Embedding Entrepreneurially Minded Learning in Communication Systems Education

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Abstract

This paper presents the integration of Entrepreneurially Minded Learning (EML) principles into a junior-level Communication Systems (ECCS 3191) course, a mathematically intensive required course in Electrical Engineering program at Ohio Northern University (ONU). The primary objective of embedding EML in this course is to develop students' entrepreneurial mindset (EM), characterized by curiosity, connections, and value creation (the 3C's), while also providing extensive technical training. The redesigned course integrates well-structured EM frameworks, including the Question Formulation Technique (QFT) and the Need-Approach-Benefits/Costs-Competition (NABC) model, to promote inquiry-driven learning, EM-based thinking, and value-oriented problem solving. Two major EML-based modules are developed and introduced in the course; the first focuses on EML in AM and FM Receiver Design, and the second on EML-Based Challenge Design Problems. The impact of these two modules is assessed, and students' performance is evaluated through rubric-based grading, including student reflections, design reports, and research papers. The results confirm the strong alignment with recognized entrepreneurial outcomes.

1. Introduction

Rapid advances in wireless and digital communication technologies have fundamentally reshaped our society, economy, and technology. Thus, it has created tremendous opportunities and complex challenges across all sectors. In addition, it has led to a high demand for engineers with expertise in the technical side as well as the ability to innovate and create value in this rapidly evolving environment [1].

Communication Systems (ECCS 3191) is usually a junior-level core course in the Electrical Engineering (EE) program at ONU. The course typically covers modulation theory, signal interference, noise analysis, bandwidth efficiency, and receiver design. Despite the significance of these topics in the course, students often perceive the material as very abstract and feel disconnected from the real world [2]. Traditional engineering courses, particularly in communication systems, are more inclined towards theoretical mastery and analytical problem-solving, while sacrificing the broader entrepreneurial competencies, including opportunity recognition, stakeholder awareness, creative problem-solving, and value creation [3].

To address these educational gaps, national initiatives such as the Kern Entrepreneurial Engineering Network (KEEN) have advocated for the intentional integration of Entrepreneurially Minded Learning (EML) into engineering curricula, which aims to progressively develop the entrepreneurial mindset (EM) alongside technical skills [4]. Contemporary engineering education is thus called to cultivate both disciplinary expertise and entrepreneurial thinking to equip graduates in innovation-driven industries [5]. Training students with such skills requires updating curricula to equip them with a mindset of curiosity, opportunity recognition, interdisciplinary connections, and value creation [6].

This manuscript presents the integration of EML within the Communication Systems course in our curricula. The technical assignments in this course are updated to integrate curiosity, entrepreneurial thinking, and value-creation skills. By embedding EML principles, the course aims to foster an entrepreneurial mindset along with mastery of analog and digital communication systems. Thus, this work adds to evidence that an entrepreneurial mindset can be introduced within mathematically intensive core courses, which also aligns with the ASEE Entrepreneurship & Engineering Innovation Division's mission to prepare engineers to address societal needs and emerging market opportunities.

2. Background and Literature Review

The entrepreneurial mindset has received significant attention in engineering education to prepare graduates for changing technological and economic environments [1] [4]. Entrepreneurially Minded Learning (EML) is a pedagogical approach that embeds the entrepreneurial mindset (EM) into engineering curricula, that aims to develop curiosity, connections, and value creation [1] [4]. The Kern Entrepreneurial Engineering Network (KEEN) defines the entrepreneurial mindset through the 3C's: Curiosity, Connections, and Creating Value [7]. This mindset emphasizes opportunity recognition, systems thinking, and stakeholder awareness in technical problem-solving [8].

The literature has shown improvements in students' expertise when EML is embedded in core engineering courses [3] [9]. Furthermore, the recent literature discusses integrating EM activities into core courses while maintaining the technical strength of courses [10] [11].

The EML has been implemented in Electrical and Computer Engineering courses such as circuits, signal processing, and capstone design [5] [12] [13]; however, the Communication Systems course has not received much attention for EML. Students often find these courses to be mathematically intensive and abstract [14]. Project-based learning techniques have been shown to increase student engagement when real-world communication scenarios are integrated with theoretical concepts and mathematical formulation [15].

Several frameworks support EML implementation. The Question Formulation Technique (QFT) provides a mechanism for developing inquiry skills and promotes student participation. QFT empowers students to generate, prioritize, and investigate their own questions, which fosters inquiry, ownership, and critical thinking skills [16]. Rothstein and Santana [16] demonstrate that QFT increases students' ownership of their learning and critical thinking.

The NABC (Need, Approach, Benefits/Costs, Competition) model is widely used as an innovative pedagogy [17] [18]. In addition, the NABC improves value proposition analyses and communication skills of students. Moreover, the NABC requires communicating technical feasibility, stakeholder value, and competitive differentiation to implement entrepreneurial thinking [19] [20].

This work builds on prior literature by synthesizing QFT, NABC, and EML within a single Communication Systems course and empirically evaluating student outcomes. While EML integration has been reported in various Electrical and Computer Engineering courses, there remains a notable gap for the EML integration in the Communication Systems course. This gap motivates the present work.

3. Course Redesign and EML Implementation

The Communication Systems (ECCS 3191) course is a four-credit, junior-level core course that includes a three-hour weekly laboratory component and is structured over a 15-week semester. To foster the entrepreneurial mindset alongside technical and mathematical content, the course was comprehensively redesigned to embed Entrepreneurially Minded Learning (EML) throughout its structure. The course is redesigned based on the three key principles: (1) integration of EML within existing content rather than addition as a separate stand-alone assignment, (2) explicit framework of the EM development, and (3) alignment with the Expanded KEEN Student Outcomes (eKSO) [21]. The design project and problem assignments in the course are restructured to incorporate EML outcomes without sacrificing technical or mathematical content. The course redesign with EML is carried out using the following frameworks:

- The Question Formulation Technique (QFT) for inquiry-driven learning, which promotes student-generated questioning, researching, and exploration;
- The 3C's framework (Curiosity, Connections, Creating Value) to introduce the EM mindset and value-driven approaches;
- The NABC model (Need, Approach, Benefits/Costs, Competition) for structured analysis and communication of value propositions.

Two major modules were introduced into the restructured assignments: (1) EML in AM and FM Radio Receiver Design, and (2) EML-based Challenge Design Problems. Both modules are explicitly mapped to eKSO and are designed to provide authentic, inquiry-driven, and value-oriented learning experiences within the Communication Systems curriculum.

4. Module 1: EML in AM and FM Radio Receivers Design Projects

Module 1 in this course serves as the primary experiential pillar for the EML integration within the Communication Systems course. Traditionally, design projects, which is typically based on AM and FM receiver design, emphasize hardware implementation, the project report, and the presentation. While such a design project is highly effective for reinforcing technical, mathematical, and hands-on skills; however, it often limits opportunities for inquiry, market understanding, and value-creation skills. To address these limitations, the AM and FM receiver design projects were redesigned as a three-stage, EM design experience structured around the QFT, the KEEN 3C's framework, and the NABC model. The three stages are sequential yet interrelated, reinforcing the development of the EM alongside technical, mathematical, and hands-on competencies.

4.1 Stage 1: QFT-Based Inquiry, Research and Exploration

Stage 1 fosters students' curiosity by applying QFT through a structured process. The QFT, grounded in generating questions, researching, and exploration, aligns directly with KEEN eKSO outcome 1(a) [21], which relates to curiosity, particularly the development of a propensity to ask meaningful questions.

At the beginning of the module, the class is divided into two design tracks: an AM receiver group and an FM receiver group. Within each track, students begin with an individual question formulation exercise. During a timed in-class activity, each student generates a comprehensive list of technical questions related to their assigned receiver system. Then, students switch to collaborative question exploration in groups, where they improve their individual questions, order the most salient ones, and select the top five questions for deeper investigation. This process of refinement enables students to think critically about the technical relevance and feasibility. Finally, students conduct independent research to explore these questions using textbooks, technical standards, and peer-reviewed sources.

The deliverable for Stage 1 is a Question Exploration Research Paper, in which each group synthesizes its findings into a technical narrative. Students are required to integrate research findings within a well-organized discussion that demonstrates conceptual understanding and analytical reasoning. This part of Stage 1 directly corresponds to KEEN eKSO 2(b) [21], which relates to Connections, i.e., Identify sources of information and research to explore answers of their own questions.

Through this process, students transition from inactive receivers of information to active investigators. The QFT-based structure integrates curiosity with measurable learning outcomes and establishes a strong groundwork for later design stages.

4.2 Stage 2: Three C's Framework in Receiver Design

Stage 2 incorporates the KEEN 3C's framework; Curiosity, Connections, and Creating Value, into the receiver design exercise. While Stage 1 emphasizes inquiry, Stage 2 focuses on helping students recognize how entrepreneurial thinking influences their technical decision-making.

During the design project, students are introduced to the 3C framework and its relevance to engineering innovation using real-world communication system examples. Following this discussion, students remain in their AM or FM design groups and analyze their ongoing receiver projects through the lens of each "C." Students are required to articulate:

Curiosity: How questioning and investigation directed their understanding of receiver design, performance trade-offs, and design alternatives.

Connections: How concepts from communication systems, signals and systems, electronics, and electromagnetics informed their design decisions.

Creating Value: How their receiver design creates value for users or society, such as reliability, accessibility, cost, or societal needs.

Three eKSOs are combined to develop one outcome to align the objectives of Stage 2 with the 3C's framework in receiver design, i.e., Explore multiple viewpoints (KSO 1-g, Curiosity), connect life experiences with the project (KSO 2-c, Connections), and understand to develop outcomes from the project (KSO 3-c, Creating Value).

4.3 Stage 3: Hardware Implementation and NABC Analysis

Stage 3 represents the culmination of the AM and FM receiver design projects, in which students implement the technical solutions and describe the value creation in a communication system using the NABC framework. Students design subsystem blocks, select components, and assemble a complete receiver system. In this stage of hardware implementation, students remain in touch with the instructor and frequently discuss and receive formative feedback that supports iterative improvement.

Teams are responsible for preparing a bill of materials, identifying component suppliers, and considering basic cost constraints. These economic components of the project familiarize students with real-life situations, such as availability, trade-offs, and feasibility, establishing connections between engineering design and real-life limitations. Once completed, each group prepares a final project report and oral presentation, including the NABC framework:

Need: The motivation, as well as the societal context or user requirements for AM or FM receiver systems.

Approach: The technical design, modulation methods, and design rationale.

Benefits and Costs: Performance advantages, limitations, complexity, and economic aspects.

Competition: Comparison with alternative modulation schemes or receiver architectures.

The project shifts from "what was built" to "why this solution matters" when students present their design project, including technical work, within the NABC structure. This final stage strengthens the EM by requiring students to communicate engineering solutions in line with professional practice and stakeholder engagement.

Readers and interested instructors are referred to [22], which provides the complete assignment description, rubrics, course syllabus, and student sample work of Module 1. The course syllabus clearly lists all topics, course outcomes, and ABET student outcomes. In addition, the course syllabus confirms that there was no sacrifice in the course's mathematical component. The reference [22] shows that EM is integrated into the course through projects and homework assignments completed outside class hours.

For NABC implementation in the course, the readers are referred to [23] for more details, including assignment descriptions and rubrics.

5. Module 2: EML-based Challenge Design Problems

While Module 1 emphasizes inquiry and value creation within the receiver design projects, Module 2 extends EML by engaging students in open-ended, real-world challenge problems.

This module integrates ambiguity, technical constraints, and client requirements, which also introduces characteristics of professional engineering practice.

The challenge design problems are structured around real-world consulting-style scenarios in which students assume the role of practicing engineers responding to client needs. These activities are aligned with the 3C's framework and are structured to foster Curiosity, Connections, and Creating Value across both analog and digital communication systems.

Two challenge design problems are assigned during the semester to cover the two main technical components of the course: analog modulation and digital modulation techniques. Each challenge design problem follows a consistent four-step EML structure that guides students from inquiry to impact analysis.

5.1 Challenge Design Problem #1: Analog Communication System Design

The first challenge design problem is brought up after the coverage of Double-Sideband (DSB) and conventional amplitude modulation techniques. At this point in the course, students have sufficient fundamental understanding to analyze analog modulation but have not yet fully explored real-world considerations such as compliance regulations, spectrum availability, and interference.

In this challenge, students were tasked with designing a radio broadcasting station for the town, with technical and financial limitations, based on the client RfP. The open-ended style of the problem purposely avoids prescriptive procedures, requiring students to frame the problem space before proposing a solution. This strategy promotes entrepreneurial thinking by requiring students to evaluate engineering decisions within technical, economic, regulatory, and social contexts.

5.2 Challenge Design Problem #2: Digital Communication System Design

The second challenge design problem is brought up during the digital modulation techniques section of the course, following lectures on binary modulation schemes. This challenge focuses on short-range wireless communication and mirrors industry decision-making methods related to technology selection. The scenario assigned in this challenge design problem includes recommendations for a company-owned wireless phone service to communicate with all employees within a one-mile radius.

An EML-based, structured four-step process is provided to guide students in addressing each challenge design problem.

Step 1: Fueling Curiosity Through Independent Inquiry

The first step of the challenge emphasizes curiosity by asking students to generate their own sets of questions and observations about radio broadcasting systems. In addition, the first challenge problem requires students to identify the information necessary to proceed with the design, such as AM or FM, bandwidth, frequency availability, transmission power, and regulatory limits.

Similarly, students explore various wireless mobile phone technologies, such as walkie-talkie systems or private wireless networks, in the second challenge problem. This step reinforces curiosity by requiring students to evaluate alternatives rather than accept a predetermined solution.

The outcome of this step requires a summary of findings, in which students describe the technical and regulatory limitations relevant to the challenge problem. This inquiry-based approach measures an outcome, eKSO 1(m): Observes trends about the changing world with a future-focused orientation/perspective.

Step 2: Cruising with Connections

In the second step, students connect their research findings to theoretical and mathematical concepts from this course and any other prior coursework. Connections to courses including electromagnetics, signals and systems, and probability theory are explicitly encouraged. This step strengthens interdisciplinary reasoning and reinforces systems-level understanding.

This step integrates the outcome: KEEN eKSO 2(d) Connect content from multiple courses to solve a problem, which requires students to connect knowledge from multiple courses and domains. Thus, the challenge enables students to have a broader systems-level thinking.

Step 3: Creating Value Through Design Decisions

Once students have established technical feasibility and regulatory compliance, they must propose a complete design and/or recommendation that delivers value to the client. Value creation is framed through multiple dimensions, including reliability, signal interference, spectrum usage, transmission power, and economic feasibility. Students justify modulation selection, carrier frequency choice, and power levels based on both engineering performance and client benefits.

This step introduces the outcome: eKSO 3(c), Create a solution to the problem that meets the requirements, which requires students to articulate how technical decisions translate into tangible value.

Step 4: Technical, Economic, and Societal Impact Analysis

In the final step, students evaluate the extensive implications of their proposed solution. In this step, students evaluate technical impacts such as reliability, robustness, as well as scalability. In addition, students analyze economic impacts, including operational cost as well as accessibility, and then study societal impacts related to information dissemination, public awareness, and civic engagement.

This analysis broadens students' understanding of engineering principles beyond theoretical design and underscores the community responsibility inherent in the development of communication systems. In addition, this impact analysis reinforces client-centered engineering design and is closely aligned with with the development of an entrepreneurial mindset.

Readers and interested instructors are referred to [24], which provides the complete assignment description, rubrics, course syllabus, and student sample work of Module 2.

6. Learning Outcomes and Assessment Methods

Assessment of EML within the Communication Systems course was designed to align instructional activities with measurable learning outcomes defined by the Expanded KEEN Student Outcomes (eKSOs). The assessment methods employed a measurable approach to evaluate students' performance through artifacts, including question submissions, research papers, project reports, and challenge design solutions. To ensure consistency, all EML-related outcomes were evaluated using structured rubrics and performance-based artifacts rather than self-reported student perceptions. Each module covers specific EM outcomes and employs assessment tools appropriate to the nature of the learning activity.

6.1 Assessment of Module 1 Learning Outcomes

Three primary learning outcomes were incorporated and assessed in Module 1, which are described as follows:

Learning Outcome 1: Develop a propensity to ask more questions (eKSO 1-a: Curiosity)

Students demonstrate the ability to generate meaningful, technically relevant questions that reflect curiosity, recognition of knowledge gaps, and interest in understanding system-level thinking.

Students engaged in the QFT during the early stages of the AM and FM receiver design projects. Student-generated question sets were evaluated using a standardized QFT formulation rubric, which assessed questions based on quantity, relevance, depth, curiosity, and knowledge gaps. This assessment provided direct evidence of students' propensity to ask questions and allowed for measurable performance.

Learning Outcome 2: Identify sources of information and conduct research to explore answers to self-generated questions (eKSO 2-b: Connections)

Students demonstrate the ability to identify reliable information sources, synthesize external knowledge, and apply research findings to engineering problems. Students worked in design groups to select and prioritize the most salient questions. Groups then conducted independent research to explore these questions using textbooks, scholarly articles, and peer-reviewed publications.

Each group submitted a Question Exploration Research Paper summarizing findings related to their selected questions. The assignment was evaluated on the basis of credibility, research, citation, and written communication. This outcome assessed students' ability to form connections between newly acquired information and existing technical knowledge. The emphasis on external research and synthesis provided measurable evidence of students' ability to extend learning beyond classroom materials.

Learning Outcome 3: Explore multiple viewpoints (KSO 1-g, Curiosity), connect life experiences with the project (KSO 2-c, Connections), and understand to develop outcomes from the project (eKSO 3-c, Creating Value)

Students demonstrate the ability to evaluate alternative design approaches, integrate personal and academic experiences, and articulate how engineering solutions create value. During the three C's reflection exercise, students analyzed their AM or FM receiver design process through the lenses of Curiosity, Connections, and Creating Value.

Groups discussed alternative design solutions, reflected on learning experiences, and considered the wider benefits of their receiver systems. Student submissions were evaluated based on multiple design perspectives, prior coursework, depth of reflection, and reasoning. This assessment captured higher-order EM behaviors by requiring students to synthesize technical knowledge, experiential learning, and value-oriented reasoning.

6.2 Assessment of Module 2 Learning Outcomes

Module 2 stressed open-ended, real-world challenge problems. Assessment focused on students' ability to operate under ambiguity, integrate interdisciplinary knowledge, and create client-centered solutions.

Learning Outcome 4: Observes trends about the changing world with a future-focused orientation/perspective. (eKSO 1-m, Curiosity)

Students demonstrate awareness of changing technological, regulatory, and market trends influencing communication systems. Students conducted market and regulatory research, such as identifying available frequency bands, spectrum constraints, and emerging communication technologies. Student reports were evaluated on the basis of opportunity identification, regulatory resources, and reasoning, which influence design decisions. This outcome assessed students' ability to analyze environmental trends and apply them to engineering design contexts.

Learning Outcome 5: Connect content from multiple courses to solve engineering problems (eKSO 2-d: Connections)

Students integrate knowledge from communication systems, signals and systems, electromagnetics, probability theory, and related courses to develop a complete system-level solution. In addition, students applied interdisciplinary concepts to estimate coverage area, determine transmit power, evaluate modulation schemes, and justify design assumptions. The criteria to evaluate this learning outcome includes concepts from multiple courses, integration of theory into system design, and justification of interdisciplinary assumptions. This assessment provided direct evidence of students' ability to integrate learning across the ECE curriculum.

Learning Outcome 6: Create a solution to the challenge problem that meets the requirements (eKSO 3-c, Creating Value)

Students design a feasible solution that meets client requirements and technical constraints. Student solutions were evaluated based on problem requirements, feasibility, constraints, design trade-offs, and articulating value to the client. This outcome emphasized value creation by requiring students to provide solutions that satisfy the client's needs rather than theoretical objectives.
By aligning learning outcomes, instructional strategies, and assessment instruments, this approach provides a structured and replicable model for evaluating EML integration in upper-level engineering courses.

7. Results and Discussion

Assessment data were collected using rubrics aligned with the KEEN eKSOs and analyzed using the EAMU performance framework (Excellent, Adequate, Minimal, Unsatisfactory). The EAMU framework provides a quantitative mechanism for measuring EM development, even when qualitative assessment methods are difficult to implement.

In this study, EAMU performance levels were defined as follows: Excellent (90–100%), Adequate (75–89%), Minimal (60–74%), and Unsatisfactory (<60%). Student performance levels throughout all assessed outcomes are summarized in Table 1.

As shown in Table 1, results confirm strong achievement across curiosity, connections, and creating value outcomes in both instructional modules. High concentrations of Excellent and Adequate performance levels were noted throughout all outcomes, with no instances of Unsatisfactory performance.

The predominance of higher-level Excellent ratings suggests that students participated in EML activities and also exhibited an entrepreneurial mindset aligned with KEEN-defined competencies. The limited occurrence of Minimal ratings, primarily within Module 2, reflects the increased openness and complexity of the challenge-based assignments.

Table 1: Summary of EAMU Outcome Assessment

Module	Learning Outcome	eKSO Outcome	Excellent	Adequate	Minimal	Unsatisfactory
1	1	1-a (Curiosity)	57%	43%	0	0
1	2	2-b (Connections)	100%	0	0	0
1	3	3-c (Creating Value)	100%	0	0	0
2	4	1-m (Curiosity)	64%	22%	14%	0
2	5	2-d (Connections)	64%	29%	7%	0
2	6	3-c (Creating Value)	64%	36%	0	0

7.1 Module 1 Results and Discussion

In Module 1, the results confirm students' strong performance. For Learning Outcome 1 (eKSO 1-a, Curiosity), 57% of students achieved Excellent, and 43% achieved Adequate performance. This distribution implies effective attention with the QFT, supporting students' ability to generate meaningful technical questions.

Learning Outcome 2 (eKSO 2-b, Connections) demonstrated high performance, with 100% of students achieving an Excellent rating. All groups cited reliable sources of information and described their research findings to address their questions. This outcome provides quantitative evidence of students' ability to connect external knowledge with engineering problem-solving.

Similarly, Learning Outcome 3 (eKSO 3-c, Creating Value) showed 100% Excellent performance. Students effectively explored multiple design viewpoints, connected prior experiences to receiver design activities, and articulated the value created through their solutions. These data show that structured reflection can produce measurable evidence of value-oriented thinking.

7.2 Module 2 Results and Discussion

Module 2 introduced open-ended, real-world challenge problems that also demand greater autonomy and systems-level thinking. While performance remained strong in Module 2, slightly greater variation was observed compared to Module 1.

For Learning Outcome 4 (eKSO 1-m, Curiosity), 64% of students achieved Excellent, 22% Adequate, and 14% Minimal. The presence of limited Minimal ratings likely reflects the increased ambiguity inherent in market- and standards-driven design problems.

Learning Outcome 5 (eKSO 2-d, Connections) exhibited similar trends, with 64% Excellent, 29% Adequate, and 7% Minimal performance. Most teams successfully integrated concepts from communication systems, signals and systems, and electromagnetics to justify design decisions. These results suggest that challenge-based learning effectively promotes interdisciplinary thinking, though there is variability in students' comfort with synthesis across domains.

For Learning Outcome 6 (eKSO 3-c, Creating Value), all students demonstrated Excellent or Adequate performance. Teams produced technically feasible solutions that satisfied the client's requirements. The absence of Minimal or Unsatisfactory ratings indicates students' strong ability to translate open-ended problem statements into requirement-driven engineering solutions.

8. Conclusion and Future Work

This paper demonstrates that Entrepreneurially Minded Learning (EML) can be successfully incorporated into a junior-level Communication Systems course without sacrificing technical and mathematical content. The EM-based modules in this course developed students' skills in both subject areas and an entrepreneurial mindset.

Assessment results are evaluated using the EAMU approach, which is consistent with KEEN Entrepreneurial Student Outcomes. In addition, the results confirm strong achievement across curiosity, connections, and creating value dimensions. These findings confirm that the development of an entrepreneurial mindset is achievable within technically and mathematically intensive engineering courses.

The future work will examine the longitudinal impacts of EML integration on student learning and career preparedness, including performance in subsequent courses and early-career outcomes.

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