

An Integrated Theoretical and Conceptual Framework for Innovation, Entrepreneurial, and Lifelong Learning Competencies in Engineering and Technology Education

Extended Abstract

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Abstract— Knowledge economies require engineering graduates who are not only technically proficient but also capable of continuous adaptation, opportunity recognition, and value creation across careers that are likely to outlast any specific technology they have studied. While accreditation frameworks have begun to acknowledge these expectations, the underlying competencies—entrepreneurial, innovative, and lifelong learning—remain inadequately operationalized at the level of pedagogical and curricular design. This extended abstract presents an integrated theoretical and conceptual framework that unifies constructivist and experiential pedagogy, effectuation theory, and validated competency taxonomies (EntreComp, the Universal Innovation Framework, and a 21st-century engineering skills model) within a single coherent structure. The framework is designed to be embedded within formal engineering and technology education without requiring structural curricular disruption, and is simultaneously adaptable to lifelong learning contexts including continuing professional development, micro-credentialing, workplace learning, and informal learning pathways. The contribution articulates how a common competency core, once made explicit, can serve as the conceptual bridge between formal and lifelong engineering learning, supporting coherence across an individual’s professional trajectory and across the institutional and policy levels of the knowledge economy.

Keywords: *lifelong learning, engineering education, entrepreneurial mindset, innovation competencies, EntreComp, effectuation, constructivism, conceptual framework.*

1. Introduction

The accelerating pace of technological change, together with the broadening of competencies expected of engineering graduates, has rendered lifelong learning an operational necessity rather than an aspirational ideal [1], [2]. The European Council recommendation on key competences for lifelong learning [1], the OECD Learning Compass 2030 [2], and the long-standing UNESCO Delors framing of the four pillars of education [3] converge on a common premise: education systems must prepare individuals to keep learning, adapting, and creating value across their working lives. For engineering and technology education, this premise extends well beyond the consolidation of technical knowledge; it requires explicit attention to the cognitive and dispositional habits—curiosity, opportunity recognition, comfort with ambiguity, and iterative learning from feedback—that underpin both entrepreneurial action and lifelong learning behavior.

Despite their evident overlap, however, the literatures on engineering entrepreneurial education and lifelong learning have largely developed in parallel rather than in dialogue, and few frameworks articulate the shared conceptual core that would permit coherent design across the two. This extended abstract proposes such a framework, integrating established theoretical foundations with validated competency taxonomies, and demonstrating how a single conceptual structure can be instantiated within formal engineering and technology education and adapted to lifelong learning contexts.

2. Theoretical Foundations

The framework rests on three theoretical pillars, each with independent grounding in the lifelong learning literature. The first is constructivist and experiential pedagogy [4], [5], which conceptualizes learning as an active, learner-centered process of meaning-making through engagement with authentic problems. Constructivism is, in epistemological terms, the foundational stance of lifelong learning, given that it treats the learner as an agent who

continuously constructs understanding from experience rather than as a recipient of fixed content. Kolb's experiential cycle [5] operationalizes this stance through iterative engagement with concrete experience, reflective observation, abstract conceptualization, and active experimentation, hence providing the pedagogical infrastructure for sustained learning beyond formal instruction.

The second pillar is effectuation theory [6], which characterizes expert entrepreneurial decision-making as an iterative, feedback-driven mode of acting under uncertainty. Effectuation specifies that actors begin with their available means—what they know, who they know, and who they are—and shape goals adaptively in response to contingencies. This logic encodes precisely the dispositions that lifelong learners need: tolerance of ambiguity, willingness to act despite incomplete information, and readiness to treat failure as informational rather than evaluative.

The third pillar is integrative competency modelling. EntreComp [7] articulates entrepreneurial competence across three domains (ideas and opportunities, resources, and into-action), while context-specific engineering competency models, such as that developed for the Qatari knowledge economy by Abdulwahed and Hasna [8], identify the knowledge, skills, and attitudes that connect technical capability to innovative and entrepreneurial action. When juxtaposed with established lifelong learning competency frameworks, these models reveal substantial overlap, particularly in self-management, learning-to-learn, social and civic competence, and initiative.

3. The Integrated Conceptual Framework

The proposed framework synthesizes these foundations into a coherent structure with four interacting components organized around a shared competency core. At the centre lies a unified competency core, which integrates EntreComp domains, the Universal Innovation Framework's desirability–feasibility–viability triad [9], a 21st-century engineering skills model [8], and lifelong learning key competences [1]. This core specifies what is to be developed; it is intentionally tool-agnostic and discipline-extendable, hence portable across institutional and learner contexts.

The first surrounding component is pedagogical orchestration, drawing on constructivist and experiential designs—project-based learning, design-based courses, and authentic problem engagement—that activate the competency core through learner-centered iteration. The second is decision-and-action logic, drawing on effectuation and lean and agile methods [10], that develops the dispositions and routines required for acting under uncertainty. The third is curricular and learning-pathway integration, which positions the framework as embeddable within existing structures (whether engineering courses, continuing-education modules, or workplace learning programs) without requiring new credits, courses, or minors. The fourth is governance and assessment, which aligns the framework with accreditation standards such as ABET in formal contexts, and with competency-attestation and recognition mechanisms in lifelong learning contexts, while emphasizing rubric-based, evidence-driven assessment of process and artefact rather than recall.

An operational instantiation of the framework, the Innovation Advancement System (IAS), has been developed within an ongoing three-year QRDI-funded project at Qatar University (Grant ARG01-0602-230463). The IAS integrates EntreComp and Universal Innovation Framework elements into a structured advancement model and has been piloted across three curricular venues, namely first-year skills and ethics, undergraduate innovation and entrepreneurship, and graduate research methodology, alongside seminars within capstone graduation projects. These pilots provide initial empirical grounding for the framework while leaving the conceptual structure portable to other institutional and learning contexts.

4. Embedding in Formal Education and Adaptation for Lifelong Learning

The framework's distinguishing feature is that the same conceptual core can be instantiated across the spectrum from formal initial education to lifelong learning contexts. Within formal engineering and technology education, the framework is embedded through curricular venues already present in the typical engineering programme: first-year skills and ethics courses, project-based and design courses, internships, capstone projects, and graduate research methodology courses. Each venue is mapped to a subset of the competency core, with pedagogical

orchestration and assessment governance adjusted to the venue's level and scope. The integration is additive in coverage but not in credit load, hence preserving compatibility with accreditation requirements such as ABET.

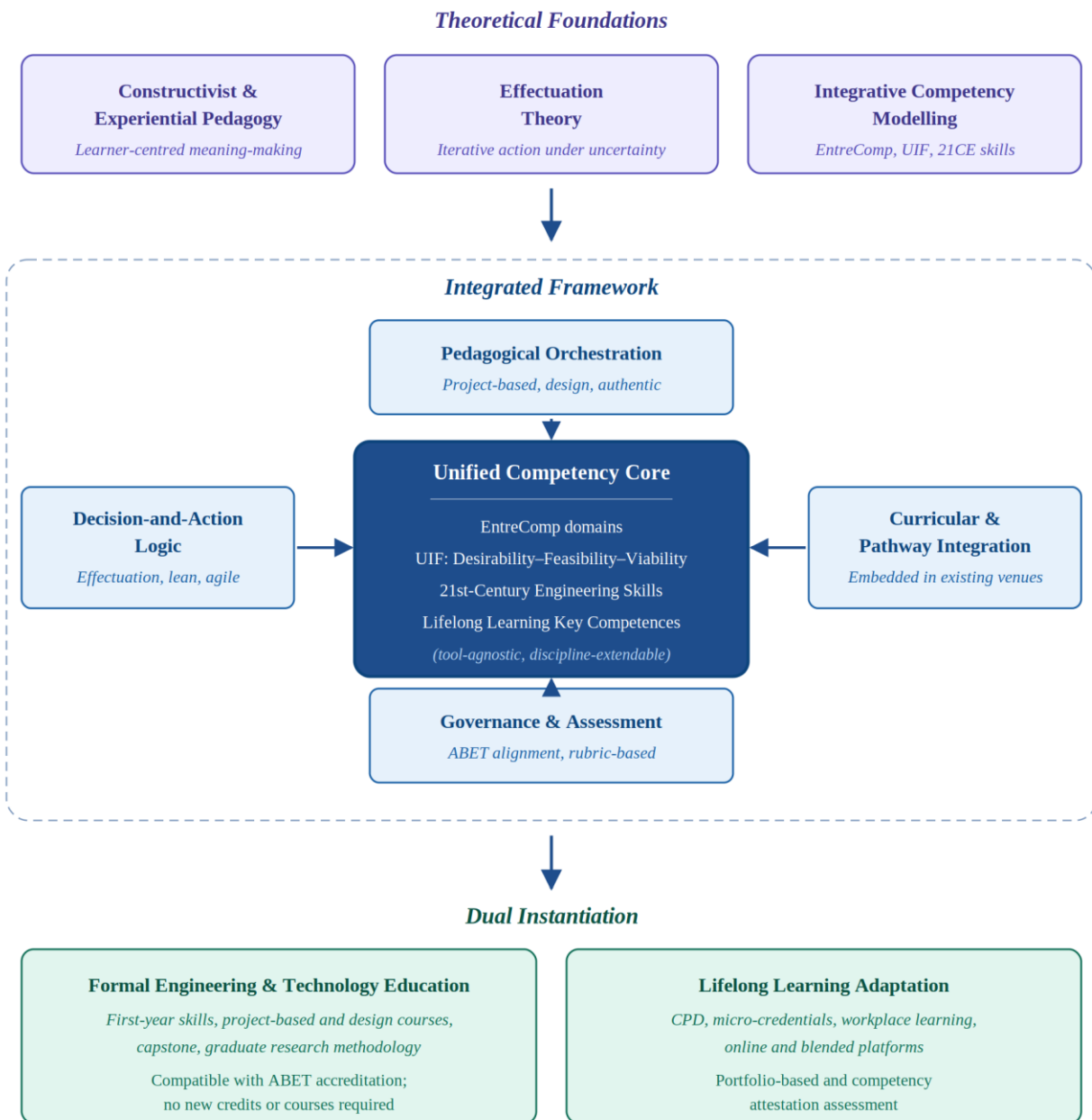


Figure 1. Conceptual framework for entrepreneurial competency development in formal education and LLL

For lifelong learning contexts, the same competency core is reinstantiated through different vehicles: continuing professional development modules, micro-credentials and stackable certificates, employer-led learning programs, online and blended platforms, and structured workplace experiential learning. The pedagogical orchestration shifts from sustained semester-length engagement to shorter, modular, and self-directed cycles, while the decision-and-action logic of effectuation gains additional salience given that adult learners frequently apply learning to immediate professional challenges. Assessment, in turn, can shift from grade-based to portfolio-based and competency-attestation-based evaluation, aligned with emerging frameworks for the recognition of prior and informal learning. This dual-instantiation property is itself the framework's contribution to the lifelong learning agenda, given that it

provides institutional and policy actors with a coherent way to align initial and continuing education within a single competency architecture, rather than treating them as disconnected systems. See Figure 1 for the full framework.

5. Conclusion

The framework proposed here offers a unified, theoretically grounded, and empirically anchored basis for cultivating innovation, entrepreneurial, and lifelong learning competencies in engineering and technology education. By bridging constructivist pedagogy, effectuation logic, and validated competency models, and by being designed for instantiation across both formal curricula and lifelong learning vehicles, the framework offers a structured response to a central pedagogical challenge of the knowledge economy. Future work will report empirical results from ongoing pilot implementations and refine the framework's adaptation guidelines for diverse institutional and lifelong learning contexts.

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