Integrating Project-Based Learning and Cooperative Education for Future Engineers: Insights and Best Practices from the Iron Range Engineering Bell Model

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Abstract

The Iron Range Engineering (IRE) Bell Model combines project-based learning (PBL) with cooperative education to enhance students' technical and professional skills. The program begins with the Bell Academy—a semester-long bridge emphasizing foundational engineering principles, design thinking, and career development. Students then undertake 24-month paid co-op placements while completing remote coursework, supported by learning coaches who foster self-directed learning and reflective growth. Recent data highlight high co-op placement rates and a strong sense of community, demonstrating the model's effectiveness across diverse student populations. This paper discusses key strategies, including assessment tools, self-directed learning, student recruitment, and support, which have been integral to the program's success. By sharing these best practices and lessons learned, we aim to present an adaptable model for other institutions seeking to integrate experiential learning into their engineering curricula, ultimately promoting both academic excellence and career readiness.

Keywords: Iron Range Engineering, Project-based Learning, Work-based Learning, Cooperative Education

1 Introduction: an overview of Iron Range Engineering (IRE) program

The Iron Range Engineering (IRE) program, an upper-division engineering initiative supported by Minnesota State University, Mankato, exemplifies a transformative model in engineering education. Founded in 2009 and inspired by the globally renowned Aalborg University PBL model (Kolmos, Bøgelund, Spliid., & Monrad, 2019), IRE bridges the gap between theoretical instruction and industry practice (MacLeod, et al., 2020) through a comprehensive methodology combining project-based learning (PBL), work-integrated experiences, and self-directed learning (Johnson, Ulseth, & Wang, 2018). It challenges conventional frameworks prioritizing technical expertise while underemphasizing professional and workplace competencies. The program also addresses educational disparities faced by geographically isolated and diverse student populations, often referred to as "engineering education deserts," (Hillman, 2016) by collaborating with community colleges nationwide to create streamlined transfer pathways (Maki, et al., 2019). IRE's curriculum emphasizes developing "whole engineers" by integrating technical knowledge, professional growth, ethical responsibility, and adaptability across three core domains: technical learning, design thinking, and professionalism. Its innovative approach has earned notable recognition, including the ABET Innovation Award in 2017 and being identified as an "emerging world leader" in engineering education in MIT's Global State of the Art in Engineering Education report (Graham, 2018). Since 2019, IRE has gradually integrated co-ops into PBL curriculum known as the Bell Model. This version of the program was inspired by the Charles Sturt University engineering program in Australia (Lindsay & Morgan, 2021). Currently, the IRE Bell Model has graduated 96 students and achieved a five-semester graduation rate of 80%.

2 Program Structure in IRE Bell Model

Students start their first semester at Bell Academy (BA), a semester-long bridge program designed to support them in transitioning from foundational STEM coursework to industry placements. BA equips students with technical, design, and professional competencies necessary for successful co-op placements and future careers in engineering (Christensen, Singelmann, & Mann, 2023). The program implements a traditional way of implementing PBL, where students collaborate on industry-related design projects and receive training in technical subjects through 6 modular one-credit courses in Mechanical and Electrical Engineering (Fig. 1). These one-credit courses focus on the fundamental principles essential for passing the Fundamentals of Engineering (FE) exam, a key step toward becoming a licensed professional engineer. Each course also requires students to complete a deep learning activity—such as a simulation, experiment, or technical report—related to the course content. Professional skills such as leadership, conflict management, and public speaking are integrated into the 3-credit design course, which is a semester-long industry project. There are two highlights in furthering students' career preparation. First, the BA fosters self-directed learning by encouraging reflective practices and personal development, ensuring students are prepared for real-world engineering challenges while building a strong professional identity. Second, learning coaches guide students in developing comprehensive job packages, including resumes, cover letters, mock interviews, and career fair participation. To maximize job placement success, students are encouraged to apply for approximately 50 positions within one month into the Bell Academy (Rogalsky, Johnson, & Ulseth, 2020).

Following Bell Academy, students enter 24-month paid, full-time industry positions while completing their technical courses remotely (Figure 1). They receive support from faculty to develop self-directed learning plans. There are also ABET-driven assessment tools (discussed in the next section) to ensure high-quality learning when they are remote learners. From the perspective of financial stability, students typically earn $21-$23 per hour for a 40-hour work week (Spence, Siverling, Karlin, & James, 2023), often covering tuition and living expenses. This unique model ensures graduates emerge not only with strong academic credentials but also with extensive industry exposure, enhancing their competitiveness in the job market.

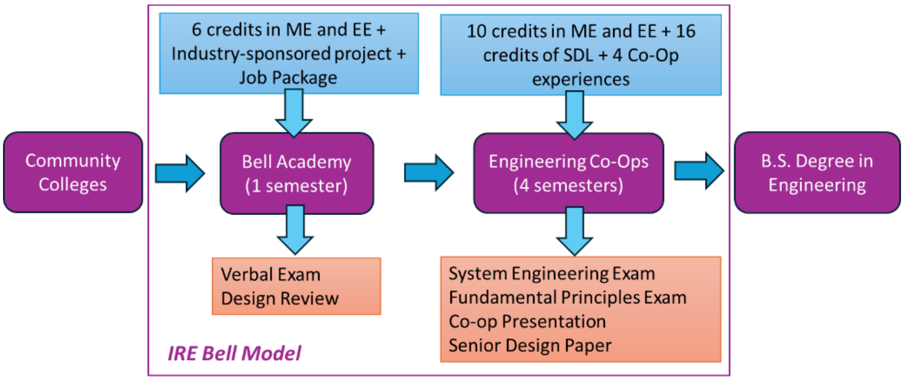

Figure 1 IRE Bell Model structure and major assessment tools

3 Best Practices in the IRE Bell Model

3.1 Self-directed Learning

Self-directed learning (SDL) at IRE is a core element of its PBL framework, empowering students to take ownership of their educational journey. SDL begins in the Bell Academy, where students are introduced to cognitive frameworks like goal-setting, self-regulation, and reflection (Clausen, Ulseth, & Johnson., 2021). These foundational skills enable students to manage their learning effectively. During the co-op phase, SDL becomes more prominent through Student-Led Advanced (SLA) courses up to 16 credits. In SLAs, students identify a technical topic relevant to their work or personal interests, and then design a personalized syllabus specifying learning outcomes, deliverables, and timelines. After gaining approval from the faculty advisor, they will independently engage in the coursework. This culminates in a thesis-style verbal exam where students present their deliverables and demonstrate their mastery. The entire process requires high levels of initiative, critical thinking, and problem-solving while fostering adaptability and confidence in tackling complex engineering challenges.

3.2 Assessment Tools

IRE employs a variety of assessment tools (Figure 1) across its diverse learning formats to gauge students' understanding of engineering fundamentals and their capacity to apply these concepts in design work. Among these methods, verbal examinations (Christensen, Singelmann, Sleezer, & Siverling, 2023) stand out for evaluating both technical competence and the ability to convey complex ideas—a critical yet often underdeveloped skill among engineering students. These exams are aligned with the course's predefined learning outcomes and are supported by formative assessments like reflective journals, quizzes, and project deliverables. During each verbal exam, students respond to structured and adaptive questions, demonstrating not only their problem-solving acumen but also their communication strategies. Immediate feedback reinforces IRE's learner-centered pedagogy and fosters continuous improvement. A standardized 5-point grading scale (Singelmann, Wang, & Christensen, 2023) assesses performance. The numerical grade is associated with the "job satisfaction" level in industry: 1 – unacceptable and 5 - exemplary, which encourages iterative growth and feedback over static grades. For students in co-op programs, four main assessment tools evaluate technical growth and professional development every semester:

Systems Engineering Exam: Students present real-world projects—ranging from HVAC systems to telecommunications networks and solar panels, focusing on key components, interactions, and maintenance strategies. Tackling complex systems transform uncertainties into opportunities for deeper learning.

Co-op Presentations: Students share on-the-job project experiences, detailing technical challenges, skill development, and professional advice. These conference-style presentations allow peers to learn collectively about industry practices and standards.

Fundamental Principles Exam: By explaining concepts such as virtual work, diodes, heat convection, and PID controllers, students develop a strong understanding of key principles essential for the FE Exam. Through solving related closed-ended problems, they reinforce their problem-solving skills. Students are encouraged to define or illustrate each concept, discuss a real-world application, and connect it to other principles, deepening their comprehension and strengthening their analytical abilities.

Table 1 A typical structure of an IRE Senior Design Paper

Chapters	**Key Components and Associated ABET Performance indicators**
Introduction	Personal background, motivation, and program impact on professional development.
Technical Learning	Literature review of technical knowledge, key engineering principles and documentation of co-op/project applications. (ABET 1)
Design Learning	Design principles, tools, standards, stakeholder analysis, and real-world project applications based on co-op projects (ABET 1, 2 & 8)
Professionalism Learning	Analysis of skills like teamwork, conflict management, communication, and inclusivity. Documentation of experiences in professional environments (e.g., inter-team communication and leadership). (ABET 4)
Reflection	Self-assessment of growth as an engineer, including technical persistence, empathy, and understanding. Discuss how the educational and professional journey has shaped the individual's identity and future aspirations as an engineer.

ABET 1: An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. ABET 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. ABET 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. ABET 8: An ability to incorporate an entrepreneurial mindset, including value creation for a broad spectrum of stakeholders, across the breadth of engineering design work.

Senior Design Paper: This paper functions as a comprehensive, reflective, and technical capstone that consolidates each student's academic and co-op experiences into a single, cohesive document (Table 1). It typically includes a robust technical literature review and detailed design methodologies, supported by modern engineering tools such as CAD and FEA. Students examine stakeholder interests, conduct feasibility analyses, and address professional skills like communication, teamwork, and conflict resolution. By showcasing how theoretical principles are applied to real-world challenges, this paper fulfills ABET performance indicators (ABET Engineering Accreditation Commission, 2020) and underscores readiness for complex, interdisciplinary environments. In detailing their accomplishments and reflecting on pivotal learning moments—from breakthroughs to setbacks—students also articulate the evolving sense of identity and emotional investment that accompanies their transformation into industry-ready engineers.

3.3 Student Support from Learning Coaches

Learning coaches play a pivotal role in bridging the gap between academic learning and professional development. Unlike traditional faculty roles, learning coaches are engineering professionals with industry experience who provide personalized guidance to students throughout their educational journey (Christensen, et al., 2024) in three major areas. First, they provide clear communication and alignment among students, their work supervisors, and professors, forming a supportive triad that keeps everyone's expectations in sync. Second, they oversee weekly written reflections where students answer targeted prompts to identify strengths, set goals, and reinforce new knowledge, as well as regular verbal reports over the phone or online to dive deeper into personal growth. By customizing these discussions while drawing on a shared library of reflection topics, they help students cultivate a continuous improvement mindset (Wang & Ewert, 2021). Third, they also guide students in balancing their work, academic, and personal lives, offering strategies for time management, schedule adjustments, and holistic well-being (Spence, Nyberg, Chasmar, Nelson, & Tsugawa, 2022). These combined efforts make learning coaches a key connector, mentor, and advocate, helping students excel throughout their co-ops and internships in the IRE program.

3.4 Student Recruitment Strategies

Recruiting is achieved through building meaningful relationships with community college partners around the United States. The transfer process for students can be a daunting task, and staff and faculty at the university level must work collaboratively with community college partners to make personal connections with students and support them in the transfer process (Mann, et al., 2022). The combination of university and community college collaboration and intentional relationship-building builds personal connections and helps to increase student engagement, attainment, and satisfaction (Doss, 2021).

Instead of solely attending transfer fairs and handing out flyers, IRE staff visit classrooms at community colleges to provide a brief overview of the program face-to-face. During these visits, students are introduced to the unique work-based/experiential learning model that sets IRE apart from typical transfer opportunities. The introduction is kept short to highlight the program's distinctiveness and allow students to ask questions. Interest cards are distributed, and students can provide their contact information if they find the program appealing. When students express interest, it's essential to follow up promptly via email or text, inviting them to continue the conversation. These follow-ups often lead to in-person or virtual meetings via Zoom or Microsoft Teams, where detailed information is shared, questions are answered, and students are formally invited to engage with the IRE community through a virtual visit with faculty, staff, and current students.

Students who reach this stage and demonstrate strong interest are invited to an onsite campus visit in northeastern Minnesota. This visit includes a campus tour, meetings with program-level advisors to discuss course equivalencies and transfer requirements (Bates, 2024), and opportunities to strengthen connections with faculty, staff, and current students. Additional support is provided for resume building, updating LinkedIn profiles, and exploring personal interests. These strategies help students feel integrated into the IRE community and offer valuable networking experiences, even for those who decide not to transfer.

4 Program Evaluation

4.1 Demographics and Inclusivity

IRE attracts a diverse student population, reflecting its commitment to expanding access to engineering education. Currently, IRE is recruiting students from 20+ community colleges nationwide and serves a demographic comprising 60% white students, 16% Hispanic, 11% African American, and 10% Asian. Additionally, 31% of students identify as female, and 36% are first-generation college students. The program also supports a significant proportion of non-traditional students (35%), underscoring its adaptability to varied educational backgrounds and career trajectories. These statistics showcase IRE's ability to attract underrepresented groups in engineering, contributing to the diversification of the profession.

4.2 Student Progress and Co-op Placement

In a recent survey of 93 current students, 80 successfully secured co-op positions during the Bell Academy, demonstrating the program's effectiveness in linking students with industry opportunities. Among these students, 43 transitioned to new co-op roles while 34 chose to remain in current positions. These findings highlight the flexibility and agency students experience in tailoring their learning and professional pathways.

4.3 Student Feedback and Challenges

A strong sense of community and self-identification as engineers are hallmarks of the IRE experience. In the same survey, 71 students reported feeling well-supported and accepted as integral members of the IRE community. This robust sense of belonging is reinforced by social events and peer interaction, which foster collaboration and camaraderie. Furthermore, 82 students rated their agreement with the statement "I see myself as an engineer" at 5 or higher (scale 1-6), indicating that the program successfully cultivates a strong engineering identity among its participants.

Student feedback (Table 2) also reveals several aspects that are particularly appreciated. The flexibility in learning approaches allows students to adapt their educational experience to their individual needs and preferences. Interactions with learning coaches are highly valued, providing personalized guidance and mentorship. The Bell Academy is lauded for its role in developing professional skills and fostering a sense of belonging through structured social events. Nonetheless, many felt overwhelmed creating and following SDL plans, unsure how to apply these methods across diverse engineering disciplines. Others noted inconsistent connections between courses, making it difficult to manage various aspects of their studies. The heavy emphasis on writing and metacognition was also cited as a stressor, with some students feeling reflective assignments were overly demanding. To address these issues, the program could offer more structured mentoring, guiding students in designing and maintaining checkpoints in self-directed learning. Additionally, streamlining the curriculum with clearer links, along with communicating the value of writing assignments, may ease workload concerns and better support students' professional and academic growth.

Table 2 Student feedback from graduating seniors

Most enjoyable experiences	**Most challenging experiences**
Flexibility of learning	Lost on developing self-directed learning plans
Working with learning coaches	Lack of consistency and connection between courses; Hard to manage learning various aspects of engineering
Strong professional skills developed	Overwhelming writing and metacognition
Sense of belonging and social events	Lack of professional development opportunities

5 Future Directions

IRE Bell Model will examine its long-term influence on graduates' careers, covering leadership roles, technical contributions, and overall professional growth. Adapting the model to a wider range of institutions, including those in underserved regions or global settings, could greatly expand its reach. Integrating AI-driven analytics and adaptive learning could strengthen the assessment of self-directed learning and professional skills. Offering interdisciplinary and global collaboration opportunities—like virtual co-ops and cross-cultural projects—would prepare students for increasingly interconnected engineering challenges. The recently published Engineering Mindset Report (Bertoline, 2024) proposes many themes for improvement in the future of engineering education and includes the following directions that IRE is considering: 1) Efforts to boost underrepresented groups' participation, coupled with mentorship and culturally responsive teaching which could foster greater diversity and inclusion. 2) Investigating the model's economic benefits, such as workforce development and reducing students' financial burdens, may further enhance its value. 3) Experimenting with curriculum refinements, like hybrid or shorter co-op cycles, can help balance academic and professional commitments, ensuring the model's broader applicability and long-term viability.

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