and multi-source approach for converting heterogeneous evidence into capability architectures and action pathways. The framework builds on the SKILLBRIDGE observatory, which integrates evidence from stakeholder interviews, best practice cases, policy and labor market reports, scientific literature, job vacancies and education program documentation. Through AI-supported extraction, human-in-the-loop curation and semantic alignment with ESCO, the observatory generates structured intelligence on emerging skills, weak signals, capability needs and transformation challenges.

Beyond skills anticipation, the framework responds to a challenge increasingly recognized across education, industry, and public policy: the need to navigate systemic transformation. Artificial intelligence does not operate in isolation. It interacts with digitalization, sustainability transitions, demographic change, geopolitical uncertainty, evolving organizational models and shifting societal expectations, creating complex and rapidly evolving socio-technical environments. Consequently, the central question is no longer simply how to identify emerging skills but how to develop intelligence systems capable of supporting adaptation, resilience and transformation across multiple levels of intervention.

From this perspective, skills represent only the visible layer of a deeper architecture of change. Beneath individual competencies lie capability systems, organizational capacities, ecosystem relationships and transformation challenges that ultimately shape the ability of institutions, enterprises, and regions to respond effectively to emerging opportunities and disruptions. This paper therefore examines how a multi-source transformation intelligence infrastructure can connect skills evidence with capability development and intervention pathways, helping educational institutions, enterprises, start-ups, innovation ecosystems, and policymakers move from evidence gathering towards coordinated transformation action.

The paper makes four contributions:

- First, it proposes a conceptual progression from skills intelligence to capability intelligence and transformation intelligence. This progression reframes skills intelligence as a system-level function for supporting adaptation rather than as a descriptive monitoring activity.
- Second, it introduces four domain-specific capability diamonds covering foresight and futures intelligence, AI and deep tech systems, innovation and entrepreneurship systems, and sustainability and green transition systems. These diamonds provide a structured translation layer between granular skills evidence and broader capability requirements.
- Third, it links the capability diamonds to a transformation challenge architecture derived from the synthesis of more than 300 critical issues identified through stakeholder interviews, best practice cases, policy and labor market reports. The resulting architecture provides a structured bridge between

capability intelligence and intervention pathways spanning curriculum modernization, workforce development, entrepreneurship, ecosystem orchestration and policy innovation.

- Fourth, it demonstrates how this architecture can support program-level analysis through documented alignment signals rather than simplistic performance rankings.

The central argument is that AI-supported observatories will only become transformative if they move beyond skills monitoring toward integrated capability and transformation intelligence. Such systems must help actors understand not only what skills are emerging but which capabilities are required, where transformation challenges are concentrated, and how evidence can be converted into coordinated educational, organizational, and ecosystem action.

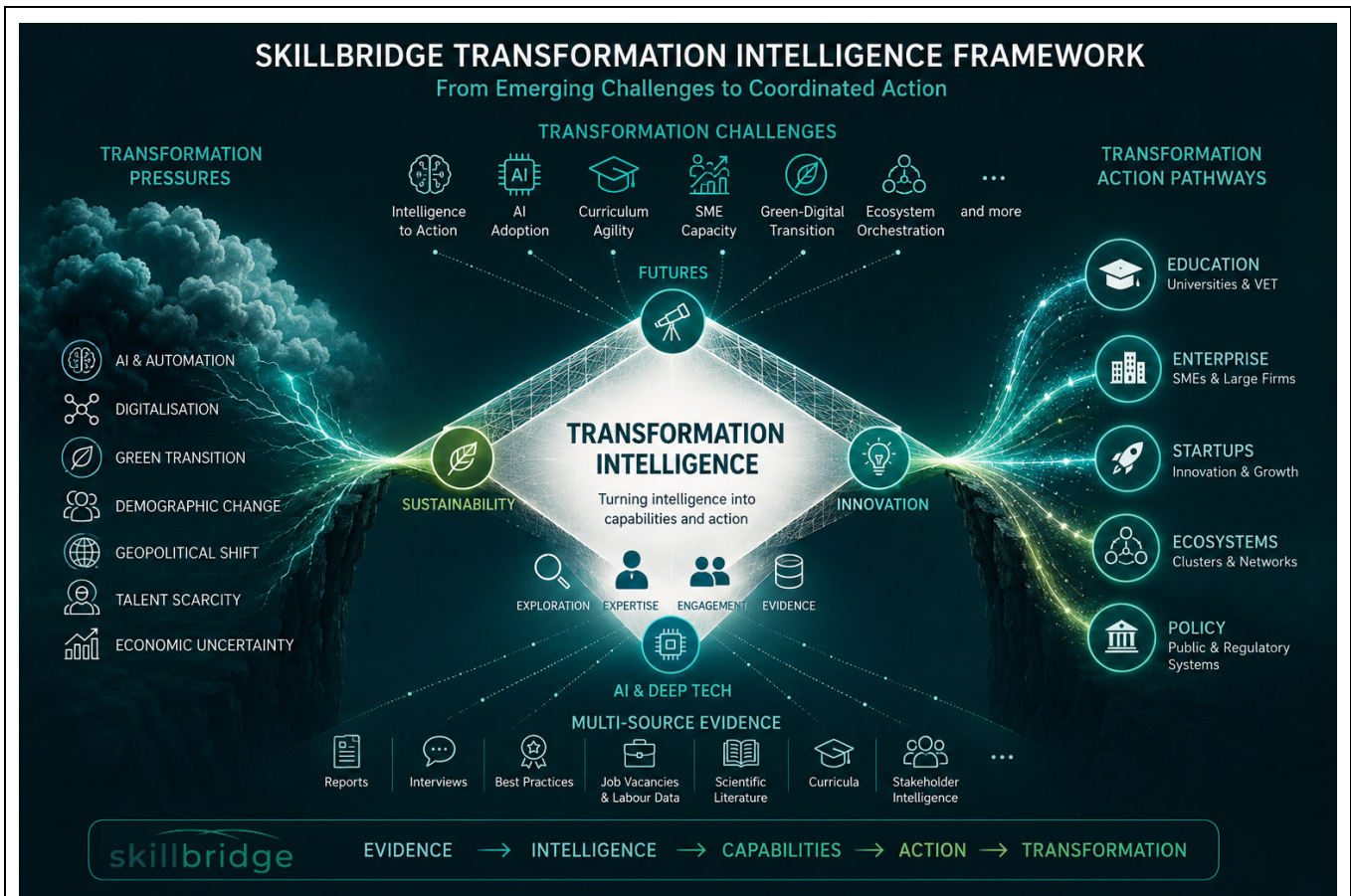


Figure 1. SKILLBRIDGE transformation intelligence framework.

Figure 1 summarizes the central proposition underpinning this paper. Transformation pressures such as artificial intelligence, digitalization, sustainability transitions, demographic change, and geopolitical uncertainty generate increasingly complex transformation challenges affecting multiple actors simultaneously. Addressing these challenges requires more than isolated interventions or reactive skills policies. It requires transformation intelligence: the ability to collect, interpret and mobilize evidence from diverse sources and translate it into capability development and coordinated action. Within the framework, the four strategic domains function as complementary capability systems, while the four capability dimensions exploration, evidence, expertise, and engagement, provide a common organizing logic for capability development. Together, these elements support multiple action pathways spanning curriculum modernization, workforce development, entrepreneurship, ecosystem orchestration and policy innovation.

The figure also highlights a broader shift in the role of intelligence systems. Rather than functioning primarily as

repositories of information, observatories and foresight systems become transformation infrastructures capable of supporting decision-making, capability formation and collective action across multiple levels of intervention. This proposition provides the foundation for the theoretical discussion developed in the next section.

2. THEORETICAL BACKGROUND

The growing prominence of artificial intelligence, digitalization, and sustainability transitions has intensified interest in mechanisms capable of anticipating future capability requirements and supporting adaptive responses across education, labor markets and innovation ecosystems. Over the past decade, substantial progress has been achieved in the development of skills intelligence systems, occupational taxonomies and labor market analytics. However, the increasing complexity of transformation processes has exposed the limitations of approaches that focus primarily on identifying skills without sufficiently addressing how intelligence is translated into capability development and systemic action.

This section introduces the conceptual progression underpinning the present study: skills intelligence, capability intelligence and transformation intelligence. Rather than representing competing approaches, these concepts can be understood as successive and complementary layers within an emerging intelligence architecture designed to support adaptation under conditions of uncertainty.

2.1 Skills intelligence

Skills intelligence has emerged as a central pillar of workforce development, education planning and labor market policy. Contemporary approaches combine labor market analytics, occupational forecasting, vacancy analysis, educational statistics, and stakeholder consultation to understand evolving skills demand. Increasingly, these approaches employ data-driven methodologies to identify emerging skill requirements and support anticipatory decision-making [4]. Cedefop [5] highlights the evolution of skills intelligence from forecasting exercises towards integrated systems supporting anticipation, matching and lifelong learning.

Similarly, the European Skills, Competences, Qualifications and Occupations framework has provided an increasingly important semantic infrastructure for harmonizing skills information across sectors, occupations, and educational contexts [6]. This policy trajectory also builds on earlier European efforts to strengthen human capital, employability and skills relevance through initiatives such as the New Skills Agenda for Europe [7].

These developments have strengthened evidence-based policymaking. Nevertheless, most skills intelligence systems remain predominantly descriptive. They identify emerging skills, monitor trends, and support labor market matching, but often provide limited guidance on translating identified needs into curriculum redesign, organizational transformation or ecosystem-level interventions. Moreover, skills intelligence frequently remains fragmented across educational, labor market, innovation and policy domains, although transformation challenges increasingly cut across institutional boundaries.

This limitation becomes particularly visible in the context of AI-driven change. Emerging capabilities often appear first as weak signals dispersed across research communities, entrepreneurial ecosystems, experimental organizational practices and informal learning environments. Consequently, the challenge is no longer merely the identification of skills but the interpretation of skills within broader transformation contexts.

2.2 Capability intelligence

The concept of capability intelligence extends traditional skills intelligence by shifting attention from individual competencies toward systems of capability creation, deployment, and adaptation.

Earlier work on anticipatory skills systems emphasized that rapidly changing environments require not only updated skills inventories but also adaptive capacities capable of responding to uncertainty and disruption [8]. This perspective is supported by innovation studies showing that organizational performance depends not simply on

individual skills, but on the ability to combine, mobilize, and transform capabilities across different innovation contexts [9]. It is further reinforced by research on knowledge intensive service activities, which shows that innovation capability depends on how organizations access, combine, and transform internal and external knowledge sources into sustained capability development [10].

The SKILLBRIDGE Handbook adopts this position through a capability architecture structured around strategic domains, capability areas and capability pathways [3]. This approach is informed by the context–people–process–impact logic embedded within the CASI-F framework, which highlights the importance of understanding capabilities as dynamic and relational phenomena rather than static inventories of competencies [11, 12, 13, 14, 15].

From this perspective, intelligence systems should support the identification of capability configurations rather than isolated skills. The resulting analytical focus moves from labor market matching toward capability formation, organizational readiness and ecosystem resilience.

The four capability diamonds introduced in this paper (Figure 6) operationalize this move by organizing capability areas within each strategic domain around creative exploration, analytical evidence, strategic expertise, interactive engagement and cross-cutting core capabilities.

2.3 Transformation intelligence

While capability intelligence expands the analytical focus beyond individual skills, transformation intelligence represents a further evolution concerned with supporting adaptation and coordinated action under uncertainty, complexity, and rapid change. The concept reflects recognition that challenges such as artificial intelligence, digital transformation, sustainability transitions and demographic change cannot be addressed through fragmented intelligence systems or isolated interventions [16].

Recent foresight research emphasizes that transformation processes unfold through non-linear interactions across technological, economic, environmental, social, and institutional systems [1]. Under such conditions, intelligence systems must move beyond monitoring trends and forecasting demand. They must also support the detection of weak signals, the interpretation of emerging dynamics, the identification of capability needs and the design of actionable transformation pathways across multiple stakeholder and decision-making contexts.

Transformation intelligence is therefore defined as the capacity to generate, integrate and mobilize diverse evidence in support of adaptive decision-making and coordinated transformation. It combines foresight, skills intelligence, capability analysis and stakeholder engagement within a common framework linking evidence with action.

This perspective is particularly relevant in AI-enabled contexts, where technological developments interact with education systems, labor markets, innovation ecosystems, governance structures and societal priorities.

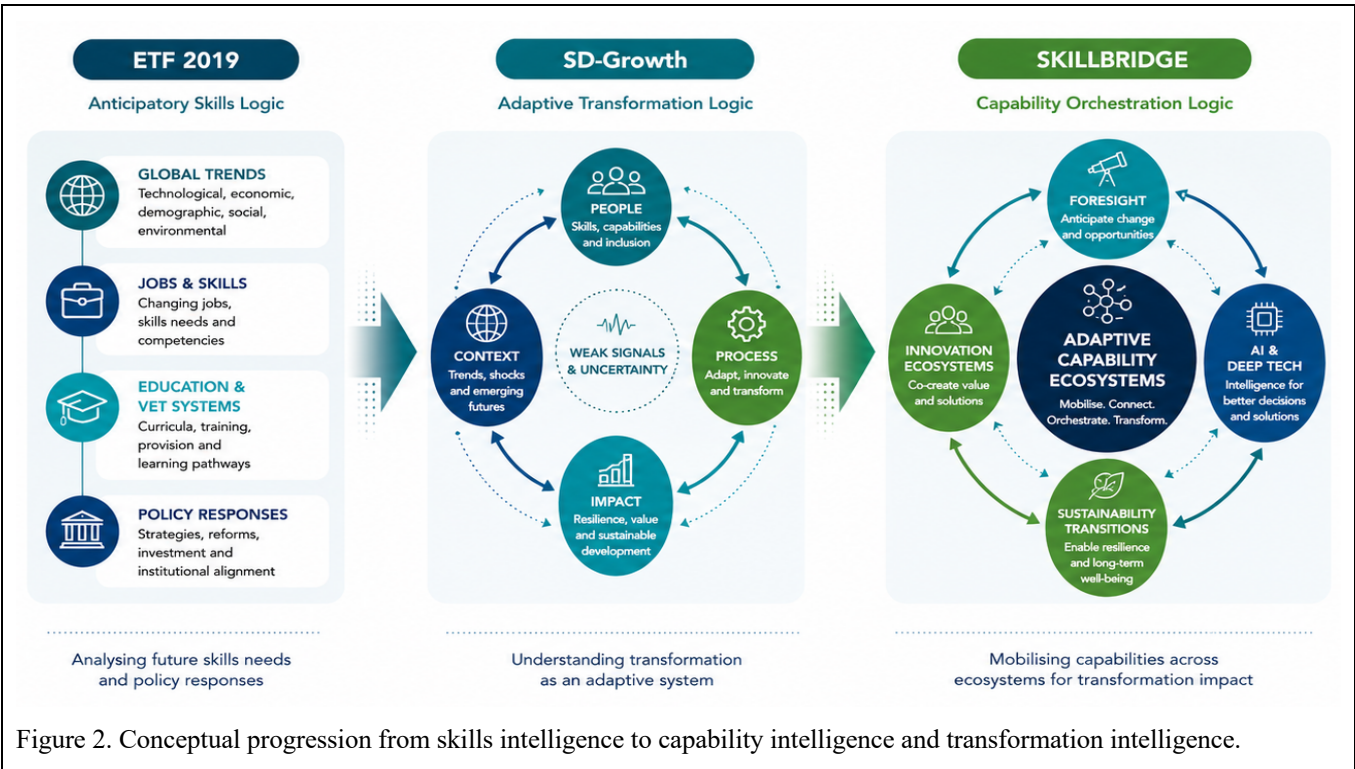
A distinguishing characteristic of transformation intelligence is its multi-actor orientation. Recent work on innovation

ecosystems, entrepreneurial universities and transformative agendas highlights the importance of collaboration between education providers, enterprises, start-ups, policymakers, researchers, and civil society actors [17]. Intelligence systems capable of supporting such interactions require shared conceptual architectures through which different actors can interpret evidence, identify priorities, and coordinate responses.

Building on these foundations, this paper proposes that skills

intelligence, capability intelligence, and transformation intelligence should be understood as complementary layers within a broader intelligence architecture.

Skills provide the evidence base. *Capabilities* provide the interpretative and organizational layer. *Transformation intelligence* provides the mechanisms through which capabilities are mobilized to address complex challenges and create desired futures.



The progression illustrated in Figure 2 reflects an expansion of analytical scope and strategic purpose. It moves from understanding what is changing, to identifying what capabilities are required, and ultimately to determining how actors can respond collectively and effectively. In this sense, observatories, foresight systems and intelligence platforms evolve from repositories of information into transformation infrastructures capable of supporting capability development, stakeholder alignment and coordinated action.

This conceptual progression provides the theoretical foundation for the SKILLBRIDGE transformation intelligence framework presented in the following section, where these principles are operationalized through a multi-source intelligence architecture, the skills observatory, strategic domains, capability areas, capability diamonds and the transformation challenge architecture. The core proposition of the SKILLBRIDGE approach is that intelligence creates value only when it can be translated into capabilities, capabilities into action, and action into transformation.

3. THE SKILLBRIDGE TRANSFORMATION INTELLIGENCE FRAMEWORK

This section defines the SKILLBRIDGE transformation intelligence framework and explains how its core constructs

are operationalized through the SKILLBRIDGE skills observatory. Building on the conceptual progression established in Section 2, the framework explains how skills intelligence can be transformed into capability intelligence, and how capability intelligence can be mobilized as transformation intelligence across education, enterprise, innovation ecosystem, and policy contexts.

The section therefore has a dual purpose. First, it presents the core conceptual architecture of SKILLBRIDGE: strategic domains, capability areas, the 4Es, capability diamonds and transformation challenges. Second, it positions these elements as an integrated and transferable framework for converting evidence into capability-based action.

For clarity, three terms are used operationally throughout the paper. *Capability architecture* refers to the overall structure that organizes skills into *strategic domains*, *capability areas* and *capability-development pathways*. *Capability areas* are intermediate categories that group related skills into actionable clusters within each strategic domain.

Capability diamonds are domain-specific analytical configurations that organize capability areas through the four dimensions of *exploration*, *evidence*, *expertise*, and *engagement*, providing a structured lens for capability prioritization and transformation.

3.1 From skills intelligence to transformation intelligence

Sections 1 and 2 argued that the growing complexity of AI-enabled transformation requires a broader intelligence paradigm than conventional skills anticipation alone. Skills intelligence remains essential for identifying emerging competences, labor market signals and changing occupational requirements. Capability intelligence extends this logic by interpreting skills as components of broader capability systems. Transformation intelligence goes further: it asks how evidence and capabilities can be mobilized to support coordinated action under conditions of uncertainty.

Transformation intelligence is defined here as the capability to collect, interpret, integrate, and mobilize diverse forms of evidence to support adaptive decision-making and coordinated action across multiple actor groups and levels of intervention. Unlike traditional intelligence systems that often focus on monitoring trends or forecasting demand, transformation intelligence connects evidence with capability development, capability development with strategic action, and strategic action with transformation outcomes.

This perspective reflects a broader evolution in foresight, innovation and capability-oriented thinking. Earlier anticipatory approaches focused primarily on identifying future developments and emerging opportunities. More recent work has emphasized adaptive capacity, resilience, mission-oriented transformation and ecosystem-level change, recognizing that the value of intelligence lies not only in prediction but also in enabling actors to navigate uncertainty and shape preferred futures.

Within this context, skills represent an important but partial layer of a broader transformation architecture. Skills provide evidence about emerging requirements, but transformation challenges are rarely expressed only at the level of individual skills. They manifest through organizational capabilities, institutional arrangements, ecosystem dynamics, implementation capacities and the ability of actors to mobilize knowledge across disciplinary and sectoral boundaries. Consequently, intelligence systems capable of supporting transformation must move beyond identifying skills shortages and begin to address capability formation, organizational adaptation and ecosystem coordination.

The SKILLBRIDGE framework operationalizes this shift through a sequence of interconnected intelligence layers. Multi-source evidence is translated into skills intelligence; skills intelligence is aggregated into capability intelligence through the identification of capability patterns and priorities; and capability intelligence is linked to transformation intelligence through the interpretation of transformation challenges and the design of action pathways.

Beyond its conceptual contribution, early evidence from SKILLBRIDGE suggests that transformation intelligence can function as more than an analytical framework. During the early stages of implementation, the approach has shown a potential ability to mobilize educators, program leaders, enterprises, and ecosystem actors around shared capability priorities.

This is significant because it indicates that the value of intelligence lies not only in its capacity to describe change but also in its ability to stimulate coordinated responses to change.

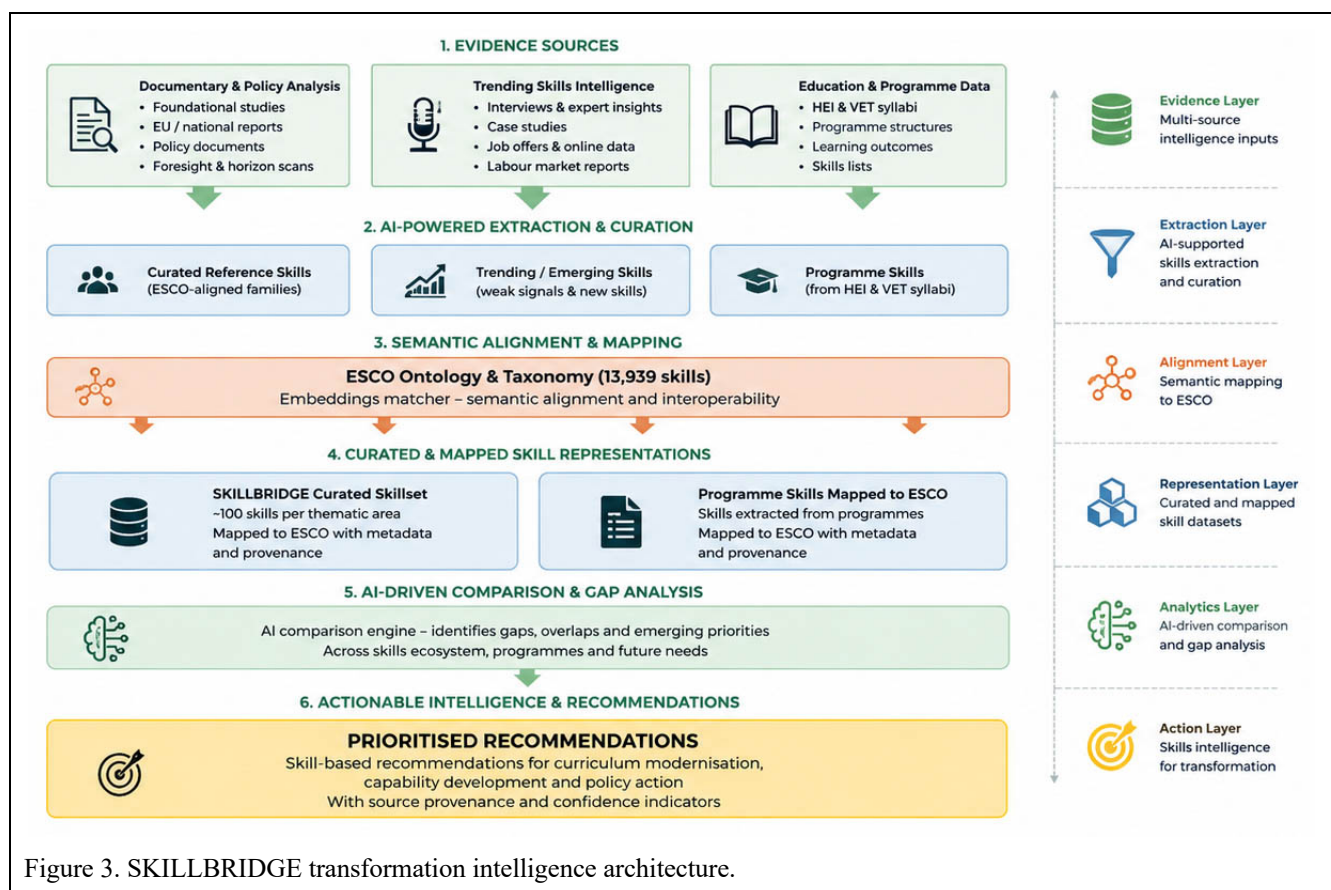


Figure 3. SKILLBRIDGE transformation intelligence architecture.

Figure 3 illustrates this operational progression. Multi-source evidence originating from foresight studies, labor market analysis, policy intelligence, stakeholder engagement, best practice cases and educational programs is processed through the SKILLBRIDGE skills observatory. The resulting intelligence is organized into strategic domains, capability areas, and capability diamonds, which together provide a structured mechanism for identifying capability priorities and addressing transformation challenges.

3.2 SKILLBRIDGE capability architecture

The transition from skills intelligence to transformation intelligence requires an intermediate layer capable of translating fragmented skills evidence into coherent capability systems. Within SKILLBRIDGE, this function is performed by the capability architecture, which provides the conceptual and operational backbone linking intelligence generation with transformation action.

The capability architecture emerged from the recognition that individual skills rarely operate in isolation. Contemporary transformation challenges, including AI

adoption, sustainability transitions, entrepreneurial innovation, workforce reskilling, curriculum modernization and organizational adaptation, require combinations of technical, operational, political, prospective, social, and ethical capacities that cannot be adequately represented through isolated skill records alone [18].

SKILLBRIDGE organizes this architecture through four strategic domains (Figure 4):

1. Foresight and futures intelligence
2. AI and deep tech systems
3. Innovation and entrepreneurship systems
4. Sustainability and green transition systems

Figure 4 summarizes the role of each strategic domain as a transferable capability system supporting transformation across educational, organizational, and ecosystem contexts. These domains should not be interpreted as disciplinary silos, sector-specific categories or thematic labels. Instead, they provide a structured lens for interpreting emerging skills, capability needs, and transformation priorities across education, enterprises, innovation ecosystems, regional development initiatives, and policy environments.

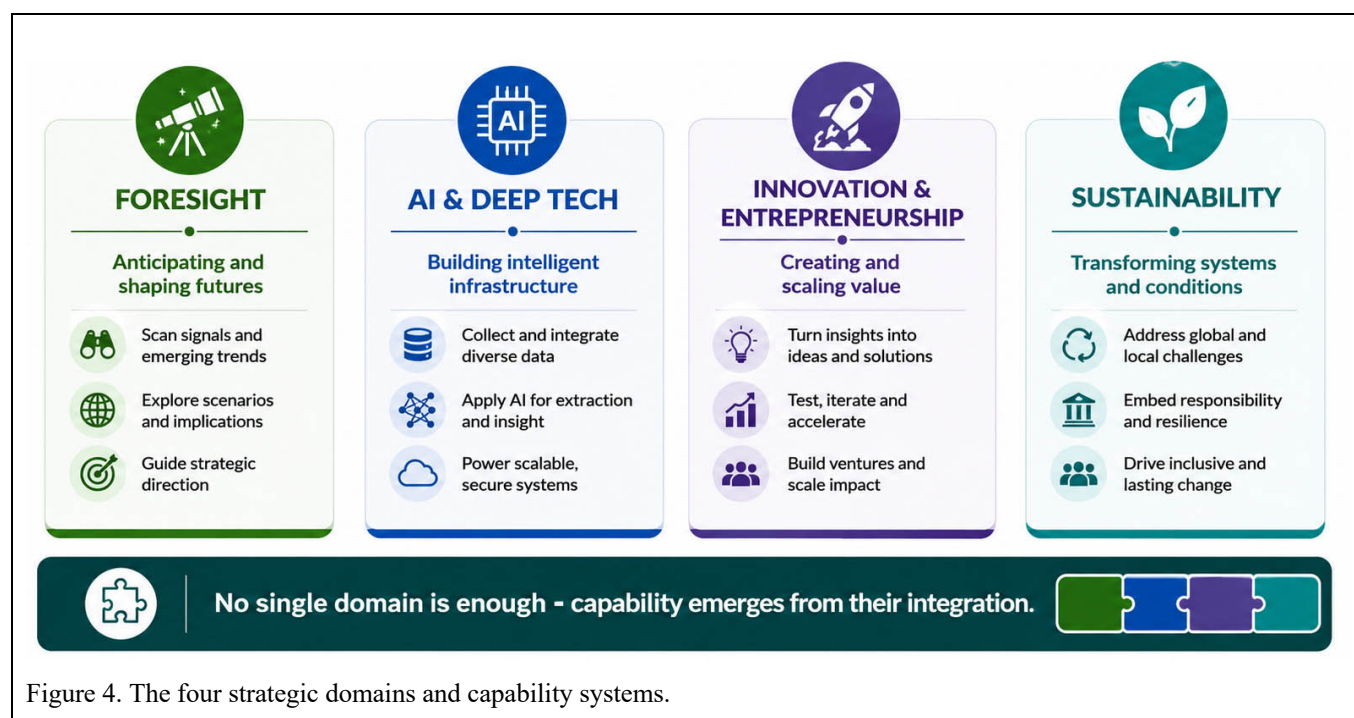


Figure 4. The four strategic domains and capability systems.

Each strategic domain contains twenty-five capability areas, creating a shared architecture through which skills can be clustered, interpreted, and prioritized. Capability areas function as the critical translation layer between granular skills intelligence and higher-level transformation objectives. Rather than relying on extensive lists of emerging skills, they enable the identification of more stable, actionable, and transferable capability patterns that can support curriculum modernization, workforce development and ecosystem transformation.

This distinction between skills and capabilities is fundamental. Skills describe specific competences, tasks, or knowledge elements that can be acquired, assessed, or observed. Capabilities describe the capacity to mobilize

skills, knowledge, resources, judgement and relationships to achieve desired outcomes under changing conditions. While skills provide the building blocks of adaptation, capabilities provide the mechanisms through which adaptation, resilience, and transformation become possible.

To ensure coherence across domains, the capability architecture is organized around four complementary capability dimensions: exploration, evidence, expertise, and engagement. Collectively referred to as the 4Es, these dimensions constitute the shared activation logic of the SKILLBRIDGE capability diamond, revealing the underlying capability DNA of each capability area and how different combinations of the 4Es contribute to capability development and transformation readiness.

The Capability Diamond (The 4Es)

Exploration, Evidence, Expertise and Engagement



Figure 5. The capability diamond and the 4Es.

The shared activation logic underpinning all capability areas is represented through the *capability diamond* shown in Figure 5. *Exploration* concerns emerging opportunities, risks, trends, and alternative futures. *Evidence* relates to generating and applying intelligence from diverse data and knowledge sources. *Expertise* encompasses the capabilities required for effective action. *Engagement* captures the collaborative and ecosystem-oriented capabilities supporting collective action and transformation.

The 4Es provide a common organizing logic across all strategic domains and capability areas. Building on the logic of the *Foresight Diamond* [19, 20], which characterizes foresight methods according to different knowledge and intelligence dimensions, the capability diamond applies a similar principle to capability systems. Rather than describing methodological configurations, it reveals the underlying capability DNA through which transformation capabilities are developed, combined, and mobilized. Rather than privileging technical knowledge alone, the framework recognizes that effective transformation depends on the balanced interaction of anticipatory thinking, evidence generation, specialized competences, and stakeholder collaboration. This balance is particularly important in AI-enabled contexts, where technological capabilities must be combined with ethical awareness, organizational readiness, societal engagement, and long-term strategic thinking.

The practical relevance of the capability architecture can be examined through its application in curriculum modernization workshops, program-level analyses and stakeholder validation activities across participating countries. Although originally developed to support a defined set of pilot institutions, the architecture appears sufficiently flexible to be applied across diverse educational contexts and disciplinary domains. Its value lies not in prescribing uniform solutions but in providing a shared

language through which different actors can interpret emerging challenges, compare capability profiles and identify transformation priorities.

The capability architecture provides the structural foundation of the SKILLBRIDGE approach. However, capabilities alone do not generate transformation. Transformation emerges when capabilities are mobilized in response to specific challenges, opportunities and strategic objectives. For this reason, the capability architecture is embedded within a broader transformation intelligence framework that connects evidence generation, capability development and transformation action.

The framework responds to a recurring challenge identified throughout both the literature and the empirical evidence gathered by SKILLBRIDGE: actors rarely struggle because they lack information alone. More often, they struggle because available evidence remains fragmented, disconnected from decision-making processes or insufficiently translated into coordinated action. The challenge is therefore not simply informational but transformational.

The SKILLBRIDGE transformation intelligence framework integrates three complementary functions: intelligence generation, capability formation and transformation action. Intelligence generation draws upon multiple evidence streams, including foresight studies, labor market intelligence, stakeholder interviews, best practice cases, program documentation, policy reports and scientific literature. Capability formation translates these signals into structured capability systems through strategic domains, capability areas and capability diamonds. Transformation action mobilizes these capabilities to address concrete transformation challenges and support adaptation across educational, organizational and ecosystem contexts.

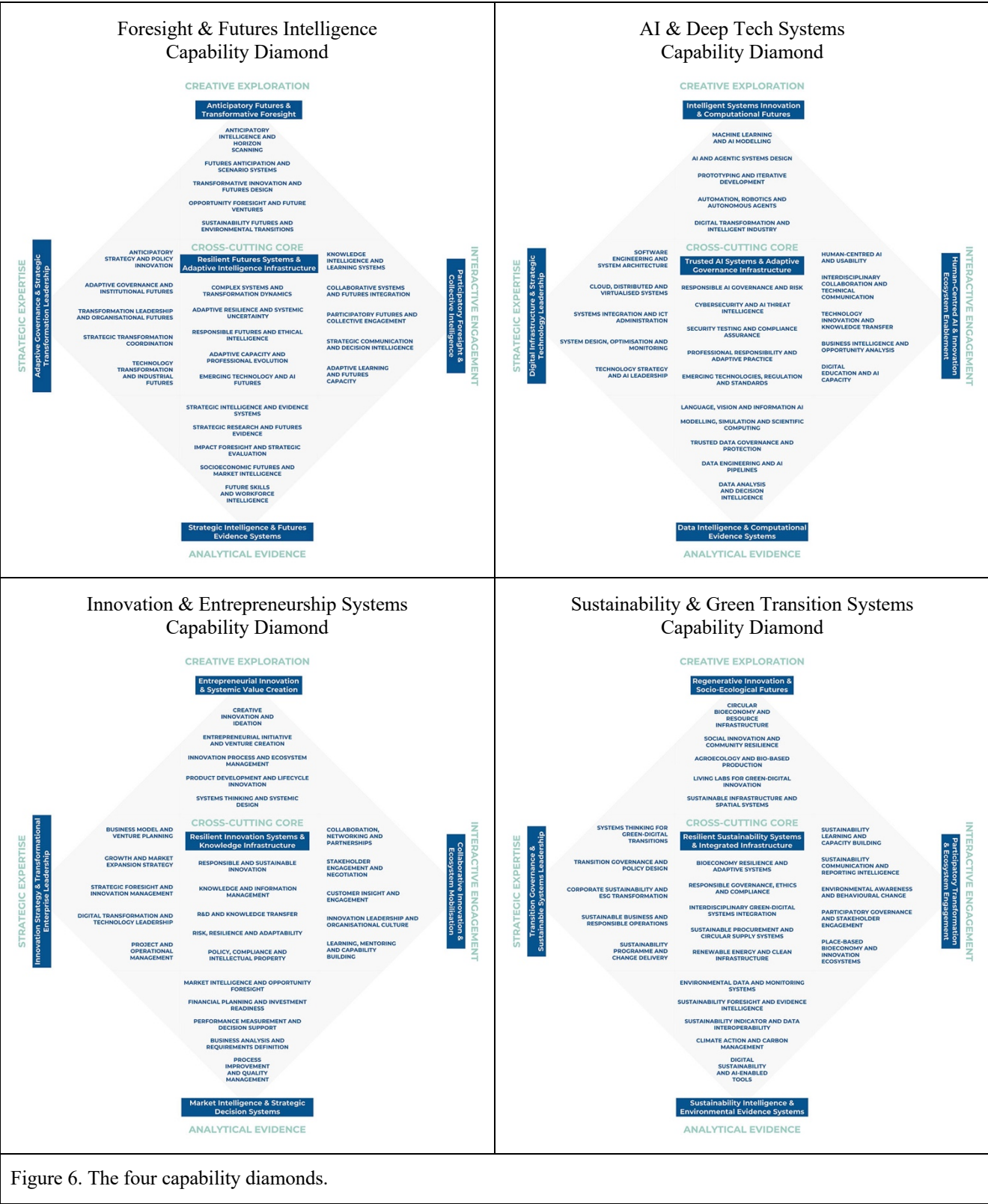


Figure 6. The four capability diamonds.

Figure 6 illustrates how the common 4Es logic is operationalized across the four strategic domains through domain-specific capability diamonds. Organized around exploration, evidence, expertise and engagement, they provide a common capability language. Their role is not to prescribe solutions but to support evidence interpretation, intervention prioritization, and context-sensitive transformation pathways. Evidence from the five participating countries reveals recurring challenges

associated with intelligence-to-action gaps, strategy-to-implementation gaps, AI adoption, sustainability operationalization, workforce adaptation, innovation translation, and ecosystem orchestration. While these challenges manifest differently across sectors and territories, they often depend on similar capability requirements. This observation provides preliminary support for transferable capability systems as a foundation for transformation-oriented intelligence.

A central contribution of the framework is therefore the introduction of a transformation challenge architecture that complements the capability architecture. Together, these two structures create a bridge between what actors need to develop (capabilities) and what they seek to address (transformation challenges). This dual perspective enables the same intelligence system to support curriculum modernization, workforce development, enterprise transformation, ecosystem strengthening and policy design.

Early implementation results further suggest that stakeholders are not primarily seeking lists of future skills. Rather, they seek mechanisms capable of helping them interpret complexity, prioritize action, and coordinate transformation efforts. The transformation intelligence framework responds to this need by positioning intelligence not as an end in itself but as a catalyst for capability development, collective sensemaking, and adaptive transformation.

3.3 Skills observatory as an intelligence infrastructure

The operationalization of the transformation intelligence framework is enabled through the SKILLBRIDGE skills observatory. While observatories are often understood as repositories of information or monitoring platforms, the SKILLBRIDGE skills observatory is conceptualized as an intelligence infrastructure capable of supporting the generation, integration, and mobilization of knowledge across multiple domains and actor groups.

The observatory combines artificial intelligence, semantic analysis, foresight methodologies, and expert validation to transform heterogeneous evidence into actionable intelligence. Rather than relying on a single source of information, it integrates multiple evidence streams, including labor market intelligence, stakeholder interviews, best practice repositories, scientific literature, program documentation, policy analyses and transformation reports. This multi-source approach reflects the assumption that no single dataset can adequately capture the complexity of contemporary transformation processes.

The skills observatory architecture is grounded in the SKILLBRIDGE capability architecture and technically implemented through a modular, AI-supported and human-validated intelligence pipeline. Its function is not limited to extracting skills from text. It structures evidence, supports semantic interoperability, preserves provenance, enables comparison, and provides an analytical basis for program modernization, capability prioritization and action road-mapping.

The architecture follows progression from evidence acquisition to intelligence generation. Raw information is collected and processed through AI-assisted extraction and semantic analysis procedures. Emerging skills are subsequently mapped to ESCO and organized into the SKILLBRIDGE capability architecture. Human-in-the-loop validation ensures methodological robustness while preserving the flexibility necessary to capture emerging, weakly codified and context-specific developments.

The resulting intelligence is structured through the four strategic domains and their associated capability areas. This

organization enables the observatory to move beyond isolated skill records and towards the identification of capability patterns, emerging priorities and transformation-relevant signals. Consequently, the observatory functions not only as a monitoring mechanism but also as a translation mechanism linking evidence with action.

SKILLBRIDGE's observatory also supports collective sensemaking by providing a shared evidence base and common capability language for stakeholder dialogue. The skills observatory therefore occupies a central position within the SKILLBRIDGE transformation intelligence framework. It provides the infrastructure through which evidence becomes intelligence, intelligence becomes capability priorities, and capability priorities become transformation pathways.

3.4 From observatory intelligence to curriculum modernization and transformation action

The ultimate value of transformation intelligence lies in its capacity to support action. For this reason, the SKILLBRIDGE framework extends beyond intelligence generation and capability modeling to include mechanisms capable of informing curriculum modernization, organizational development and ecosystem transformation.

One of the first operational applications of this approach is the Programme Alignment Analysis developed within SKILLBRIDGE. Building upon the capability architecture and skills observatory outputs, the analysis provides a structured method for examining how educational programs connect with emerging capability priorities, addressing challenges frequently identified in curriculum–labor market alignment research [21]. The approach identifies documented alignment signals between program evidence and observatory-derived capability areas, creating a basis for reflection, stakeholder dialogue and future-oriented curriculum modernization.

This distinction is important. A documented alignment signal does not imply comprehensive coverage, pedagogical quality or strategic superiority. Instead, it indicates that program documentation demonstrates an observable connection with a particular capability area. The purpose of the analysis is interpretative rather than evaluative. It provides a basis for dialogue, reflection, and future-oriented curriculum development.

The approach has been applied as an exploratory empirical demonstration that draws on program-alignment analyses conducted across more than forty HEI and VET programs.

This expansion reflects implementation progress and growing stakeholder interest in capability-based approaches to curriculum and organizational development.

Equally important is the fact that the same capability logic can be applied beyond educational settings. In the *education track*, capability diamonds support curriculum modernization in HEI and VET contexts. In the *innovation, enterprise and ecosystem track*, the same capability architecture helps interpret and address transformation challenges affecting enterprises, start-ups, regions, and policy systems. This transferability is central to the SKILLBRIDGE contribution.

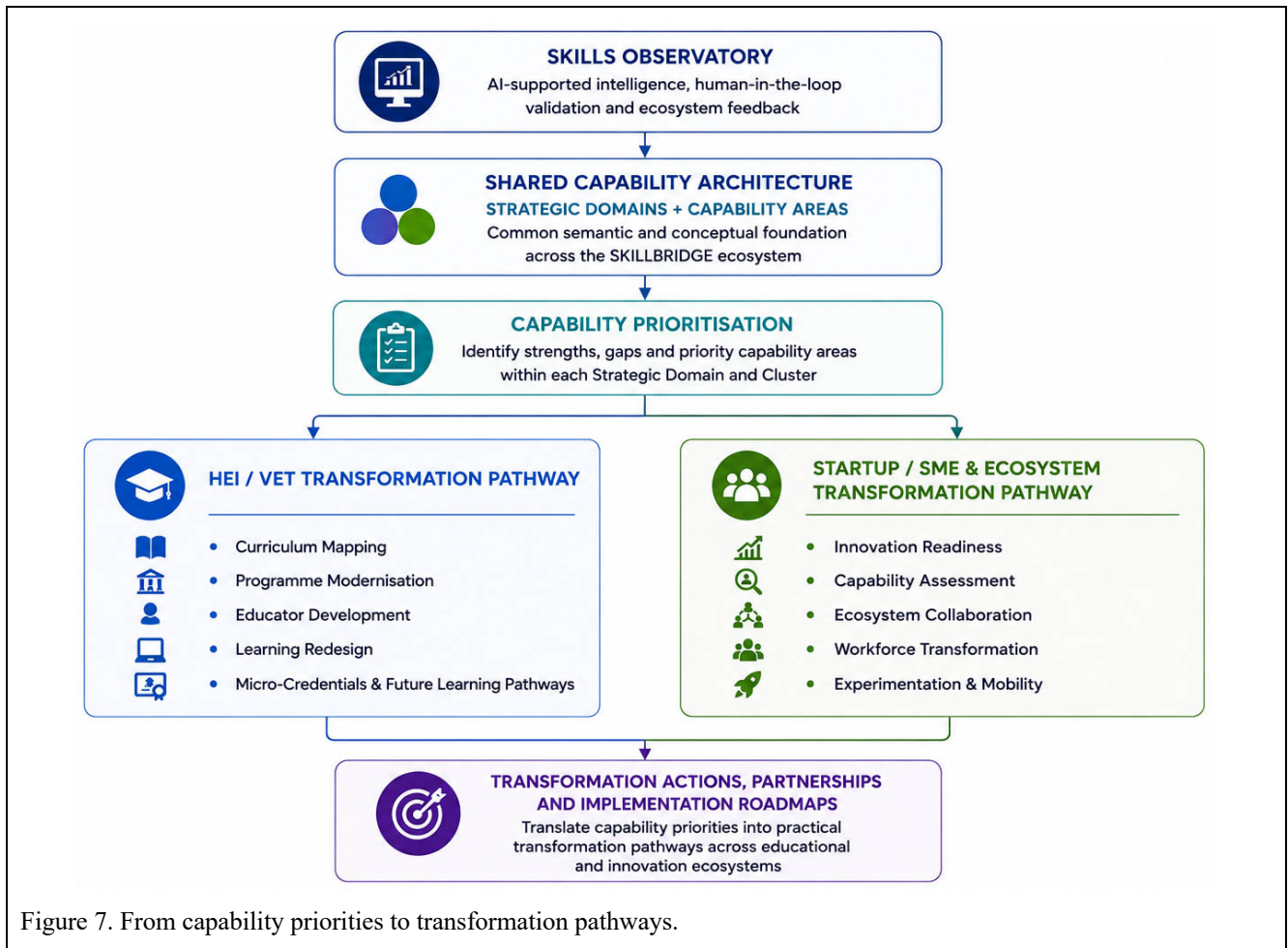


Figure 7. From capability priorities to transformation pathways.

Figure 7 illustrates how observatory intelligence is translated into capability prioritization and educational and ecosystem transformation pathways. In this paper, the program alignment analysis is treated as a proof-of-concept method for translating observatory outputs into program-level transformation signals, building on curriculum analytics and skills-based program analysis [22]. It demonstrates how observatory intelligence can inform action. By linking evidence, capabilities and stakeholder dialogue, the approach helps transform intelligence into decisions, decisions into interventions, and interventions into transformation.

A significant insight from the early implementation of SKILLBRIDGE is that capability intelligence is not generated solely through AI-supported analysis or expert interpretation. Rather, it is co-produced through structured engagement processes in which educators, learners, program leaders, enterprises, policymakers, and ecosystem actors collectively interpret, validate, and prioritize capability needs. This participatory dimension extends the role of the skills observatory beyond intelligence generation, positioning it as an emerging transformation infrastructure. The resulting approach may be described as participatory capability intelligence: the integration of evidence, expert knowledge, and stakeholder perspectives to identify context-specific capability priorities and transformation pathways. As the project progresses, this cycle is expected to support curriculum modernization, workforce development and ecosystem transformation.

More broadly, the early trajectory of SKILLBRIDGE suggests that the framework possesses characteristics associated with scalability, transferability, and stakeholder legitimacy. Although originally designed to support the modernization of a defined set of pilot programs, its application has expanded rapidly across institutions and contexts, generating sustained demand for further analysis, prioritization and transformation support. This observation reinforces the central proposition of this paper: that the future of skills observatories lies not in the production of increasingly sophisticated skills inventories, but in their evolution into transformation intelligence infrastructures capable of supporting adaptive capability ecosystems and coordinated action across education, enterprise, innovation, and policy domains.

The following section examines how this capability intelligence cycle is operationalized through the SKILLBRIDGE skills observatory, including the multi-source evidence architecture, AI-supported analytical processes, participatory prioritization mechanisms and program-alignment methodologies that collectively underpin the framework.

4. OPERATIONALIZING TRANSFORMATION INTELLIGENCE THROUGH THE SKILLBRIDGE SKILLS OBSERVATORY

The conceptual framework presented in Section 3 establishes the foundations of transformation intelligence and the role of the capability architecture in translating skills evidence into

transformation-oriented action. The next challenge concerns operationalization. If transformation intelligence is to function as more than a conceptual construct, it requires mechanisms capable of systematically collecting evidence, generating intelligence, supporting prioritization, and enabling action across diverse contexts and stakeholder groups.

The SKILLBRIDGE skills observatory was developed to address this challenge. Rather than functioning as a conventional skills-monitoring platform, the observatory serves as an intelligence infrastructure designed to support the continuous generation, interpretation, and mobilization of knowledge across education, enterprise, innovation, and policy domains. It combines artificial intelligence, foresight methodologies, semantic interoperability, expert validation, and stakeholder engagement into an integrated capability intelligence cycle capable of supporting adaptive transformation.

This section describes the methodological architecture underpinning this process. Particular attention is given to four interconnected components: (i) the multi-source intelligence architecture; (ii) the AI-supported capability intelligence pipeline; (iii) the participatory capability-prioritization process; and (iv) the program-alignment methodology through which intelligence is translated into curriculum modernization and transformation signals.

4.1 Multi-source intelligence architecture

The SKILLBRIDGE skills observatory was designed around the premise that no single source of information can adequately capture the complexity of contemporary transformation processes. Skills demand, capability needs and transformation priorities emerge simultaneously across labor markets, educational systems, innovation ecosystems, public institutions and broader societal contexts. Consequently, the observatory adopts a multi-source

intelligence architecture capable of integrating heterogeneous forms of evidence while preserving provenance and contextual richness.

The evidence base includes six categories of sources:

1. Scientific and strategic references;
2. labor market and job-vacancy intelligence;
3. stakeholder interviews;
4. best practice cases;
5. transformation reports and policy documents;
6. educational program documentation.

Together, these sources provide complementary perspectives on emerging capability requirements and transformation dynamics.

Labor market evidence highlights demand signals, drawing on online vacancy intelligence approaches similar to Skills-OVATE and other European labor market intelligence infrastructures, including Cedefop Skills Intelligence [23, 24], and wider developments in data-driven job-market analysis [25]. Educational programs provide visibility into supply. Interviews and workshops capture tacit knowledge, contextual experience and practitioner perspectives. Best practice cases reveal successful adaptation pathways, while reports and foresight studies contribute longer-term perspectives on technological, economic, environmental, political and societal change.

The resulting architecture differs from traditional observatory models in two important respects. First, it combines retrospective, descriptive and anticipatory forms of intelligence within a single framework. Second, it treats intelligence generation as a continuous learning cycle rather than a one-off analytical exercise. New evidence informs capability prioritization, while stakeholder engagement contributes interpretation and validation, creating an adaptive transformation cycle that connects intelligence, capabilities, action, and impact (Figure 8).

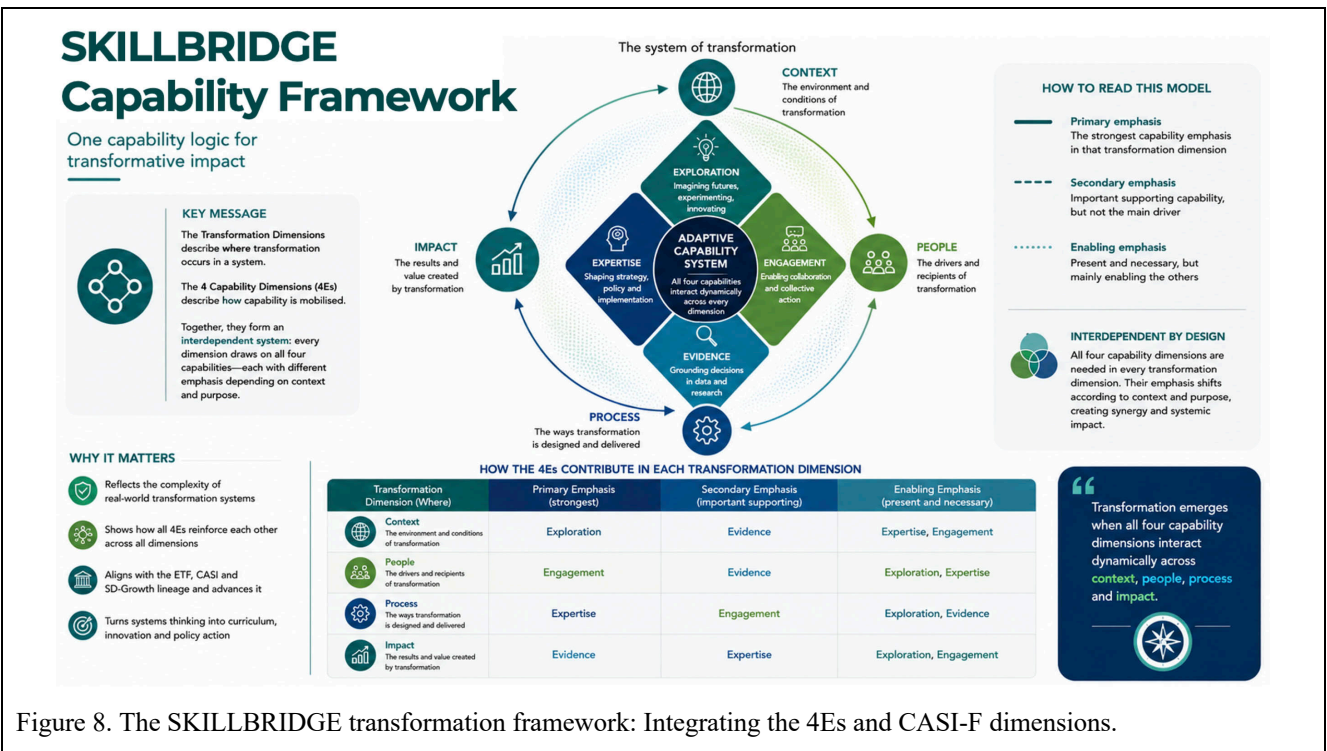


Figure 8. The SKILLBRIDGE transformation framework: Integrating the 4Es and CASI-F dimensions.

Figure 8 extends the capability diamond by integrating the 4Es with the CASI-F transformation dimensions (*context, people, process* and *impact*), providing a systemic model of how capabilities generate transformation outcomes. While the 4Es describe how capabilities are mobilized, the transformation dimensions indicate where transformation occurs. Together, they create an adaptive system through which intelligence is translated into action and impact. The framework highlights that sustainable transformation emerges not from technological capabilities alone but from the interplay of capabilities, actors, processes and context.

4.2 AI-assisted capability intelligence pipeline

The transformation of heterogeneous evidence into actionable intelligence requires analytical processes capable of operating at scale while preserving transparency, explainability and expert oversight. For this reason, the observatory combines AI-assisted extraction and semantic analysis with human-in-the-loop validation procedures.

Large Language Models (LLMs) are used as analytical accelerators rather than autonomous decision-makers, consistent with recent applications for skill and occupation extraction from unstructured text [26]. Their role includes information extraction, semantic clustering, skill normalization, and capability mapping. Interpretation, prioritization, and validation remain the responsibility of project experts and stakeholders.

In implementation terms, the current pipeline uses controlled LLM workflows supported by retrieval-augmented and context-injected prompting, building on the more detailed observatory implementation described in *AI-Driven Foresight Model for Skills Intelligence* [27]. For each analytical task, the model receives a task-specific prompt template together with retrieved contextual evidence, including source-document excerpts, relevant ESCO descriptors, domain labels, capability area definitions and, where applicable, examples of previously validated outputs. Prompts are structured to constrain the model's role, input scope, output schema, and decision criteria for candidate-skill extraction, duplicate detection, semantic refinement, ESCO comparison and provisional capability mapping.

The pipeline combines zero-shot and few-shot instructions, schema-constrained outputs and validation-oriented prompts that require the model to distinguish between explicit skills, inferred skills, weak signals, and non-matched emerging capabilities. Model outputs are stored with source provenance, prompt version and intermediate classification metadata, and are reviewed by project experts before being used in program-alignment analyses.

A central feature of the methodology is semantic interoperability through the ESCO ontology and skills dataset [6, 28], building on ontology-based approaches to skills intelligence and matching [29]. Rather than replacing European taxonomies, SKILLBRIDGE uses ESCO as a semantic backbone for comparability and integration. The methodology recognizes that emerging skills, capabilities and transformation signals may not be represented in classifications. Consequently, non-matched skills are treated as weak signals requiring expert review rather than discarded anomalies.

The analytical pipeline follows a progressive sequence:

Evidence Sources → Skills Extraction → ESCO Alignment → Capability Mapping → Capability Intelligence

This progression allows the observatory to move beyond isolated skills inventories and towards the identification of recurring capability patterns, emerging priorities and transformation-relevant signals.

A particularly important methodological innovation concerns the transition from skills to capabilities. Rather than presenting extensive lists of extracted skills, the observatory aggregates intelligence through the capability areas and strategic domains defined by the SKILLBRIDGE capability architecture. This intermediate layer significantly enhances interpretability and enables intelligence outputs to support curriculum design, organizational development and ecosystem planning.

The resulting intelligence therefore becomes simultaneously more manageable, more actionable and more transferable across contexts.

4.3 Participatory capability intelligence and prioritization

While AI can accelerate intelligence generation, capability priorities ultimately emerge through processes of interpretation, deliberation and collective sensemaking. For this reason, the SKILLBRIDGE methodology incorporates structured stakeholder engagement as an integral component of intelligence generation rather than treating validation as a separate activity.

Building upon observatory outputs, workshop participants are invited to examine capability areas, discuss their relevance and identify priorities within specific institutional, disciplinary or regional contexts. This process transforms static intelligence outputs into context-sensitive capability-development agendas.

The resulting approach is described in this paper as participatory capability intelligence. Participatory capability intelligence refers to the systematic integration of evidence, expert knowledge and stakeholder perspectives for the purpose of identifying capability priorities and transformation pathways. Rather than assuming that capability priorities can be derived solely from data, the methodology recognizes that meaningful prioritization requires contextual interpretation and stakeholder ownership. This process is operationalized through the capability diamonds. By organizing capability areas around exploration, evidence, expertise, and engagement, the diamonds provide an intuitive and transferable mechanism for discussing capability development needs. Participants are therefore able to move beyond individual skills and focus on broader transformation capacities relevant to their programs, organizations or ecosystems.

The workshops conducted to date suggest that this approach generates significantly richer discussions than traditional skills-gap exercises. Participants consistently engage not only with individual skills but also with strategic questions concerning institutional readiness, curriculum innovation, educator development, organizational transformation and ecosystem collaboration.

Consequently, stakeholder engagement functions not merely as a validation mechanism but as a capability intelligence mechanism in its own right.

4.4 Program alignment analysis and transformation signals

The final stage of the capability intelligence cycle concerns the translation of prioritized capability intelligence into actionable transformation signals.

To support this objective, SKILLBRIDGE developed a program alignment analysis methodology that compares program evidence with observatory-derived capability areas. Importantly, the methodology does not seek to rank programs, evaluate quality or calculate deficit scores. Instead, it identifies documented alignment signals indicating observable connections between program content and specific capability priorities.

This distinction is critical. Capability development is inherently contextual, and educational programs differ significantly in purpose, scope, disciplinary orientation, and institutional context. Consequently, simplistic coverage scores or gap indicators risk generating misleading interpretations. The objective of the analysis is therefore interpretative rather than evaluative.

The methodology enables program teams to:

- visualize capability profiles;
- identify strengths and opportunities;
- explore capability priorities emerging from observatory intelligence;
- support curriculum modernization discussions;
- inform future action roadmaps.

More importantly, the same analytical logic can be extended beyond educational settings. Capability profiles can support workforce-development initiatives in enterprises, innovation-readiness assessments in start-ups, ecosystem-development strategies and policy-oriented transformation planning.

The program alignment analysis therefore represents the first operational demonstration of how transformation intelligence can be translated into practical decision-support mechanisms. Rather than producing static assessments, it creates a structured basis for dialogue, prioritization and action.

Taken together, the multi-source intelligence architecture, AI-assisted capability intelligence pipeline, participatory prioritization process and program-alignment methodology form the operational core of the SKILLBRIDGE transformation intelligence framework.

The next section examines the evidence generated through this approach and explores how skills intelligence, capability intelligence and transformation intelligence converge to reveal recurring capability priorities, cross-cutting transformation challenges and emerging pathways for curriculum modernization, workforce development, ecosystem strengthening, and coordinated transformation action, including capability prioritization, intervention design, and the identification of scalable transformation pathways across diverse contexts.

5. Early evidence: Program alignment, transformation challenges and emerging demand

The operationalization of the transformation intelligence framework has generated a growing body of evidence spanning educational programs, labor market signals, stakeholder perspectives, best practice cases and transformation-oriented reports. Although the project remains in the early stages of implementation, the evidence accumulated to date already provides valuable insights into emerging capability priorities, recurring transformation challenges, and the practical applicability of the framework across different institutional and national contexts.

Rather than presenting findings as isolated outputs, this section organizes the evidence according to the three analytical layers introduced throughout the paper: skills intelligence, capability intelligence and transformation intelligence. This progression reflects the central proposition of the SKILLBRIDGE approach: intelligence becomes increasingly valuable when it moves beyond the identification of individual skills and contributes to the interpretation of capability needs, transformation challenges and coordinated intervention pathways.

5.1 Skills intelligence: Emerging signals and capability patterns

The first layer of findings concerns the generation of skills intelligence through the SKILLBRIDGE skills observatory. Analysis of the multi-source evidence base, including scientific literature, policy and labor market reports, stakeholder interviews, best practice cases and educational programs, reveals a consistent emphasis on AI-related capabilities, digital transformation skills, sustainability competences, entrepreneurial capacities and futures-oriented skills across the five participating countries.

Beyond the identification of individual skills, the analysis highlights a more significant pattern. Emerging skills rarely appear in isolation; rather, they cluster around broader capability systems that cut across sectors, occupations and educational contexts. This finding supports the central premise of the SKILLBRIDGE capability architecture: the most actionable forms of intelligence are not extensive inventories of skills, but structured capability patterns capable of informing strategic decision-making and prioritization.

A second important observation concerns the identification of emerging and weakly codified skills that do not align fully with existing classification frameworks. Rather than being treated as anomalies, these signals provide valuable indications of evolving capability requirements and areas where existing taxonomies may lag behind technological and societal change. Their presence reinforces the importance of combining semantic interoperability with anticipatory intelligence approaches capable of detecting emerging developments before they become formally institutionalized.

Collectively, these findings suggest that skills intelligence remains an essential foundation for transformation-oriented decision-making, but its value increases when interpreted through capability structures that reveal underlying patterns, priorities and emerging capability needs.

5.2 Capability intelligence: Cross-country priorities and capability areas

The second layer of findings concerns capability intelligence. Through the aggregation of skills into capability areas and strategic domains, the observatory provides a richer and more actionable understanding of capability-development priorities.

Evidence gathered across the participating countries demonstrates both convergence and diversity. While national contexts differ in terms of economic structure, educational systems, innovation capacity, and institutional arrangements, several recurring capability themes appear consistently across the evidence base.

Among the most prominent are:

- AI and responsible digital transformation capabilities;
- innovation and entrepreneurial capacities;
- sustainability implementation and systems-thinking capabilities;
- foresight, anticipation and strategic adaptation capabilities;
- collaboration, stakeholder engagement and ecosystem-building capacities.

Importantly, these priorities extend beyond technical expertise. Capability areas associated with exploration and engagement repeatedly emerge alongside more technical capability requirements. This finding reinforces the central role of the 4Es framework and suggests that effective transformation depends on balancing technical, analytical, anticipatory, and collaborative dimensions.

The workshop prioritization exercises conducted within SKILLBRIDGE provide additional support for this interpretation. Participants consistently engage more readily with capability areas than with isolated skill lists. Capability areas appear to provide an effective intermediate layer between intelligence generation and practical decision-making, enabling stakeholders to discuss future needs in ways that are both actionable and context-sensitive.

A second important observation concerns the transferability of the capability architecture. Although originally developed within the context of curriculum modernization, the same capability structures prove relevant for workforce development, innovation support, ecosystem strengthening and policy design. This reinforces the argument that the strategic domains and capability areas function as transferable capability systems rather than education-specific frameworks.

Table 1: Illustrative capability priorities emerging across countries and evidence streams

Capability Priority	Dominant Evidence Streams	Indicative Relevance
AI literacy and responsible AI adoption	Reports, interviews, job vacancies, programs	Trustworthy AI and digital transformation
Data-informed decision-making and analytics	Reports, job vacancies, programs	Evidence-based adaptation and competitiveness
Systems thinking and complexity management	Interviews, best practices, foresight studies	Transformation leadership and resilience
Sustainability integration and green-transition capabilities	Reports, interviews, best practices	Sustainability and regulatory readiness
Innovation and entrepreneurial capability	Interviews, best practices, programs	Startup growth and innovation performance
Strategic foresight and futures thinking	Foresight studies, interviews, workshops	Anticipation and preparedness
Stakeholder collaboration and ecosystem engagement	Interviews, workshops, best practices	Ecosystem development and coordination
Change leadership and organizational transformation	Reports, interviews, workshops	Transformation implementation
Digital transformation and emerging technology adoption	Job vacancies, reports, programs	Technology absorption and competitiveness
Lifelong learning and adaptive capability development	Interviews, programs, workshops	Workforce resilience and continuous upskilling

The evidence suggests that capability intelligence provides a more stable and actionable basis for intervention than skills intelligence alone. It enables the identification of shared priorities while preserving contextual flexibility and interpretation. Rather than focusing on skills that may evolve or become obsolete, capability areas capture patterns of capability development that remain relevant across educational, organizational, and ecosystem settings.

The capability priorities emerging from evidence streams demonstrate the value of combining foresight, labor market insights, multi-actor perspectives, best practice cases, and program analysis within a common framework. While capabilities vary across countries and sectors, recurring priorities associated with AI adoption, innovation, sustainability, foresight, and ecosystem collaboration appear consistently throughout the evidence.

5.3 Transformation intelligence: From critical issues to transformation challenges

The third and most significant layer of findings concerns transformation intelligence. While skills intelligence identifies emerging signals and capability intelligence reveals recurring capability patterns, transformation intelligence seeks to understand how these patterns relate to the systemic challenges confronting educational institutions, enterprises, start-ups, ecosystems, and policymakers. Its primary focus is the identification of intervention priorities, transformation pathways and coordinated responses capable of translating intelligence into action.

Across the five participating countries, evidence from more than 120 stakeholder interviews, 25 best practice cases, over 140 reports and policy documents, labor market intelligence, and program analyses generated a repository of more than 300 critical issues encompassing barriers, drivers, opportunities, threats, and weak signals. Through thematic clustering, validation, and synthesis, these issues were consolidated into ten cross-cutting transformation challenges that capture significant barriers and opportunities across the SKILLBRIDGE ecosystem. Together, they support capability prioritization, intervention design, and transformation pathways across contexts and stakeholders.

Table 2: The SKILLBRIDGE transformation challenge architecture

TC	Transformation Challenge	Description
TC1	Intelligence-to-Action & Transformation Governance	Converting intelligence into coordinated decisions, implementation and adaptive governance.
TC2	AI & Responsible Digital Transformation	Accelerating AI adoption while ensuring trust, ethics, governance and organizational readiness.
TC3	Workforce Reskilling & Talent Renewal	Addressing capability gaps created by technological, demographic and labor market change.
TC4	Curriculum Agility & Learning-System Transformation	Increasing the responsiveness of education and lifelong-learning systems.
TC5	SME Innovation & Technology Absorption	Strengthening the ability of SMEs to adopt technologies and build innovation capacity.
TC6	Innovation Translation & Commercialization	Bridging research, innovation and market impact.
TC7	Start-up Scale-Up & Entrepreneurial Growth	Supporting venture growth, investment readiness and entrepreneurial ecosystems.
TC8	Sustainability & Green-Digital Transition	Integrating sustainability capabilities with digital and technological transformation.
TC9	Regional Capability Ecosystems & Collaboration	Strengthening collaboration across education, industry, innovation and policy actors.
TC10	Capability Recognition & Scaling	Improving validation, visibility, transferability, and diffusion of capabilities.

A notable characteristic of these transformation challenges is that they rarely correspond to isolated skills deficiencies. Instead, they emerge from combinations of capability, organizational, institutional, and ecosystem-level constraints. AI adoption challenges, for example, frequently involve governance, leadership, workforce readiness, and organizational culture. Similarly, innovation and entrepreneurship challenges often reflect weak ecosystem coordination, limited absorptive capacity, or insufficient commercialization pathways.

This finding provides strong empirical support for the transformation intelligence perspective developed throughout the paper. The evidence suggests that many contemporary bottlenecks are better understood as capability and transformation challenges than as discrete skills shortages. Equally important is the observation that the transformation challenges frequently span multiple strategic domains simultaneously. This reinforces the value of the capability diamond approach and supports the use of integrated capability systems rather than fragmented intervention strategies.

The ten transformation challenges provide the operational bridge between intelligence generation and intervention design. They connect the capability architecture with curriculum modernization, workforce development, innovation support, ecosystem orchestration, and policy action, enabling stakeholders to prioritize capability investments using a common transformation language.

The successful application of this architecture during the SKILLBRIDGE ecosystem and workforce transformation workshops provides evidence of its practical relevance. Rather than starting from skills lists, participants prioritized transformation challenges and subsequently identified capabilities and action pathways required to address them.

This demonstrates the framework's potential as a mechanism for translating intelligence into coordinated transformation action. More importantly, it suggests that transformation challenges can function as a shared intervention layer linking capability intelligence, stakeholder priorities and context-specific transformation pathways across diverse organizational and ecosystem settings.

5.4 Program alignment, transformation prioritization and emerging demand

The final layer of evidence concerns the practical application of the framework through program-alignment activities, capability prioritization exercises, and stakeholder engagement processes.

Within higher education and VET contexts, the program alignment analysis demonstrates that observatory-derived capability areas can be used to identify documented alignment signals and support structured discussions around curriculum modernization. Importantly, the analysis is not intended to rank programs or assess educational quality. Its primary purpose is to stimulate reflection, identify opportunities and support future-oriented capability development.

Complementing this educational perspective, the newly introduced ecosystem and workforce transformation Workshops demonstrate how the same architecture can be applied within enterprise, start-up and innovation ecosystem contexts. Rather than assessing curricula, participants prioritize transformation challenges, identify associated capability needs and explore potential transformation actions relating to workforce development, innovation support, ecosystem collaboration, and policy intervention.

Early implementation results suggest considerable potential for scalability. While the project initially committed to supporting the modernization of thirty-one programs, program-alignment activities have already expanded beyond this target, with additional institutions expressing interest in participating in future stages of the process. Similarly, ecosystem stakeholders have demonstrated strong interest in applying the transformation challenge architecture as a mechanism for strategic prioritization and collaborative action design.

This expansion is noteworthy because it provides evidence of stakeholder demand rather than project delivery. Feedback from workshops indicates that the framework helps participants interpret complexity, prioritize capability needs and identify transformation pathways. Similar responses have emerged from educators, program leaders, SMEs, start-ups, innovation intermediaries and ecosystem actors across participating countries.

Taken together, these observations provide preliminary evidence that the SKILLBRIDGE framework functions not only as an intelligence-generation mechanism but also as a catalyst for collective learning, capability development, and transformation-oriented dialogue. The combination of AI-supported intelligence, capability architecture, transformation challenges, participatory prioritization, and program alignment appears capable of generating actionable insights while simultaneously fostering stakeholder ownership and engagement.

The findings therefore support the central proposition of this paper: the future value of observatories lies not in producing increasingly sophisticated skills inventories, but in evolving into transformation intelligence infrastructures that support adaptive capability ecosystems and coordinated, evidence-informed transformation action across education, enterprise, innovation, and policy domains.

6. DISCUSSION: FROM SKILLS MONITORING TO TRANSFORMATION INFRASTRUCTURE

The findings presented in the previous section suggest that the contribution of the SKILLBRIDGE approach extends beyond the development of a skills observatory or curriculum modernization methodology. Taken together, the capability architecture, transformation challenge architecture, skills observatory and program alignment analysis point towards a broader shift in how intelligence systems can support adaptation in the age of AI.

This section discusses the implications of these findings from theoretical, methodological, and practical perspectives. It examines the contribution of the framework to emerging debates on skills, capability and transformation intelligence; explores implications for education, enterprises, ecosystems, and policy; and reflects on the potential emergence of a new generation of intelligence infrastructures designed to connect evidence, capability development, and coordinated transformation action.

6.1 Contribution to skills, capability and transformation intelligence literature

This paper began with the observation that contemporary societies face a growing mismatch between the pace of technological, economic, environmental, and societal change and the capacity of existing intelligence systems to support adaptation. Traditional approaches to skills intelligence have generated valuable insights regarding labor market demand, educational provision, and workforce development. However, they frequently remain constrained by a focus on individual skills, occupational classifications, or static forecasting exercises.

The findings presented in this paper suggest the need for a broader conceptual lens. While skills remain important units of analysis, the evidence indicates that many contemporary challenges, including AI adoption, sustainability transitions, innovation capacity building, and ecosystem development, cannot be adequately understood through skills inventories alone. Instead, they require attention to broader capability systems and the transformation challenges they are intended to address.

The principal conceptual contribution of this paper is therefore the introduction and operationalization of transformation intelligence. Building upon existing work in foresight, skills intelligence, and capability development [3, 20, 27, 30], Transformation intelligence is proposed as an intelligence paradigm concerned not only with identifying emerging skills but also with understanding how evidence can support adaptation, decision-making and coordinated transformation across multiple stakeholder groups.

The progression from skills intelligence to capability intelligence and ultimately to transformation intelligence provides a conceptual framework through which intelligence systems can evolve from descriptive monitoring tools into mechanisms capable of supporting strategic action.

In this respect, the paper contributes to emerging debates concerning anticipatory governance, adaptive capability ecosystems, and the future role of intelligence infrastructures in managing socio-technical transitions.

Importantly, the findings suggest that capabilities may provide a more stable and transferable unit of analysis than individual skills. Equally significant, the transformation challenge architecture demonstrates how recurring barriers and opportunities can be translated into capability priorities and intervention pathways, providing a practical bridge between intelligence generation and transformation action. While specific technologies, occupations, and skill requirements evolve rapidly, capability systems appear better suited to supporting long-term adaptation across educational, organizational, and policy contexts. This observation reinforces the importance of the capability architecture and capability diamond frameworks introduced by SKILLBRIDGE.

6.2 Multi-source data, evidence governance and AI policy relevance

A second contribution concerns the role of data and evidence in supporting AI-related policy, education, and transformation decisions.

Current debates surrounding artificial intelligence are characterized by high levels of uncertainty. Questions relating to technological adoption, workforce readiness, digital inclusion, cybersecurity, trust, governance, and societal impact continue to evolve rapidly. Under such conditions, reliance on single-source intelligence systems risks generating incomplete or misleading interpretations.

The SKILLBRIDGE experience suggests that effective transformation intelligence requires the integration of multiple forms of evidence. The framework presented in this paper draws upon a multi-source evidence base comprising more than 120 stakeholder interviews, 25 best practice cases, over 140 reports and analytical documents, labor market intelligence, scientific literature, and educational program documentation collected across five European countries. These sources capture complementary dimensions of transformation processes, ranging from institutional experience and practitioner knowledge to labor market demand and strategic foresight perspectives.

The resulting approach demonstrates the value of combining documentary, observational, labor market, educational, and stakeholder-derived evidence within a single intelligence architecture. The synthesis of these heterogeneous evidence streams into more than 300 critical issues and subsequently into ten transformation challenges illustrates how AI-supported intelligence systems can transform large-scale data collection into actionable strategic insights. Equally important is the governance model underpinning this process. Rather than relying solely on automated analytics, the framework combines AI-supported extraction and clustering with human validation, contextual interpretation, and stakeholder engagement. This human-in-the-loop approach helps preserve transparency, legitimacy, and trust while enabling large-scale evidence processing.

From an AI policy perspective, the implications are significant. The findings suggest that intelligence systems designed to support AI-related decision-making should move beyond narrow metrics of technology adoption or skills demand. They should also capture emerging capability needs, weak signals, transformation bottlenecks and digital-divide dynamics that may otherwise remain invisible. Such

systems can contribute to more adaptive and evidence-informed approaches to AI governance, workforce development, and digital transformation policy.

More broadly, the paper highlights the importance of mainstreaming evidence generation, interpretation, and utilization as core components of future AI strategies. In an era characterized by rapid technological change, intelligence infrastructures may become as important as technological infrastructures themselves.

6.3 Implications for HEI and VET curriculum modernization

The findings have important implications for curriculum modernization in higher education and vocational education and training systems. A recurring challenge identified through SKILLBRIDGE concerns the difficulty of translating rapidly evolving labor market, technological, and societal signals into meaningful educational change. Traditional curriculum-review cycles often struggle to respond to the pace of AI-enabled transformation, while approaches based mainly on adding emerging technology content risk becoming obsolete as tools and platforms evolve.

The SKILLBRIDGE framework offers different logic. Rather than treating curriculum modernization as the continuous insertion of new technical topics, it emphasizes transferable capability systems that remain relevant across changing contexts. This is particularly important for AI.

While specific AI tools may evolve rapidly, capabilities such as systems thinking, foresight, evidence interpretation, responsible innovation, collaboration, adaptive learning, mathematical reasoning, and disciplinary judgement provide longer-term foundations for resilience and employability.

Curriculum modernization should therefore be understood as a capability-building process. It should strengthen the ability of institutions and program teams to identify, prioritize, and integrate emerging capability needs, while preserving strong foundations in mathematics, scientific reasoning, analytical thinking, and domain-specific knowledge. The objective is not to replace disciplinary depth with generic future skills but to connect foundational knowledge with transformation-oriented capabilities.

The program alignment analysis developed within SKILLBRIDGE provides one mechanism for supporting this process. By mapping program content against capability areas and strategic domains, institutions can identify documented alignment signals, explore modernization opportunities, and engage stakeholders in evidence-informed curriculum discussions.

These signals should not be interpreted as rankings, quality measures or deficit scores. Rather, they provide a basis for reflection, prioritization, stakeholder engagement, and evidence-informed curriculum transformation.

This approach may also support micro-credential design, educator development, and interdisciplinary learning pathways by helping program teams identify where capability development is already visible, where it is implicit, and where future priorities may require stronger articulation.

In this sense, SKILLBRIDGE offers a practical model for curriculum modernization that is adaptive rather than reactive, capability-based rather than skills-list-driven, and sufficiently flexible to support diverse HEI and VET contexts.

6.4 Implications for enterprises, start-ups, ecosystems and policy

Although initially developed within an educational context, the findings indicate that the SKILLBRIDGE framework possesses wider applicability.

One of the most significant insights emerging from the transformation challenge architecture is that many contemporary transformation barriers cannot be reduced to educational or workforce issues alone. Challenges such as AI adoption, innovation commercialization, ecosystem coordination, regional resilience, and sustainability implementation frequently involve combinations of capability constraints, organizational factors, and systemic dynamics.

This observation suggests that the capability architecture may also function as a practical tool for supporting transformation management within enterprises, start-ups, innovation ecosystems, and policy environments.

In educational contexts, capability areas support curriculum modernization. In enterprise contexts, the same capability areas can help organizations assess readiness, identify capability-development priorities and strengthen innovation capacity. Within start-up ecosystems, they can support entrepreneurial capability development, scaling strategies and ecosystem engagement. At regional and national levels, they may contribute to policy design, smart-specialization strategies and transformation road-mapping.

The transformation challenge architecture further reinforces this potential by providing a structured mechanism for connecting capability development with specific transformation objectives. By synthesizing more than 300 critical issues into ten recurring transformation challenges, the framework offers stakeholders a practical means of prioritizing interventions, coordinating action and designing context-sensitive transformation pathways. Rather than treating skills development as an end in itself, the framework encourages stakeholders to view capabilities as instruments for addressing concrete transformation challenges.

This dual-track logic, capability areas supporting educational transformation while simultaneously contributing to enterprise and ecosystem transformation, represents one of the most distinctive features of the SKILLBRIDGE approach and may prove particularly relevant for future AI for good initiatives seeking to bridge education, innovation, and societal impact.

6.5 Methodological contributions and emerging intelligence paradigms

Beyond its conceptual contributions, the paper proposes several methodological innovations.

The first concerns the re-conceptualization of skills observatories as intelligence infrastructures. Traditional observatories frequently function as repositories of labor

market information or skills-monitoring platforms. The SKILLBRIDGE skills observatory demonstrates an alternative model in which intelligence generation, interpretation, validation, and action are integrated within a continuous capability intelligence cycle.

The second contribution concerns the introduction of participatory capability intelligence. The findings suggest that meaningful capability prioritization cannot emerge exclusively from algorithms or expert analysis. Instead, it requires structured processes through which evidence, expertise, and stakeholder perspectives are combined to identify context-specific priorities and transformation pathways. Workshops, validation activities, and multi-actor engagement therefore become integral components of intelligence generation rather than supplementary dissemination activities.

A third contribution concerns the notion of documented alignment signals. By avoiding deficit-oriented interpretations and simplistic gap analyses, the program alignment analysis provides a more nuanced mechanism for exploring the relationship between intelligence outputs and educational programs. This approach may prove particularly valuable in contexts where institutional diversity and contextual variation make standardized benchmarking problematic.

Finally, the capability intelligence cycle proposed in this paper offers a practical framework for integrating AI-supported analytics, semantic interoperability, stakeholder engagement and transformation-oriented action. The resulting model extends beyond curriculum modernization and provides a potential foundation for future intelligence infrastructures supporting education, innovation, workforce development, and policy design.

Collectively, these methodological innovations suggest the emergence of a new generation of observatories designed not simply to monitor change but to support adaptive capability ecosystems, intervention design and coordinated transformation processes across education, enterprise, innovation, and policy domains.

6.6 Limitations, responsible interpretation and future research

Several limitations should be acknowledged.

First, the findings presented in this paper emerge from an ongoing project that remains in the early stages of implementation. Although the evidence base is substantial and continues to expand, many activities, including curriculum modernization, capability prioritization and ecosystem engagement, are still evolving. Longitudinal evaluation will therefore be required to assess the longer-term impacts of the framework.

Second, the program alignment analysis should not be interpreted as a measure of program quality, performance, or effectiveness. The methodology identifies documented alignment signals between program content and capability priorities derived from observatory intelligence. Such signals inform discussion and reflection but do not constitute educational evaluations.

Third, while the evidence base spans multiple countries,

sectors and stakeholder groups, contextual differences remain important. Capability priorities, transformation challenges and implementation pathways are likely to vary across institutional, regional, and national settings. Future research should therefore explore the transferability and adaptation of the framework across different environments.

Finally, further work is needed to investigate the relationships between capability areas, transformation challenges and measurable transformation outcomes. Future phases of SKILLBRIDGE provide a valuable opportunity to examine how capability intelligence can support curriculum innovation, workforce development, organizational adaptation, and ecosystem transformation over time.

Taken together, these limitations highlight the need for continued experimentation, validation, and refinement. At the same time, they do not diminish the central finding of this paper: that intelligence infrastructures capable of integrating evidence, capabilities, and stakeholder engagement may offer a promising pathway for addressing the complex transformation challenges associated with the age of AI.

7. CONCLUSIONS

Artificial intelligence, frontier technologies and accelerating socio-technical change are transforming the conditions under which individuals, organizations, and societies learn, innovate and adapt. While significant progress has been made in the development of skills intelligence systems, many existing approaches remain constrained by fragmented data sources, static taxonomies, and limited connections between intelligence generation and transformation action. This paper has argued that addressing contemporary transformation challenges requires a broader and more adaptive intelligence paradigm capable of linking evidence, capabilities, and coordinated responses across multiple stakeholder groups.

Building upon the experience of the SKILLBRIDGE initiative, the paper introduced and operationalized the concept of transformation intelligence as an evolution of conventional skills intelligence approaches. The proposed framework integrates multi-source evidence, AI-supported analytics, human-in-the-loop validation, capability modeling and stakeholder engagement into a coherent architecture designed to support adaptive decision-making and coordinated transformation. Central components of this architecture include the SKILLBRIDGE capability framework, strategic domains, capability areas, capability diamonds, skills observatory architecture, participatory capability intelligence, transformation challenge architecture and program alignment methodology.

The empirical evidence generated during the early stages of implementation provides encouraging support for the proposed approach. Collectively, the observatory currently integrates evidence from more than 120 stakeholder interviews, 25 best practice cases, over 140 reports and policy documents, labor market intelligence sources, scientific literature and more than 40 educational programs. Drawing on this multi-source evidence base, the framework demonstrates how skills intelligence can be translated into capability priorities, transformation challenges, and intervention pathways supporting curriculum modernization, workforce development, and ecosystem transformation. The

rapid expansion of program-alignment activities and growing demand for stakeholder engagement further suggest that capability-based approaches address needs not fully met by traditional skills-monitoring systems.

The findings also carry broader implications for AI-related education, policy, and capacity-building initiatives. As artificial intelligence becomes increasingly embedded within economies and societies, the challenge is no longer simply to identify emerging technical skills. It is to create intelligence infrastructures capable of integrating diverse forms of evidence, supporting inclusive participation, identifying weak signals, and enabling continuous adaptation. In this respect, the future of skills observatories may lie in their evolution from monitoring platforms into transformation intelligence infrastructures capable of supporting responsible innovation, workforce resilience, and sustainable development.

More broadly, the paper suggests that the next generation of capability ecosystems may require new forms of collaboration linking education providers, enterprises, innovation actors, policymakers, and civil society around shared intelligence resources, transformation challenges and common objectives. Such ecosystems will need to combine technological capabilities with anticipatory thinking, evidence-informed decision-making, stakeholder engagement, and long-term capacity development.

At the same time, the work presented here remains at an early stage of a broader research and implementation agenda. The framework, capability architecture, and transformation challenges should therefore be regarded as evolving constructs rather than final classifications. Future phases of SKILLBRIDGE, including the completion of curriculum modernization and ecosystem-transformation workshops across participating countries, will provide opportunities to validate, refine, and extend the proposed approach.

The results presented in this paper should consequently be interpreted as an initial but promising step towards the development of transformation intelligence infrastructures capable of supporting long-term adaptation and coordinated action.

Ultimately, the contribution of this paper is not simply to present a new skills observatory or capability framework but to demonstrate how a multi-source intelligence infrastructure can support the transition from skills identification to capability development, transformation challenge prioritization and coordinated action.

The SKILLBRIDGE case illustrates how intelligence can be translated into intervention pathways that connect education, workforce development, innovation ecosystems and policy objectives.

As the SKILLBRIDGE skills observatory and associated frameworks evolve, they offer practical tools for exploring capability needs, prioritizing transformation challenges, and designing pathways for action. In an era defined by uncertainty, artificial intelligence, and accelerating socio-technical change, the capacity to transform intelligence into capabilities, capabilities into action, and action into societal impact may become a defining challenge, and opportunity, of the decade.

More fundamentally, SKILLBRIDGE suggests that the next generation of AI-supported skills observatories may need to evolve beyond monitoring labor-market demand and emerging skills. Their future value may lie in becoming transformation intelligence infrastructures that connect evidence, capabilities, stakeholder engagement and coordinated action in support of more adaptive, innovative and resilient societies.

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REFERENCES

- [1] Popper, R., Villarroel, Y., & Popper, R. W. (2025). Towards a sustainable disruptive growth model: Integrating foresight, wild cards and weak signals analysis. *Foresight and STI Governance*, 19(1), 32–49.
- [2] Andersen, PD., Bevolo, M., Ilevbare, I., Malliaraki, E., Popper, R. and Spaniol, M.J., (2023) *Technology Foresight for Public Funding of Innovation: Methods and Best Practices*, Publications Office of the European Union, Luxembourg, 2023, doi:10.2760/759692, JRC134544.
- [3] Popper, R. (2026). *SKILLBRIDGE Handbook: Skills Intelligence, Capability Architecture and Transformation Framework*. Internal project handbook, Erasmus+ SKILLBRIDGE Project (Project ID 101247086). [Not publicly available].
- [4] Brasse, J., Förster, M., Hühn, P., Klier, J., Klier, M., & Moestue, L. (2024). Preparing for the future of work: A novel data-driven approach for the identification of future skills. *Journal of Business Economics*, 94(3), 467–500. <https://doi.org/10.1007/s11573-023-01169-1>
- [5] Cedefop. (2024). *Next generation skills intelligence for more learning and better matching: Skills anticipation trends, opportunities and challenges in EU Member States*. Publications Office of the European Union. <http://data.europa.eu/doi/10.2801/180485>
- [6] European Commission. (2019). *ESCO handbook: European Skills, Competences, Qualifications and Occupations*. Publications Office of the European Union.

- [7] European Commission. (2016). A New Skills Agenda for Europe: Working together to strengthen human capital, employability and competitiveness. COM(2016) 381 final. Brussels: European Commission.
- [8] Popper, R., & Loikkanen, T. (2019). The future of work and skills in ETF partner countries. European Training Foundation.
- [9] Green, L., Jones, B., & Miles, I. (2013). Skills and innovation. In D. Cox & J. Rigby (Eds.), *Innovation policy challenges for the 21st century* (pp. 185–206). Routledge.
- [10] Martinez-Fernandez, C., & Miles, I. (Eds.). (2011). *Innovating in practice: Perspectives on knowledge-intensive service activities*. Edward Elgar Publishing.
- [11] Popper, R., Popper, M., & Velasco, G. (2017). Towards a more responsible sustainable innovation assessment and management culture in Europe. *Engineering Management in Production and Services*, 9(4), 7–20.
- [12] Popper, R., Popper, M., & Velasco, G. (2020). Sustainable innovation assessment and management framework: Principles, methodology and practice. In M. Martini, R. Holskens, & R. Popper (Eds.), *Governance and management of sustainable innovation: Learning from experience to shape the future* (pp. 3–39).
- [13] Velasco, G., Popper, R., & Popper, M. (2020). An inductive and multidimensional approach to sustainable innovation: Evidence from multiple case studies. In M. Martini, R. Holskens, & R. Popper (Eds.), *Governance and management of sustainable innovation: Learning from experience to shape the future* (pp. 181–198).
- [14] Velasco, G., Popper, R., & Miles, I. (2021). Repositioning people in creative futures: A method to create sound advice with exploratory scenarios. *Foresight and STI Governance*, 15(2), 25–38. <https://doi.org/10.17323/2500-2597.2021.2.25.38>
- [15] Martini, M., Holskens, R., & Popper, R. (Eds.) (2020). *Governance and management of sustainable innovation*. Springer International Publishing.
- [16] Pajula, T., & Popper, R. (2020). Towards a hybrid framework for sustainable innovation. In M. Martini, R. Holskens, & R. Popper (Eds.), *Governance and management of sustainable innovation: Learning from experience to shape the future* (pp. 199–205).
- [17] Popper, M., Popper, R., Rapetti, C. A., & Piqué, J. M. (2025). Integrating policy agendas for sustainable innovation: A quadruple helix approach to the European Green Deal and sustainability transitions. *Engineering Management in Production and Services*, 17(2).
- [18] Economic Commission for Latin America and the Caribbean. (2026). Overview of Public Management in Latin America and the Caribbean, 2025: State innovation for managing vital transformations. Executive summary. (LC/PUB.2026/3).
- [19] Popper, R. (2008). How are foresight methods selected? *Foresight*, 10(6), 62–89.
- [20] Popper, R. (2008). Foresight methodology. In L. Georghiou, J. Cassingena, M. Keenan, I. Miles, & R. Popper, *The handbook of technology foresight: Concepts and practice* (pp. 44–88). Edward Elgar.
- [21] Aljohani, N. R., Aslam, A., Khadidos, A. O., & Hassan, S. U. (2022). Bridging the skill gap between the acquired university curriculum and the requirements of the job market: A data-driven analysis of scientific literature. *Journal of Innovation & Knowledge*, 7(3), 100190. <https://doi.org/10.1016/j.jik.2022.100190>
- [22] Kitto, K., Sarathy, N., Gromov, A., Liu, M., Musial, K., & Buckingham Shum, S. (2020). Towards skills-based curriculum analytics: Can we automate the recognition of prior learning? In *Proceedings of the 10th International Conference on Learning Analytics and Knowledge* (pp. 171–180). ACM. <https://doi.org/10.1145/3375462.3375526>
- [23] Cedefop. (n.d.). Skills intelligence. European Centre for the Development of Vocational Training. Retrieved June 8, 2026, from <https://www.cedefop.europa.eu/en/tools/skills-intelligence>
- [24] Cedefop. (n.d.). Skills-OVATE. Retrieved June 8, 2026, from <https://www.cedefop.europa.eu/en/tools/skills-online-vacancies>
- [25] Rahhal, I., Kassou, I., & Ghogho, M. (2024). Data science for job market analysis: A survey on applications and techniques. *Expert Systems with Applications*, 251, 124101. <https://doi.org/10.1016/j.eswa.2024.124101>
- [26] Kavargyris, D. C., Georgiou, K., Papaioannou, E., Petrakis, K., Mittas, N., & Angelis, L. (2025). ESCOX: A tool for skill and occupation extraction using LLMs from unstructured text. *Software Impacts*, 25, 100772. <https://doi.org/10.1016/j.simpa.2025.100772>
- [27] Sicilia, A., Popper, R., Cerezo, M., & Larrosa, D. (2026). AI-Driven Foresight Model for Skills Intelligence (D2.1). Erasmus+ SKILLBRIDGE Project.
- [28] European Skills, Competences, Qualifications and Occupations (ESCO) (Version 1.0.3). (2018). [Data set]. European Commission, Directorate-General for Employment, Social Affairs and Inclusion. <http://data.europa.eu/88u/dataset/european-skills-competences-qualifications-and-occupations>
- [29] Rentzsch, R., & Staneva, M. (2020). Skills-matching and skills intelligence through curated and data-driven ontologies. In *Proceedings of the DELFI Workshops 2020*.
- [30] Teece, D. J. (2018). Business models and dynamic capabilities. *Long Range Planning*, 51(1), 40–49.