Framework for Sustainable and Inclusive Entrepreneurial Education in Engineering: Lessons from the Internationalization of Startups

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Abstract

This paper proposes a framework for sustainable and inclusive entrepreneurial education in engineering, inspired by startup globalization processes. While engineering education has traditionally emphasized technical competencies, contemporary professional practice increasingly requires transversal capabilities related to entrepreneurship, sustainability, inclusion, and global orientation. Drawing on research on innovation ecosystems, sustainable business models, and inclusive innovation, this study adopts a Design Science Research approach to develop an applied pedagogical artifact. The framework integrates three interdependent dimensions (sustainability, diversity, equity and inclusion, and global orientation) and operationalizes them through tools such as the EcoCanvas, Internationalization Canvas, Empathy Maps, and Personas. A proposed application demonstrates how the framework can be applied in project-based engineering courses to support student engagement, systems thinking, and responsible innovation. The study contributes a theoretically grounded and practically applicable model that aligns engineering education with the United Nations Sustainable Development Goals and the evolving demands of innovation-driven economies.

Introduction

Engineering education is undergoing a fundamental transformation, shifting its focus from technical expertise to the development of comprehensive graduate profiles that integrate transversal, ethical, and entrepreneurial competencies to address complex global challenges. Driven by globalization, sustainability demands, and accreditation standards, engineering programs now emphasize competencies in communication, teamwork, ethics, sustainability, and societal impact alongside technical expertise [1], [2]. This shift resonates with employer and student perspectives, which frequently point to professionalism and system-oriented problem-solving as critical. Nonetheless, a disconnect persists, as graduates continue to show gaps in business understanding and sustainability awareness [2], [3].

Responding to this expanding view of engineering competence, entrepreneurship has become a core pedagogical strategy for developing transversal and professional skills. Current research suggests that the true educational value of entrepreneurship transcends "teaching about" business; it resides instead in experiential, socially embedded, and action-oriented processes. These methods allow students to create meaning, develop a professional identity, and build agency despite uncertainty [4], [5]. By prioritizing experimentation and reflection, these approaches foster self-efficacy, resilience, and innovation-oriented mindsets [5]. Furthermore, studies indicate that practice-based formats, ranging from venture projects to student-led ecosystems, consistently outperform traditional lectures in strengthening entrepreneurial intentions and opportunity recognition [6-8].

Despite this momentum, sustainability and inclusion remain largely weakly embedded in the core of engineering curricula. While institutions frequently endorse the United Nations Sustainable Development Goals (SDGs), studies reveal that integration is often superficial, favoring fragmented add-on initiatives over transformative curricular redesign [9-11]. In most programs, sustainability is still relegated to isolated modules or electives rather than being integrated into required design and decision-making courses [12], [13]. Moreover, sustainability is reduced to environmental performance, while social dimensions like equity and community engagement remain on the periphery [14]. This disconnect suggests that, despite popular support for the SDGs, students continue to perceive sustainability and inclusion as peripheral concerns rather than basic ideas guiding their real curriculum experiences.

When viewed together, these three literature domains, (i) the development of transversal competencies, (ii) the power of experiential learning, and (ii) the lack of integration of sustainability into engineering curricula, point to a gap in engineering education. While programs are expected to produce ethical, entrepreneurial, and globally oriented graduates through practice-based learning, sustainability and inclusion remain decoupled from these innovation designs. This paper seeks to bridge this gap by proposing a framework for sustainable and inclusive entrepreneurial education. Inspired by the globalization processes of startups, the proposed framework conceptualizes innovation as an iterative, ecosystem-based, and globally embedded process of value creation.

Entrepreneurial Competencies in Engineering

Engineering entrepreneurship education has gained prominence over the last two decades, becoming a common feature of engineering curricula. Research indicates that such offerings are most effective in developing opportunity recognition and problem-solving abilities when grounded in experiential and project-based learning practices [15], [16]. Beyond a narrow emphasis on venture creation, recent studies increasingly conceptualize entrepreneurship as a broader **entrepreneurial mindset**, encompassing curiosity, initiative, resilience, learning from failure, and value creation under uncertainty [17], [18]. Importantly, these attributes substantially overlap with professional competencies that are fundamental to engineering practice, including teamwork, communication, ethical responsibility, and self-regulation [19]. From this perspective, entrepreneurial education contributes not only to innovation outcomes but also to engineers' capacity to navigate the socio-technical complexity of real-world problems [20], [21]. Despite this expanded understanding, engineering entrepreneurship courses continue to be predominantly framed around commercialization-oriented outcomes. Prevailing pedagogical models typically prioritize business plans, pitching, prototyping, and intellectual property or market-entry strategies, reinforcing a market-centric interpretation of opportunity development [22], [23]. This emphasis has raised concerns in the literature regarding the risk of decontextualizing entrepreneurship from its social, ethical, and environmental dimensions, thereby supporting a restricted notion of value creation [24]. Although pioneering initiatives have begun to connect entrepreneurial learning with sustainability and social impact through transdisciplinary and challenge-based projects [25], such approaches remain the exception rather than the norm. Empirical evidence indicates that, despite strong rhetorical commitments to the Sustainable Development Goals (SDGs), entrepreneurship and sustainability are rarely integrated systematically within engineering curricula [26]. Consequently, engineering education often prioritizes the formation of technically proficient engineers focused on technology commercialization rather than preparing graduates to design ecologically responsible and socially inclusive solutions.

Sustainability in Engineering Education

Sustainability has emerged as a key normative and policy objective in engineering education worldwide, yet its practical translation into everyday classroom experience remains inconsistent. For example, most programs incorporate sustainability and the SDGs into their institutional missions and accreditation frameworks. Still, these commitments are rarely deeply embedded in engineering design, analysis, and decision-making within the core curriculum [27]. Instead, sustainability is relegated to isolated modules or elective capstones, reflecting an "add-on" rather than catalyzing a transformative curricular logic [11]. This fragmented integration produces measurable gaps between intended competencies and graduates' demonstrated proficiencies, as evidenced by cross-national surveys [10], [28]. In addition, the existing literature highlights bias in engineering education toward environmental analysis tools, such as life-cycle assessment and emissions metrics, while the social, ethical, and economic dimensions receive less systematic attention [10], [29]. Consequently, students may leave engineering programs adept at quantifying environmental impacts but unprepared to facilitate public participation or situate their work within engineering's broader societal purpose [30], [31]. In response to this limitation, scholars argue that sustainability must evolve from a peripheral constraint into the foundational logic of engineering value creation. Drawing on sustainable business model research, Bocken and Geradts [32] emphasize that sustainability should shape the fundamental purpose of innovation, not merely its side effects. Considering engineering education, this implies redefining design objectives so that environmental integrity, social equity, and long-term societal well-being are co-equal with technical performance and economic feasibility [29], [33]. Frameworks grounded in systems thinking, the SDGs, and circularity principles similarly advocate for realigning program outcomes, pedagogical practices, and assessment around sustainability competencies [11].

Diversity, Equity, and Inclusion in Engineering Education

Research on innovation and team-based work increasingly consistently underscores how diversity, equity, and inclusion (DEI) drive creativity, learning, and problem-solving by expanding the range of expertise, perspectives, and ideas available within groups, particularly when inclusive conditions enable equitable participation and sustained information exchange [34]. Within engineering education, where collaborative, project-based environments are prevalent, these dynamics are particularly crucial. The mechanisms of team formation, task framing, and user representation dictate whether cognitive variety yields high-quality solutions or is stifled by unequal participation and "universal," homogeneous assumptions about the user. For example, studies in design pedagogy reveal that when social context and power relations are overlooked, students may graduate with sharp technical skills yet remain ill-equipped to anticipate how engineering decisions impact diverse groups across dimensions of ability, gender, and socio-economic status [35], [36]. These arguments help elucidate how culture and corporate governance may influence DEI among engineers. To support this DEI-education transition, emerging research identifies empathy-driven and community-engaged pedagogies as effective mechanisms for addressing these limitations while also enhancing technical creativity. Approaches grounded in empathic and inclusive design highlight direct interaction with diverse stakeholders as a means of strengthening ethical awareness, contextual sensitivity, and reflexive judgment regarding the long-term consequences of technical choices [37]. Design thinking and inclusive studio models indicate that engaging users from diverse social and cultural backgrounds broadens problem framing, encourages exploration of alternative materials and performance criteria, and leads to more original and socially responsive prototypes [38], [39], building a new vision of cultural aspects and DEI development. While tools (e.g., personas and stakeholder mapping) help translate user research into concrete design inputs, their efficacy hinges on sustained interaction with real communities rather than relying on static representations [40], [41]. At the programmatic level, frameworks such as Universal Design for Learning (UDL) and asset-based pedagogies are linked to increased student engagement and a deeper sense of belonging, which are crucial for underrepresented groups, even as institutional constraints continue to challenge the systematic integration of such practices [42], [43].

Research Design

This study adopts a Design Science Research (DSR) methodology [44], [45] to develop a pedagogical framework as a design artifact for engineering education. We conducted an adapted DSR cycle [46] comprising five interrelated steps: problem identification, definition of design objectives, design and development of the artifact, demonstration, and formative analytical evaluation.

Problem Identification: Problem identification was conducted through a structured review at the intersection of the engineering education curricula design, entrepreneurial learning, sustainability-oriented pedagogy, and DEI. This analytical process exposed a lack of integrative pedagogical models capable of coherently aligning technical learning with entrepreneurial agency, social responsibility, and global orientation within engineering programs [47], [48].

Definition of Design Objectives and Theoretical Foundations: The framework's design objectives emerge from a synthesis from four complementary theoretical pillars: (i) **innovation and entrepreneurial ecosystem theory** provide a lens to view innovation as a product of multi-actor, non-hierarchical, and platform-mediated networks [41]; (ii) **entrepreneurial and experiential learning theories**, which shift the focus toward action, reflection, and identity formation within socially embedded contexts [4], [6]; (iii) **sustainability-oriented pedagogy**, positioning social and environmental responsibility not as external constraints, but as the very essence of engineering value creation [12], [13]; and (iv) **inclusive and empathy-based methodologies** ensure that stakeholder diversity and power dynamics serve as primary drivers of ethical awareness and innovation quality [37], [50]. From this theoretical convergence, a preliminary design-oriented dimension set was defined, including global orientation, opportunity recognition in multi-actor systems, systems thinking, sustainability-driven value creation, stakeholder inclusion, and learning through action and structured reflection. These dimensions, in turn, form the basis of specific design principles that dictate the framework's pedagogical function. Each principle is framed as a conditional logic linking educational intent to concrete mechanisms. For instance, if the goal is to develop global orientation, then learning activities must require engagement with transnational stakeholders, regulatory contexts, or cross-cultural collaboration. Similarly, to embed sustainability as a core design value, project goals and assessment criteria must explicitly integrate environmental and social performance into the same fabric as technical and economic metrics.

Design and Development of the Artifact: The framework integrates theoretical synthesis and empirical evidence. Beyond the literature base, our study leverages a rich corpus of primary qualitative and documentary materials collected during international academic and industry missions. This empirical dataset comprises structured field notes, reflective logs, and minutes from high-level meetings with innovation hubs, startups, and global industry partners. These materials provide a gap in contemporary institutional strategies and university-industry collaboration practices across diverse international contexts. The analysis followed an iterative, theory-guided approach. First, open coding was employed to identify recurring patterns in competency demands, such as global collaboration and entrepreneurial agency, and pedagogical configurations, including project-based learning and transnational partnerships. Subsequently, axial coding was used to map these empirical themes onto the theoretically derived design principles. This abductive process ensured that the framework remained conceptually coherent yet firmly grounded in the realities of institutional and innovative settings. The proposed framework conceptualizes engineering learning as a progressive, ecosystem-oriented process inspired by the dynamics of global startup growth. The framework organizes learning as a sequence of interrelated phases through which students progressively expand the scope, context, responsibility, and impact of their engineering decisions. Across these phases, sustainability, DEI, and global orientation function as cross-cutting decision criteria that shape problem framing, design choices, experimentation strategies, and evaluation of outcomes. The resulting framework was operationalized into a modular architecture composed of three interdependent dimensions, sustainability, DEI, and global orientation, crossed with four pedagogical layers: (i) learning activities (e.g., project briefs, design challenges, venture simulations, and international collaboration tasks), (ii) boundary objects and design tools (e.g., EcoCanvas, Internationalization Canvas, empathy maps, and personas), (iii) stakeholder configurations (e.g., industry partners, startups, community organizations, and international academic collaborators), and (iv) assessment and reflection mechanisms (e.g., SDG-aligned rubrics, reflective portfolios, peer and stakeholder feedback).

Demonstration and Reproducibility: The framework is applied through a conceptual implementation scenario that illustrates its adaptability across different curricular levels. The demonstration specifies required inputs (e.g., course type, stakeholder access, and institutional constraints), procedural steps (e.g., sequencing of learning activities, integration points for tools and stakeholder engagement, and reflection cycles), and expected outputs (e.g., competency development profiles aligned with sustainability, inclusion, and global orientation).

Formative Analytical Evaluation: Moving beyond summative empirical evaluation, our study adopts a formative and analytical assessment consistent with the early stages of DSR. The framework's viability is evaluated through its theoretical coherence, internal consistency, and cross-alignment with established scholarship in entrepreneurial learning, sustainability, and inclusive design. Furthermore, its plausibility and institutional relevance are vetted through a systematic comparison with the real-world competency demands and organizational constraints captured in the mission-based empirical corpus. This analytical validation provides a rigorous foundation for future research phases, including pilot testing, comparative case studies, and longitudinal evaluation of student outcomes.

Proposed Framework for Sustainable and Inclusive Entrepreneurial Education in Engineering

Table 1 operationalizes the proposed framework into an instructional design cycle, specifying instructor actions, student activities, and learning evidence for each phase. This mapping enables replication across institutional contexts and establishes a basis for future empirical evaluation through standardized rubrics, portfolios, and stakeholder feedback, according to the following phases:

Phase 1 – Course Scoping: This phase establishes the structural and normative foundations of the framework by aligning course objectives with institutional learning outcomes, accreditation standards, and strategic priorities related to sustainability, DEI, and global engagement. Instructors define a targeted set of technical, entrepreneurial, and transversal competencies, such as systems thinking, ethical reasoning, opportunity recognition, and intercultural collaboration, that will guide subsequent pedagogical design. This alignment ensures that the framework is replicable across institutional contexts while maintaining coherence with formal program requirements and quality assurance mechanisms. Institutions must first evaluate how their existing programs are currently structured before attempting to scope curriculum transformation in a focused and implementable way. This "program structure diagnosis" is essential to define a technically grounded scope for DEI and environmental integration, ensuring that inclusion and environmental performance are treated as engineering competencies. Without this baseline mapping of what is already taught, assessed, and institutionally feasible, DEI and environmental goals risk becoming additive, fragmented, or misaligned with core engineering formation. This includes analyzing global SDG targets.

Phase 2 – Ecosystem Framing: In this phase, the learning environment is positioned as an innovation ecosystem in which external partners, including industry, startups, public organizations, and community actors, are identified and engaged as co-contributors to the educational process. Instructors and partners collaboratively define the scope of the design challenge, clarifying regulatory, cultural, and sustainability constraints that shape the problem space. This process situates student work within authentic, real-world contexts and introduces the institutional, social, and environmental boundaries that characterize entrepreneurial and engineering practice in globalized settings. Many universities are increasingly anchoring their programs in innovation ecosystems through hubs and partnership networks that connect startups and companies nationally and internationally, strengthening internationalization as a structuring driver of challenge selection, collaboration models, and learning outcomes.

Phase 3 – Sustainable and DEI Design: This phase operationalizes DEI and sustainability through structured, empathy-driven design activities. Students develop personas, an EcoCanvas, an Internationalization Canvas (adding diverse cultural aspects), and empathy maps grounded in stakeholder research, and translate these insights into value propositions that integrate sustainable objectives. Connecting user needs, societal impact, and technical feasibility, this phase encourages students to move beyond technical optimization and to frame engineering solutions as instruments of responsible and inclusive value creation.

Phase 4 – Entrepreneurial Experimentation: students can be assigned technical engineering problems that require market research, drawing on corporate sustainability reports, social impact disclosures, and industry benchmarks, to define requirements, justify design choices, and anticipate implementation barriers. They can work in teams, they would triangulate evidence across sources, compare competing solutions, and articulate how proposed designs create value not only in technical and economic terms but also in sustainable terms, thereby fostering a more expansive view of students' professional and personal development. Students can engage in iterative cycles of concept development, prototyping, and systems-level evaluation. Design briefs and requirements documents guide the translation of value propositions into technical and organizational solutions. At the same time, rubric-based reviews are used to assess the integration of sustainability and inclusion criteria. This process emphasizes learning through experimentation, feedback, and refinement, enabling students to test assumptions, evaluate trade-offs, and adapt designs in response to technical performance, stakeholder input, and contextual constraints. By requiring teams to evidence claims with external sustainability and social data and to reflect on who benefits, who is burdened, and whose perspectives are represented, these activities can operationalize DEI as a design and decision competency.

Phase 5 – Reflection and Assessment: The final phase consolidates learning outcomes through structured reflection, performance assessment, and feedback exchanges among students, instructors, and external partners. Students critically evaluate the sustainable implications of their solutions, while instructors assess competency development using aligned rubrics and learning indicators. Insights generated in this phase are reintegrated into course design and institutional planning, reinforcing the framework's role as a feedback- learning ecosystem that supports continuous improvement and long-term alignment with sustainability and inclusion goals.

Proposed Application of the Framework in Engineering Education

The proposed framework is designed to be operationalized within existing engineering courses, particularly project-based, capstone, and design-oriented subjects, by embedding entrepreneurial, sustainability-oriented, and inclusion-aware practices into the core structure of learning activities. Rather than functioning as a standalone module, it serves as an organizing logic that guides how students frame problems, engage stakeholders, and evaluate technical solutions across the project lifecycle. Application follows an iterative learning logic inspired by models of entrepreneurship, emphasizing cycles of problem framing, stakeholder interaction, learning, and adaptation rather than linear progression [51], [52]. In this approach, students revisit assumptions and design choices as new social, environmental, and regulatory constraints emerge through peer, instructor, and external feedback. Operationalization is supported by a set of boundary objects and design tools that translate the framework into concrete pedagogical actions. Empathy Maps and Personas ground design challenges in diverse user perspectives and inclusion criteria, the Internationalization Canvas supports analysis of institutional and geographic context, and the EcoCanvas structures reflection on environmental and social impacts, making sustainability trade-offs explicit in engineering decisions. In its current form, the framework is proposed as a transferable and adaptable design artifact rather than a validated intervention. The accompanying table provides a practical guide for instructors to replicate and tailor the framework across institutional contexts, while establishing a basis for future empirical evaluation of learning processes and outcomes.

Discussion and Conclusion

Integrating Entrepreneurship, Sustainability, and DEI as Engineering Competence

This study advances engineering education by reframing entrepreneurship, sustainability, and DEI as structurally interdependent dimensions of engineering competence. Whereas traditional curricula often treat sustainability as a technical constraint, entrepreneurship as an add-on, and DEI as an institutional policy concern, the proposed framework positions these elements as mutually reinforcing drivers of innovation. The framework reflects how contemporary startups and engineering organizations operate in globally connected, socially complex, and sustainability-driven environments. Drawing on startup internationalization theory, students are encouraged to iteratively test technical decisions against evolving stakeholder expectations, regulatory contexts, and environmental limits, thinking globally. This logic aligns with experiential and project-based learning models that emphasize reflection, uncertainty, and real-world engagement as central mechanisms for developing professional agency and innovation-oriented mindsets [53], [54].

Operationalizing Inclusion and Sustainability in Design Practice

The framework contributes to inclusion in engineering education by translating abstract DEI principles into concrete design mechanisms. Empathy Maps and Personas provide structured ways for students to integrate multiple user perspectives into technical requirements, addressing a persistent gap in curricula. This approach is consistent with research showing that heterogeneous perspectives enhance the quality of innovation when effectively incorporated into problem-solving processes [50], [55]. Sustainability is similarly operationalized through the EcoCanvas, focusing on ecological aspects of new business models. Rather than treating environmental and social considerations as external constraints, the framework embeds them in the core logic of value creation, aligning with sustainable business model research that emphasizes early-stage integration of sustainability into innovation processes [32], [56]. In this way, sustainability becomes a domain of applied engineering analysis, enabling students to explicitly engage with sustainable and DEI trade-offs, system boundaries, and long-term sustainable consequences as part of routine design work.

Table 1 - Framework-to-Course Mapping for Sustainable and Inclusive Entrepreneurial Engineering Education

Framework Phase	**Pedagogical Objective**	**Instructor Actions**	**Student Activities**	**Core Tools & Artifacts**	**Learning Evidence & Assessment**	**Transferability Across Institutions**
1. Course Scoping	Define technical, entrepreneurial, sustainability, and inclusion competencies aligned with accreditation goals	Select graduate attributes; define learning outcomes; design competency rubrics	Analyze syllabus and competency map; reflect on personal learning goals	Competency Mapping Canvas; Accreditation Alignment Matrix; Rubric Template	Pre-course self-assessment; baseline competency survey; rubric alignment document	Replicable across institutions using local accreditation standards
2. Ecosystem Framing	Situate learning within a real socio-technical and institutional context	Identify partners (national industries, startups, communities); define challenge brief; clarify regulatory, cultural, and sustainability constraints	Conduct stakeholder analysis; research ecosystem actors; contextual risk and opportunity mapping	Stakeholder Map; Ecosystem Canvas; Internationalization/ Context Analysis Tool, Internationalization Canvas	Stakeholder, sustainable and transparency reports; contextual analysis memo; partner feedback	Adaptable to local, regional, or international ecosystems and partner availability
3. Sustainable and DEI Design	Embed sustainability, inclusion, and ethical considerations into problem formulation and solution design	Introduce SDG criteria; train students in inclusive and empathic design methods; define sustainability and inclusion metrics	Develop personas, empathy maps, and value propositions, integrating social, environmental, and economic goals	Empathy Map; SDG Design Checklist; Sustainable Value Proposition Canvas	Design brief, requirements, and rubric-based review of sustainability and inclusion	Align with local SDG priorities, cultural norms, and institutional ethics
4. Entrepreneurial Experimentation	Foster learning through iteration, testing, and stakeholder engagement	Structure sprints; facilitate prototyping and validation sessions; coordinate external reviews	Build and test prototypes; conduct stakeholder interviews; iterate business/impact models	Sprint Planning Board; Prototype Log; Experimentation Journal; Pitch Deck	Prototype evaluation; stakeholder validation forms; reflective learning logs	Scalable across class sizes and resource levels (digital, physical, or hybrid)
5. Reflection & Assessment	Generate evidence of competency development and learning outcomes	Apply multi-dimensional rubrics; collect external and peer evaluations; synthesize learning evidence	Compile learning portfolios; conduct self- and peer-assessments; reflect on ethical, social, and technical trade-offs	Competency Rubric; Learning Portfolio Template; External Feedback Form	Portfolio assessment; partner evaluation; post-course competency survey	Enables cross-institutional benchmarking through standardized rubrics and surveys

Implications for Education, Faculty, and Innovation Ecosystems
For engineering programs, the framework offers a structured, flexible pathway for embedding professional, entrepreneurial, and sustainability competencies into core technical courses, supporting more coherent, holistic curricular designs [19]. By aligning learning objectives, teaching activities, and assessment practices around a unified set of transversal competencies, the framework integrates entrepreneurship, ethics, and sustainability topics. For faculty members, the use of canvases and empathy-based tools provides a practical means of scaffolding complex, interdisciplinary learning processes without displacing disciplinary rigor. These tools translate abstract institutional priorities into concrete teaching practices that can be adapted across engineering disciplines. From the student perspective, the framework supports the development of an entrepreneurial mindset that is directly connected to professional engineering practice. By engaging with real-world constraints, diverse stakeholders, and international contexts, students learn to approach engineering as a form of responsible value creation. This orientation prepares graduates to work effectively in innovation-driven environments, where technical excellence must be combined with ethical judgment, sustainability awareness, and intercultural competence. At the institutional level, the framework aligns engineering education with broader policy and societal agendas (e.g. SDGs). Universities can strengthen their role as active contributors to regional and global development by positioning engineering programs as hubs for collaboration among national and international industries, startups, and communities, connecting educational practice to innovation ecosystems and entrepreneurial dynamics.

Limitations and Future Research
This study presents the framework as a transferable design artifact rather than a validated instructional intervention. Its long-term effects on learning outcomes, career trajectories, and innovation performance remain to be empirically assessed. At the same time, engineering education is increasingly shaped by labor-market and industry pressures that collectively demand new competency profiles that integrate technical depth with entrepreneurial agency, sustainability, and inclusion. These pressures are not merely contextual; they actively constrain and incentivize curriculum reform, influencing what institutions prioritize, how learning is assessed, and which partnerships become strategic.

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