Designing a Vertical Entrepreneurship Thread: Rationale for Curricular-Wide Innovation Integration

Dr. Bryan James Higgs, University of the District of Columbia

Dr. Bryan Higgs is a native of southwest Virginia. Currently, he is an Assistant Professor in the Department of Civil Engineering at the University of the District of Columbia. Prior to this position, he was an Intelligence Community Postdoctoral Researcher.

Alex Peebles, University of the District of Columbia
Dr. Thabet Kacem, University of the District of Columbia

is a tenured associate professor of computer science at the University of the District of Columbia. He obtained his PhD in information technology at George Mason University in May 2016. He obtained his master's in computer science at the University of the District of Columbia in January 2010. His research interests include cyber security, intelligent transportation systems, smart cities, cyber-physical systems, blockchains, and climate change. He is the principal inventor of the US Patent number 11022696 entitled "ADS-BSec: A holistic framework to secure ADS-B". He has served as principal and co-principal investigator in several sponsored projects from NSF and NSA. His research sits at the intersection of Artificial Intelligence, Cybersecurity, and Cyber-Physical Systems, with a focus on developing trustworthy, intelligent, and resilient technologies for safety-critical infrastructures. His work integrates machine learning, deep learning, secure system design, and data-driven modeling to address challenges in intelligent transportation, mobile systems, and emerging digital infrastructures. He is particularly interested in building robust and explainable AI systems, improving digital trust and security, and advancing AI driven analytics for complex, real-world environments. Through interdisciplinary collaborations, his research aims to create practical, high-impact solutions that enhance safety, reliability, and decision-making in modern cyber-physical and socio-technical systems.

Prof. Pawan Tyagi, University of the District of Columbia

Prof. Pawan Tyagi is actively researching in the education field. He was trained by renowned education researcher and scholar Dr. Ken Bain via a one-year fellowship. Dr. Tyagi is the inventor of the â€œStudent Presentation Based Effective Teachingâ€ and

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Abstract

The demands of the modern, globally competitive landscape require contemporary engineering graduates to possess competencies that transcend traditional technical mastery. Engineers must not only solve complex technical problems but also identify emergent market opportunities, create sustainable stakeholder value, and drive organizational innovation within both the private and public sectors. This critical synthesis of technical and business acumen is encapsulated by the Entrepreneurial Mindset (EM), defined by the KEEN core competencies of curiosity, making connections, and creating value. Central to this framework is the identification of seven discrete entrepreneurial engineering skills—including contextual problem framing, opportunity assessment, and ethical stewardship—that bridge the gap between technical accreditation requirements and the strategic needs of industry. This paper highlights that while these entrepreneurial engineering skills can be efficiently integrated as an overlay to mandated ABET student outcomes, the implementation of dedicated immersion milestones is necessary to bring these competencies to the forefront and ensure students reach full professional mastery.

We present the comprehensive design, theoretical rationale, and structural scaffolding of a required EM vertical thread implemented within the core undergraduate engineering curriculum. The design strategy centers on a longitudinal multi-course sequence spanning four years: Introduction to Engineering, Research Methods (Mechanical) or Introduction to Civil Engineering Systems (Civil), major-specific Design Courses (e.g., Machine Design, Steel Structures), Engineering Economics, and Senior Design Projects. The rationale for this thread is validated through a mapping of EM to foundational ABET outcomes and the specialized mandates of professional frameworks, including the ASCE Civil Engineering Body of Knowledge and Vision 2025 and ASME's Vision 2030.

The structural scaffolding is organized into four distinct pedagogical phases—Exposure, Inquiry/Validation, Technical Iteration, and Realization. This paper details how discipline-specific anchors—such as Civil Engineering Systems—introduce critical concepts like systems thinking and ethical stewardship, while third-year design touchpoints reinforce iterative technical development and stakeholder desirability. The resulting curriculum design serves as a comprehensive, replicable model for embedding innovation literacy as a foundational professional identity for the 21st century engineering workforce.

Introduction

The global engineering landscape is undergoing a paradigm shift. While technical proficiency remains the bedrock of engineering education, the complexity of 21st century challenges—ranging from climate change to digital transformation—requires a new breed of ”entrepreneurial engineer” [1]. These professionals must possess the agility to navigate ambiguity and the foresight to recognize the broader implications of their technical decisions.

Graduates of engineering programs inevitably transition into diverse professional environments, primarily situated within either the private or public sectors. In the private sector, the entrepreneurial mindset is a clear driver of commercial success and organizational longevity. Engineers in this space utilize EM to enhance market competitiveness, identify untapped consumer needs, and navigate the ”fail-fast” cycles of rapid product development. By viewing technical challenges through the lens of stakeholder value, these engineers ensure that corporate RD efforts are aligned with sustainable business models and genuine market desirability [5].

Conversely, the application of an entrepreneurial mindset is equally vital within the public sector, where the focus shifts toward ”intrapreneurship” and societal stewardship. Public sector engineers—working within governmental agencies, non-profits, or public utilities—are tasked with managing complex infrastructure and regulatory frameworks under significant resource constraints. In this context, EM enables engineers to optimize public resources, innovate within bureaucratic structures to improve service delivery, and recognize societal ”pain points” as opportunities for policy or system-wide improvement. Whether designing a consumer electronic device or a regional water management system, the ability to synthesize technical rigor with a value-driven mindset ensures that the engineer’s impact is both maximized and ethically grounded.

At its core, engineering is a value-driven discipline. Engineering solutions are not measured solely by their technical elegance, but by the tangible impact they deliver and the efficient balance of their associated costs and benefits. This optimization of value—weighing technical performance against economic and social constraints—is inherently akin to the entrepreneurial mindset. Central to this evolution is the Entrepreneurial Mindset (EM). As championed by the Kern Entrepreneurial Engineering Network (KEEN), EM focuses on curiosity, making connections, and creating value [2].

Despite the clear necessity of these skills, many institutions struggle to move beyond ”entrepreneurship-as-an-elective” [1]. Isolated workshops or business-school minors often fail to reach the entire student body or, more critically, fail to integrate these concepts into the technical core. This paper outlines a pedagogical strategy to embed EM across the four-year undergraduate experience through a ”vertical thread” of core courses, ensuring that every student graduates with a validated ability to innovate and create value.

Background

ABET Student Outcomes

Engineering education in the United States is primarily guided by the ABET student outcomes, which establish the essential competencies required for professional practice [4]. The current ABET criteria (1-7) represent a mix of technical mastery and professional skills. Table 1 provides a full listing of these outcomes.

Table 1: ABET Student Outcomes (1–7)

Outcome	Description
1	An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics.
2	An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.
3	An ability to communicate effectively with a range of audiences.
4	An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts.
5	An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives.
6	An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions.
7	An ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

Analysis of Core Engineering Skills

While the integration of an entrepreneurial mindset is the primary focus of this work, it is essential to recognize that EM does not replace the core engineering skills; rather, it amplifies them. Core engineering skills, anchored in the ABET outcomes [4], are traditionally categorized into three foundational pillars:

- **Analytical and mathematical rigor:** This is the ability to use quantitative modeling to predict the behavior of physical systems (Outcome 1). In an entrepreneurial context, this rigor is what allows an engineer to move from a ”good idea” to a technically feasible solution. It provides the evidence-based foundation required for risk assessment and economic modeling.
- **Design and synthesis:** Traditional design skills focus on the technical execution of a product or system under constraints (Outcome 2). The entrepreneurial engineer expands these constraints to include market viability and stakeholder desirability. The core skill of

”designing for manufacture” or ”designing for safety” is thus augmented by ”designing for value.”

- **Data-driven decision making:** Outcome 6 emphasizes the ability to interpret data and use judgment. In professional practice, this skill is critical for iterative improvement. The core skill here involves not just the collection of data, but the discernment of which data points signal a need for technical pivoting versus those that validate current progress.

Together, these core skills provide the necessary technical substrate. Without this bedrock of engineering competence, the entrepreneurial mindset risks becoming purely speculative. The vertical thread described in this paper ensures that these core skills are developed in tandem with EM, creating a holistic professional identity [5].

ASCE Civil Engineering Body of Knowledge

In addition to ABET outcomes, discipline-specific frameworks such as the American Society of Civil Engineers (ASCE) Civil Engineering Body of Knowledge (BOK) provide a more granular roadmap for professional preparation [6]. The BOK (Third Edition) organizes the necessary competencies for professional practice into three core domains that define the breadth of the discipline.

Table 2: ASCE Body of Knowledge (BOK3) Core Domains

Domain	**Focus and Intent**
Foundational	Knowledge in mathematics, natural sciences, and humanities.
Technical	Engineering sciences and specialized design knowledge.
Professional Practice	Skills required to operate effectively in a professional environment.

Within these domains, the BOK defines 21 specific learning outcomes required for entry into the practice of civil engineering at the professional level [6].

Table 3: ASCE Body of Knowledge (BOK3) 21 Outcomes

Category	**Outcomes**
Foundational	(1) Mathematics, (2) Natural Sciences, (3) Humanities, (4) Social Sciences
Technical	(5) Materials Science, (6) Mechanics, (7) Experiments, (8) Critical Thinking and Problem Solving, (9) Design, (10) Sustainability, (11) Engineering Economics, (12) Risk and Uncertainty, (13) Breadth, (14) Depth
Professional	(15) Communication, (16) Public Policy, (17) Business and Public Administration, (18) Globalization, (19) Leadership, (20) Teamwork, (21) Professional Attitudes and Ethics

The BOK’s inclusion of outcomes such as ”Engineering Economics,” ”Risk and Uncertainty,” ”Business and Public Administration,” and ”Public Policy” highlights an industry-wide recognition that engineers must understand the broader ecosystem of their work—an alignment that reinforces the necessity of the KEEN Entrepreneurial Mindset [2].

The Vision for Civil Engineering in 2025

Complementing the structured outcomes of the BOK is the ASCE's "The Vision for Civil Engineering in 2025" [8], an aspirational document that defines the professional identity of future engineers. This vision posits that civil engineers are "entrusted by society to create a sustainable world and enhance the global quality of life." It defines five key roles that directly necessitate an entrepreneurial mindset:

1. **master builders:** Moving beyond simple construction to the holistic conceptualization of sustainable infrastructure.
2. **stewards of the environment:** Recognizing ecological constraints as design parameters for value creation.
3. **innovators and integrators:** Serving as the bridge between emerging technologies and societal needs—a role that demands the "Connections" competency.
4. **managers of risk and uncertainty:** Navigating the ambiguity of complex systems, which requires an assessment of both technical failure and market viability.
5. **leaders in public policy:** Translating technical data into compelling value propositions for the public good.

ASME's Vision 2030

Further supporting this multi-disciplinary mandate is the American Society of Mechanical Engineers (ASME) "Vision 2030" project [9]. This initiative was launched to reform mechanical engineering education to meet the increasingly complex demands of a globalized, technology-driven economy. Vision 2030 identifies significant gaps between traditional engineering pedagogy and professional requirements, specifically emphasizing the need for:

1. **innovation and creativity:** Explicitly calling for curricula that foster the ability to generate novel ideas and recognize opportunities for technological breakthrough.
2. **strengthening professional skills:** Prioritizing leadership, effective communication, and the ability to work in cross-functional teams as core technical requirements.
3. **curriculum flexibility:** Moving away from rigid, siloed coursework toward adaptable learning paths that allow students to explore interdisciplinary connections.
4. **practice-based learning:** Integrating real-world engineering challenges that require students to validate their technical solutions against market and social realities.

Engineering Management Body of Knowledge

In parallel with discipline-specific technical frameworks, the American Society for Engineering Management (ASEM) provides the Guide to the Engineering Management Body of Knowledge (EMBOK) [7]. This framework identifies the core domains and essential abilities required to lead technical organizations and manage complex projects effectively. The EMBOK highlights that successful engineering requires a blend of technical expertise and managerial acumen, particularly in strategic planning and resource optimization.

Table 4: EMBOK Core Domains

Domain	Focus Area
1	Introduction to Engineering Management
2	Leadership and Organizational Management
3	Strategic Planning
4	Financial Resource Management
5	Project Management
6	Supply Chain Management
7	Management of Technology
8	Engineering Operations Management
9	Quality Management System
10	Engineering Management Profession and Ethics
11	Legal Issues in Engineering Management

In addition to these domains, the EMBOK outlines essential abilities that bridge technical competence with professional leadership [7]. These abilities are crucial for the entrepreneurial engineer as they provide the framework for converting technical output into organizational value.

Table 5: Engineering Management Abilities and Professional Applications

Ability	Professional Application
Technical Competence	Maintaining proficiency in technical fields to lead specialized teams.
Communication	Articulating technical concepts to diverse stakeholders and decision-makers.
Leadership	Motivating teams and fostering an inclusive environment to meet objectives.
Financial Analysis	Interpreting financial data to optimize resource allocation and profitability.
Strategic Thinking	Aligning engineering projects with long-term organizational and market goals.
Ethics and Law	Navigating legal frameworks and maintaining professional integrity.

IEEE Technology and Engineering Management Society (TEMS)

Extending the managerial perspective to the electrical and computer engineering domains is the IEEE Technology and Engineering Management Society (TEMS) [10]. IEEE TEMS focuses on the essential link between engineering excellence and business performance. Its framework is structured around the management of the entire technology life cycle, emphasizing the role of the engineer as a strategic leader.

Table 6: IEEE TEMS Core Domains

Domain	Focus Area
1	Managing Innovation and Entrepreneurship
2	Managing Program and Project Portfolios
3	Strategic Management of Technology
4	Managing Technology Transitions
5	Leadership and Managing People
6	Operations and Supply Chain Management

Table 7: Essential Skills in Technology Management (IEEE TEMS)

Skill	Application in Engineering
Technology Assessment	Identifying and evaluating emerging technologies for market potential.
Strategic Roadmapping	Aligning long-term technical development with organizational vision.
Change Management	Leading technical teams through organizational or industry disruptions.
Entrepreneurial Execution	Transforming technical prototypes into viable, scalable products.
Risk Mitigation	Balancing technical ambition with operational and financial constraints.

Rationale for Curricular-Wide Innovation Integration

The comprehensive review of the ASCE, ASME, EMBOK, and IEEE TEMS frameworks [6]–[10] reveals a consistent industry mandate: modern engineering practice is now inseparable from innovation management and value creation. Consequently, the rationale for curricular-wide innovation integration is rooted in the shift from engineering as a purely technical exercise to a stakeholder-driven profession. An entrepreneurial mindset is no longer a secondary ”soft skill” reserved for electives, but a fundamental competency that must be cultivated in all graduates [1]. Moving entrepreneurship education out of isolated elective cohorts and into the technical core mitigates the ”silo effect,” ensuring that innovation literacy is developed in tandem with rigorous mathematical and scientific modeling. This systemic integration standardizes the professional identity of the graduate as a ”value creator” [5], ensuring equity of access to these critical cognitive tools across all engineering branches. Ultimately, by establishing innovation as a required curricular thread rather than an optional add-on, institutions signal that identifying stakeholder value is as essential to professional success as the integrity of technical calculations.

Integrated Skill Framework: Connecting KEEN, ABET, and Professional Standards

The synergy between the KEEN framework and ABET outcomes is foundational to this curriculum design [2], [4]. Rather than viewing EM as an addition to ABET, this paper argues that the ”3Cs” act as cognitive drivers that enable students to achieve technical outcomes through the lens of innovation and value.

Cross-Disciplinary Synthesis: Connecting KEEN to Discipline-Specific Bodies of Knowledge

To ensure a robust vertical thread, the KEEN framework [2] must be mapped not only to ABET but also to the discipline-specific visions and core domains that define modern civil, mechanical, and electrical engineering. This cross-disciplinary analysis demonstrates that the 3Cs (Curiosity, Connections, and Creating Value) are the common denominators across all engineering branches, providing a unified language for innovation.

Civil Engineering (ASCE BOK3 / Vision 2025):

- **Curiosity:** Linked to ”Social Sciences” and ”Sustainability” outcomes. A curious civil engineer investigates the societal impacts of infrastructure and explores ecological constraints as design parameters [6], [8].
- **Connections:** Linked to ”Public Policy,” ”Globalization,” and ”Risk and Uncertainty.” This requires connecting technical structural data with regulatory frameworks and global economic trends to manage systemic risks.
- **Creating Value:** Linked to the ”Master Builder” and ”Innovator” roles. Value is created when sustainable infrastructure enhances the global quality of life, moving beyond mere technical compliance to societal stewardship.

Mechanical Engineering (ASME Vision 2030):

- **Curiosity:** Directly addressed by the mandate for ”Innovation and Creativity.” Students are encouraged to explore emerging technologies and generate novel technical solutions to complex mechanical problems [9].
- **Connections:** Aligns with ”Curriculum Flexibility” and ”Cross-functional Teams.” Mechanical engineers must connect mechanical systems with software, electrical controls, and user-centered design to produce integrated products.
- **Creating Value:** Reflected in ”Practice-based Learning.” Value is validated when students apply mechanical principles to real-world challenges, ensuring the resulting systems are both technically high-performing and commercially viable.

Electrical and Computer Engineering (IEEE TEMS):

- **Curiosity:** Mapped to ”Technology Assessment.” This requires engineers to proactively scan the technical landscape to evaluate the potential of emergent digital and hardware innovations [10].
- **Connections:** Linked to ”Strategic Roadmapping” and ”Managing Technology Transitions.” Engineers must connect technical developmental milestones with

organizational vision and market timing.

- **Creating Value:** Evidenced in ”Entrepreneurial Execution.” Creating value in this domain is defined by the successful transformation of technical prototypes into scalable, viable products that achieve competitive advantage.

Entrepreneurial Engineering Skills: Professional Framework Integration

Building upon the cross-disciplinary alignment established above, we have identified seven specific entrepreneurial engineering skills. These skills translate high-level professional frameworks into actionable learning objectives that can be measured throughout the curriculum.

- **Contextual problem framing:** This aligns with ABET (1) and the KEEN mindsets of Curiosity and Creating Value. It addresses the ASCE Vision 2025 role of ”Steward of the Environment” [8] and ASME’s ”Innovation” pillar [9]. It is the ability to go beyond a given problem statement to investigate the ”why” and ”for whom,” ensuring that engineering solutions address real human needs rather than just technical gaps.
- **Opportunity identification and assessment:** This aligns with ABET (2), KEEN Connections, and Creating Value. It integrates EMBOK’s ”Strategic Planning” [7] and ASCE’s ”Risk and Uncertainty” outcomes [6]. The skill involves evaluating the feasibility, viability, and desirability of a project by calculating risk, conducting cost-benefit analyses, and recognizing technical challenges as business or societal opportunities.
- **Systems thinking and information integration:** This aligns with ABET (7) and KEEN Connections. It directly supports IEEE TEMS’s ”Strategic Roadmapping” [10] and ASCE’s ”Breadth in Civil Engineering Areas” [6]. Students practice cross-disciplinary synthesis, connecting technical data with disparate fields like economics, sociology, and environmental science to gain deeper insight into a problem’s ecosystem.
- **Value-driven design and iteration:** This aligns with ABET (2) and KEEN Creating Value. It mirrors ASME’s ”Practice-based Learning” [9] and IEEE TEMS’s ”Technology Transitions” [10]. The skill focuses on developing solutions optimized for impact rather than just performance, utilizing rapid prototyping and the resilience to treat failed tests as data points for iterative improvement.
- **Stakeholder-centric communication:** This aligns with ABET (3) and KEEN Connections. It fulfills EMBOK’s ”Communication” [7] and ASCE’s ”Public Policy” leadership roles [8]. Engineers learn to translate technical jargon into compelling value propositions for non-technical stakeholders (investors, users, or policymakers), effectively ”pitching” the benefits of a solution.
- **Collaborative leadership:** This aligns with ABET (5) and KEEN Connections. It integrates EMBOK’s ”Leadership and Organizational Management” [7] and ASME’s ”Cross-functional Teams” focus [9]. This goes beyond simple teamwork to intrapreneurial leadership—taking ownership of a project and coordinating diverse perspectives to drive a project forward.

- **Ethical and societal stewardship:** This aligns with ABET (4) and KEEN Creating Value. It addresses ASCE's "Globalization" [6] and EMBOK's "Legal Issues and Ethics" domains [7]. This skill ensures that "value" is defined ethically, evaluating long-term consequences on society and the environment and considering global sustainability alongside economic gain.

Strategic Integration Through Existing Accreditation Frameworks

The explicit mapping of these seven skills to existing accreditation requirements, as detailed in Table 9, demonstrates a strategic pathway for sustainable curriculum integration. A primary challenge in engineering education is "curricular bloat"—the difficulty of adding new content to an already credit-heavy degree program. By connecting entrepreneurial engineering skills directly to the mandated ABET outcomes [4], we provide an efficient avenue for integration that leverages the existing academic structure. Rather than viewing EM as a peripheral elective or a new set of requirements, this mapping allows it to serve as a pedagogical "overlay."

As illustrated by the cross-references in Table 9, this approach is efficient for three key reasons. First, it ensures sustainability: because institutions must already track and assess ABET outcomes 1 through 7, embedding EM skills within these categories makes their development part of the required continuous improvement process rather than a separate administrative burden. Second, it facilitates faculty adoption; by aligning competencies like "Contextual Framing" or "Failure Analysis" with familiar ABET language, instructors can see how EM enhances technical outcomes they are already teaching. Third, it provides a unified language for cross-disciplinary collaboration. By grounding the vertical thread in the common denominator of ABET, we ensure that students from all majors—civil, mechanical, or electrical—are developing innovation literacy through the same rigorous, accredited technical lens.

Table 8: Mapping Summary of ABET, KEEN, and Entrepreneurial Skills

ABET Outcome	**KEEN "C"**	**Entrepreneurial Engineering Skill**
(1) Problem Solving	Curiosity	Contextual Framing & "The Why"
(2) Design	Creating Value	Opportunity Identification & Risk Mgmt
(3) Communication	Connections	Stakeholder Value Propositions
(4) Ethics	Creating Value	Impact Assessment & Stewardship
(5) Teamwork	Connections	Inclusive Intrapreneurial Leadership
(6) Experimentation	Creating Value	Failure Analysis & Data-Driven Iteration
(7) Lifelong Learning	Curiosity	Adaptive Learning & Market Awareness

Rationale for a Vertical Thread: Developmental Phases and Strategic Scaffolding

The rationale for a vertical thread is rooted in developmental learning theory. Complex mindsets like EM cannot be mastered in a single semester; they require "scaffolding"—a process where new skills are built upon previously acquired knowledge through repeated exposure in increasingly complex contexts [3]. By spreading the cultivation of the seven entrepreneurial engineering skills across all four years, students encounter these concepts not as peripheral additions but as fundamental components of the engineering lifecycle.

This model explicitly addresses the strategic gap between traditional technical training and modern industry needs by highlighting that while skills can be efficiently integrated as an overlay to ABET outcomes, dedicated immersion milestones are necessary to achieve full professional mastery. These milestones act as high-stakes touchpoints where innovation literacy is the primary focus, encouraging students to internalize an ”innovator” identity within both private and public sector contexts [5].

This longitudinal development is organized into four distinct pedagogical phases:

- **Phase 1: Exposure and Awareness (Year 1):** The primary goal of this initial phase is to disrupt the student’s perception of engineering as a purely mathematical exercise. Through the shared ”Intro to Engineering” course, students are exposed to the concept of the stakeholder and foundational opportunity recognition.
- **Phase 2: Inquiry and Validation (Second Year):** In this phase, the focus shifts to rigorous deep inquiry and the validation of technical and market hypotheses. Mechanical Engineering students achieve this through Research Methods, while Civil Engineering students utilize the Introduction to Civil Engineering Systems course. Students learn to move from mere curiosity to evidence-based validation by conducting customer discovery and testing assumptions. Within the civil engineering context, this stage specifically introduces foundational systems thinking, ethical and societal stewardship, and opportunity identification within built environments.
- **Phase 3: Technical Iteration and Prototyping (Third Year):** This phase focuses on the design loop and the management of technical failure. In specialized Design Courses—such as Design of Steel Structures, Traffic Engineering, and Water Resources Engineering for civil engineering students, or Machine Design and Design of Control Systems for mechanical engineering students—students engage in rapid prototyping and failure analysis, learning to treat setbacks as essential data points for refinement and technical transition.
- **Phase 4: Realization and Value Delivery (Fourth Year):** The final phase focuses on the economic and professional realization of engineering solutions. Through ”Engineering Economics” [7] and the ”Senior Design Project,” students synthesize technical execution with financial modeling and stakeholder communication to deliver functional, sustainable, and high-impact products.

Implementing such a thread necessitates rigorous coordination across different engineering disciplines to identify optimal integration points within their respective curricula. This interdisciplinary approach ensures that even as students specialize technically—transitioning from shared first-year courses to discipline-specific design touchpoints—they maintain a unified innovative capability. Furthermore, this scaffolded approach recognizes that the rigorous analytical skills developed in foundational science and mathematics courses are the essential engines for these four phases of development. Mathematics provides the tools for modeling risk, while scientific principles establish the technical boundaries within which value-driven solutions must be validated.

Curricular Sequence and Scaffolding: Professional Alignment

The vertical thread is anchored by five key curricular touchpoints. Each phase is designed to map specific EM competencies and entrepreneurial engineering skills to the technical requirements of the host course while satisfying the professional mandates of industry bodies.

Phase 1: Exposure and Awareness (Year 1)

Intro to Engineering (Year 1): In the first semester of the undergraduate experience, all engineering students follow a common curriculum. This course serves as the first immersion milestone, where the primary focus is ”opportunity recognition.” Students fulfill the ASCE Vision 2025 mandate for societal stewardship [8] by performing stakeholder analysis and identifying community ”pain points.” This disrupts the ”math-only” perception and establishes ASME’s ”Innovation” pillar [9] as a foundational academic priority. Associated Skills: Contextual Problem Framing (Skill 1) and Ethical Societal Stewardship (Skill 7).

Phase 2: Inquiry and Validation (Year 2)

Research Methods (Mechanical Engineering - Year 2): This course serves as the Phase 2 touchpoint for mechanical engineering students, focusing on technical and market ”validation.” Students utilize primary research to validate problem-market fit, directly supporting IEEE TEMS’s ”Technology Assessment” competency [10]. By rigorously testing technical hypotheses against user needs, students learn to connect technical feasibility with market desirability. *Associated Skills:* Systems Thinking Information Integration (Skill 3) and Opportunity Identification Assessment (Skill 2).

Introduction to Civil Engineering Systems (Civil Engineering - Year 2): This course serves as the disciplinary anchor for civil engineering students in Phase 2. It specifically introduces foundational systems thinking, ethical and societal stewardship, and the process of opportunity identification within built and natural environments. By investigating systemic interactions, students satisfy ASCE BOK3’s ”Experiments” and ”Critical Thinking” outcomes [6] while validating the societal value of civil infrastructure solutions. *Associated Skills:* Systems Thinking Information Integration (Skill 3), Opportunity Identification Assessment (Skill 2), and Ethical Societal Stewardship (Skill 7).

Phase 3: Technical Iteration and Prototyping (Third Year)

Design Courses (Mechanical Engineering - Years 2 and 3): For mechanical engineering, Machine Design and Design of Control Systems anchor this stage where students engage with iterative technical development. These major-specific courses fulfill ASME’s Vision 2030 call for practice-based learning [9]. Students develop MVPs and use rigorous feedback loops to pivot designs, reinforcing the IEEE TEMS ”Technology Transitions” skill [10]. This ensures that technical design (ABET 2) is inextricably linked to the entrepreneurial connection of creating stakeholder desirability. *Associated Skills:* Value-Driven Design Iteration (Skill 4) and initial Collaborative Leadership (Skill 6).

Design Courses (Civil Engineering - Years 2 and 3): In the civil engineering curriculum, Design of Steel Structures, Traffic Engineering, and Water Resources Engineering serve as the specific touchpoints where students engage with iterative technical development. These courses bridge technical design (ABET 2) with stakeholder desirability by requiring students to refine structural or systemic solutions based on environmental and social constraints [6], [8]. *Associated Skills:* Value-Driven Design Iteration (Skill 4) and initial Collaborative Leadership (Skill 6).

Phase 4: Realization and Value Delivery (Fourth Year)

Engineering Economics (year 4): Serving as the second common course for all students, this acts as the professional bridge between technical design and market realization. It satisfies EMBOK's "Financial Resource Management" [7] and ASCE BOK3's "Engineering Economics" outcomes [6]. Students develop business model canvases and perform feasibility assessments to ensure long-term sustainability and viability. Associated Skills: Opportunity Identification Assessment (Skill 2) and Stakeholder-Centric Communication (Skill 5).

Senior Design Projects (Year 4): The culmination of the thread, this phase serves as the final immersion milestone, requiring students to demonstrate holistic "value creation." Students deliver projects that serve as professional artifacts, fulfilling the ASCE Vision 2025 "Master Builder" role [8] and the IEEE TEMS "Entrepreneurial Execution" mandate [10]. It represents a full synthesis of technical execution, financial modeling (EMBOK), and interdisciplinary leadership (ASME). *Associated Skills:* Synthesis of all skills, with a heavy emphasis on Collaborative Leadership (Skill 6) and Stakeholder-Centric Communication (Skill 5).

Skill Interaction and Cumulative Synthesis

The effectiveness of the vertical thread relies on the dynamic interaction between skills developed across the undergraduate lifecycle, moving from foundational inquiry to professional execution. This synthesis is not merely additive; it is an integration of technical rigor with the professional mandates established by the ASCE, ASME, EMBOK, and IEEE TEMS frameworks [6]–[10].

Foundation skills like Contextual Problem Framing (Skill 1) mastered in the first year serve as the engine for the ASCE Vision 2025 role of "Steward of the Environment" [8] and provide the essential stakeholder data required for the Value Propositions (Skill 5) and Economic Feasibility (Skill 2) assessments in the fourth year. Similarly, the Systems Thinking (Skill 3) and Ethical Stewardship (Skill 7) introduced in Phase 2—specifically through the Introduction to Civil Engineering Systems course for civil engineers and Research Methods for mechanical engineers—provide the cross-disciplinary context required for the Ethical Stewardship evaluated during the Senior Design Project.

This skill interaction bridges the gap between purely technical experimentation and the IEEE TEMS "Strategic Roadmapping" ability [10], requiring students to synthesize technical data with economic, legal, and environmental constraints. The Data-Driven Iteration (Skill 4) practiced in Phase 3 design courses—reflecting ASME's Vision 2030 ”Practice-based Learning” [9] and creates a resilient mindset that allows seniors to treat capstone setbacks not as failures, but as essential data points for refining a product. Ultimately, this cumulative synthesis ensures that the student's technical core (science and math) is inextricably linked to their professional identity as a Master Builder (ASCE) and Strategic Leader (TEMS/EMBOK), prepared to deliver maximum value in a complex global market.

Conclusion

The design and implementation of a required vertical entrepreneurship thread represents a systemic pedagogical response to the evolving demands of the global engineering profession. By scaffolding the Entrepreneurial Mindset (EM) across the undergraduate journey—from the shared foundational first semester to the interdisciplinary senior design milestones—institutions can ensure that innovation literacy becomes an inherent component of every graduate's professional identity [5]. This longitudinal model successfully synthesizes the rigorous analytical bedrock of science and mathematics with the adaptive skills of opportunity recognition and stakeholder-centric value creation.

As established by the analysis of the ASCE, ASME, EMBOK, and IEEE TEMS frameworks [6]–[10], the modern engineer is no longer tasked solely with technical execution. The separation into discipline-specific paths during the inquiry and iteration phases (Phases 2 and 3) ensures that students apply entrepreneurial principles to real-world engineering artifacts—be they civil infrastructure systems or mechanical control devices. While the efficiency of mapping EM to ABET outcomes facilitates curricular adoption, the inclusion of ”immersion milestones” where these skills are the primary focus ensures that students move beyond passive awareness to active professional mastery.

Whether operating in the public sector as a ”Master Builder” and societal steward or in the private sector as a strategic innovator, the ability to navigate ambiguity, assess multi-dimensional risks, and deliver validated value is paramount. The vertical thread provides the unifying language and structural framework necessary to meet these discipline-specific visions. By integrating these competencies into the technical core, we prepare graduates to move beyond the traditional ”problem-solver” archetype to become holistic ”value-creators.” This curriculum design serves as a replicable blueprint for modernizing engineering education to align with the strategic needs of both industry and society in the 21st century.

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