Startup of an Innovative Program x3 – Iron Range Engineering Propagated

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***Abstract*—Iron Range Engineering is an award-winning, project-based, upper-division engineering program. Its educational model has been propagated to two different implementations that meet different regional and student needs. There is evidence of student success as the model moves from start-up mode to sustainable programs in different settings. A key motivator for the model and its program is increasing access to engineering education by supporting students who transfer from two-year colleges, broadening the participation of underrepresented and first-generation (first in their families to attend college) students in engineering.**

Keywords—project-based learning, propagating education models, education innovation

I. The Creation of New Programs

The motivations behind the startup of the Iron Range Engineering program (2010) were driven both by the need for regional economic development and the desire to provide a high quality, more balanced education for all students. The engineering education opportunities in the primarily rural area of northern Minnesota were limited to pre-engineering programs at local community or two-year colleges. Two faculty colleagues envisioned an engineering education program that modeled "what engineers actually do" and to extend the educational offerings to include the opportunity for people to earn undergraduate degrees in engineering locally.

With the support of local industries and government funding sources, the dream was realized, and the Iron Range Engineering program opened in 2010 with 14 students. Regional legislative and economic agents provided the funding for the new program, while engineering professors drove the academic development. After significant work to overcome resistance and challenges, the start-up program partnered with Minnesota State University, Mankato, which is located 300 miles away from Iron Range Engineering (IRE), and drove the founding of a new department, Integrated Engineering. The program is delivered on the campus of a community college, targeting students in that part of the state and responding to the needs of local industries [1].

A national academic advisory board of leaders in engineering education was established to give guidance. Project-based learning (PBL) in the Aalborg model [2] was chosen as a starting point for adaptation and development. A curriculum was developed with the guidance of on-campus faculty in mechanical and electrical engineering. Persistence was required to overcome the resistance to change that was encountered at the college and university levels as the program developed. One helpful decision was to allow for a completely separate degree, a Bachelor of Science in engineering with distinct focus areas, rather than duplicating mechanical or electrical engineering degrees that might compete with the on-campus degrees. Other challenges included allowing for flexible registration of 1 credit technical competencies to allow for adaptation to project needs. This resulted in challenges with both registration and financial services. Industry, however, welcomed the project-based learning with a breadth across mechanical and electrical technical competencies seeing the value of the more balanced entry-level engineer. Bridging agents were identified to help mitigate the resistance on campus.

The balance that the innovation champions continue to emphasize extends across three integrated areas: engineering design, professionalism, and technical competence [3]. This approach was in response to more traditional academic pathways that focused more on the technical domains of disciplinary engineering, at the cost of the development of professional and design competence. The founders, supported by the advisory board, wanted to use student-centered experiential pedagogies to ensure a more impactful learning experience for all entering students [4]. An in-depth study of the formation of the program that includes analyses of interviews with stakeholders involved at IRE's start can be found in [5].

Ten years later, this program is thriving, having moved from a start-up mode to a sustainability mode, and has been replicated, with modifications, in two other locations. All three programs are housed in the Integrated Engineering department of Minnesota State University, Mankato.

Figure 1: The IRE Bell Program accepts transfer students from pre-engineering community college from across the nation. Students complete one semester of intensive professionalism and self-directed learning training on site, then are able to return to their home region (or any part of the country) for two years of co-op placement, earning ~$20/hour ($40,000 per year) while continuing to earn technical credit from engaged professors and support from learning coaches (facilitators).

IRE in rural, northern Minnesota was successful; the Twin Cities metro area of Minneapolis and St. Paul, MN was the next natural step in propagating this new model to a different context. The Department chair and two new engineering faculty members developed the Twin Cities Engineering (TCE) program in 2013 and 2014. The curriculum, degree, and structure are the same as the IRE program, but new community college partnerships were developed to create articulated pathways to the new program. TCE is located on an urban community college campus, much larger than the IRE community college partner. While student outcomes are the same, the programs have both developed organically based on the culture of the students, faculty, and industry partners as well as administrative constraints. For example, the TCE program has more non-traditional and veteran students, no regional economic funding stream, and a different tuition model.

IRE and TCE are both upper division, project-based programs that allow students with two-year pre-engineering work already done in community colleges to complete a bachelor's degree in Engineering. Unique attributes of the sister programs include semester-long projects with industry clients, emphasis on development of self-regulated learning abilities, dedicated project work space, technical competence learned in one-credit, small (3-20 student) learning groups, called learning conversations, which are facilitated by academic staff, and an emphasis on continuous improvement [6]. Both programs have earned ABET accreditation.

As the first generations of students completed the programs and found success in industry or graduate school, the programs have used a robust feedback system to drive substantial continuous improvement. The student experience would be changed by 10-20% each semester as new strategies were developed, tested, and improved [4].

After 5 years, others began to take notice. ABET awarded IRE its Innovation Award in 2017. Key stakeholders, including faculty, university administration, and the regional funding agency, wanted to consider ways to offer this type of innovative learning to a broader range of students, and in 2019, a third iteration of IRE began. The motivations for the Iron Range Engineering Bell Program included the emergence of the Charles Sturt University co-operative model in Australia [7] and the desire for a fiscally sustainable model for both students and society. The Bell program is centered on student experiences working directly in industry through co-op employment. Students begin the program in a one-semester intensive Bell Academy at the IRE program location in Virginia, MN where they polish the skills necessary to succeed professionally and technically during two-years of co-op placement [8, 9]. Learners are supported in distance learning from the professors, learning facilitators, and support staff while on co-op, as shown in Fig. 1.

One motivation for the Bell program is increasing access for students who are place-bound or who live in areas with little access to four-year engineering programs. More information about engineering education deserts motivating this approach can be found in [10]. By developing a program that requires students to be away from home for less than six months, more options are created for people, especially from underserved populations, to earn an accredited bachelor's degree in engineering.

The success of all three programs is dependent on students building strong collaborative relationships with faculty, facilitators, and each other. The faculty and facilitator time requirements in building social capital with each learner is significant. These three programs each have their own unique culture, based on faculty expertise, local industries, and students, but all are driven by the relational connections of students, faculty, and industry clients and mentors [8, 11]. The culture of the communities is based on shared values that are articulated and reinforced by the continuous improvement process that each program follows [12]. All programs are noted for the strength of relationships amongst students and between students and faculty. These relationships have helped create strong alumni networks that help feed interesting projects, career opportunities for students, and invested mentors back into the programs.

Some challenges include providing all student support services from the home university when students are at a distance; faculty engagement and collaboration with the home university; and inconsistency in incoming transfer students' pre-engineering work since all students are transfer students. These challenges are being addressed through our continuous improvement process.

II. Listening to Stakeholders

The continuous improvement process used in all departmental programs, both at their conception and throughout their implementation relies on input from a variety of stakeholders to ensure value is created. A common value for all parties has been increasing access to engineering education. Coupled with that has been the regional economic needs that inspire cooperation between academia and industry. At the conception of IRE, initial stakeholders were the leaders from academia that defined the initial curricular model as well as the industry and governmental partners that represented the regional economic needs as well as the financial capital to start the implementation. Workshops, white papers, and conversations were modes used in this process. This extended to students through conversations and faculty observations. At the conception of TCE, initial stakeholders were community college faculty interested in extending opportunities in a new region. Workshops, surveys, and both formal and informal conversations were crucial in gathering information about stakeholder needs and desires. At the conception of Bell, workshops with community college faculty from around the country allowed the program to gather information about nation-wide need and opportunity to increase access. A group tour of Charles Sturt University in Australia allowed a group of faculty, future learning coaches, and university administrators from Minnesota to define ways that the IRE model of project-based learning for engineering could be extended to increase industry interaction while supporting student development of competencies in professional, design, and technical skills.

Throughout program implementation, stakeholder input is regularly gathered. While it is typical for programs to have industry advisory boards, IRE has a national advisory board that consists of leaders in engineering education who can bring a broad perspective of best practices and have supported the propagation of the model [13]. Student feedback sessions, industry advisory board meetings, national academic advisory board meetings, formal feedback from program visitors, and faculty reflections all provide input to regular faculty summits where feedback is digested and converted to action plans for the upcoming term. Challenges of distance and university services are addressed with regular interaction with on-campus offices and programs to build support. Interestingly, the challenge of COVID-19 and providing services for all faculty, students and staff at a distance has opened up opportunities to better support the people of IRE, TCE and Bell. Similarly, work providing remote learning opportunities and maintaining connections within the department have provided models for other university programs. (For example, our department has been hosting meetings through telepresence and Zoom for years.)

The Bell program has provided a new challenge for interacting with stakeholders because of the geographical spread of both industry partners and students. This has been addressed through the facilitator support role. Along with supporting academic faculty, facilitators are the face of the program around the country through their responsibilities in outreach, recruiting, and building industry relationships. Bell facilitators work with student engineers from their first point of contact, often while visiting a class at their community college, through graduation. In their travels (and currently, in their electronic interactions), they meet with potential industry partners near the home community colleges. Facilitators present information about the program, but also gather information about regional needs throughout the country. Facilitators are also on the forefront of interactions with community college faculty and initiate the process of articulation agreements, which help smooth the process of transferring community college credits from multiple states and programs, which have often been designed to primarily articulate with their state's primary engineering degree program. The information they gather is used in the continuous improvement process to support all programs but is also used to support the individual students in their career pathways as they move from focused learning in an academic setting to industry-based learning and into their first jobs after graduation.

III. Student Outcomes

The programs' Program Educational Objectives were written by the original National Advisory Board in 2010 and focus on graduates' abilities to design and implement engineering solutions, continue their education as lifelong learners, create new knowledge and enterprises, and serve humanity. The world has changed much since these PEOs were written. A review for potential updates is underway.

All three programs are ABET accredited under the Engineering Accreditation Commission as "general engineering" programs. TCE and IRE, despite being in the same university department are accredited as separate programs. Bell is a modality extension of IRE.

A study was conducted in 2015 by Ulseth & Johnson [3] to capture the success of IRE graduates as compared to their peers from traditional engineering learning environments. In that study, 18 employers and 30 graduates completed a survey; the program had 74 graduates in the PBL IRE program at the time. Participants were asked to rate all new engineers in the company who were non-PBL graduates against a provided scale and then to rate PBL graduates against the same scale. One question was: "Rate other new engineers (you have supervised *[for employer survey]*, your peers *[for PBL graduate survey]*): Are professionally responsible (prompt, responsive, represent company well)."

Other similarly phrased questions related to ABET outcomes:

- Communicating effectively
- Ability to design systems, components, or processes to meet needs with constraints
- Engaging in entrepreneurial thinking
- Ability to use the techniques, skills, and modern engineering tools necessary for engineering practice
- Ability to solve engineering problems
- Ability to function well on teams

- Displaying a recognition of the need for and ability to engage as an efficient learner
- Ability to lead and manage people
- Ability to lead and manage projects

The results were encouraging. On all 10 of the graduate survey questions and in 9 out of the 10 employer survey questions, the mean score for the PBL graduates was higher than the non-PBL graduates. The one category where this was not true was "use of modern tools" on the employer survey. In this category, the PBL and non-PBL graduates scored the same. Employers indicated the greatest difference between the PBL and non-PBL graduates in the areas of "performing on teams," "lead and manage projects," and "being professionally responsible." [3,11].

The students who tend to be the most successful in these programs have, or are able to develop, skills in self-directed learning and cultivate growth mindsets [11]. Some students need additional structure that better matches their developmental academic experiences. So far, most students who enter IRE, TCE or the Bell program thrive with the hands-on learning experiences.

IV. Current Status and Next Steps

Now 10 years have passed since the inception of IRE. Ruth Graham identified IRE as an emerging world leader in her landmark study for MIT in 2018 [14]. The two related programs are successful and continuous improvement is still the norm in all programs.

Ongoing challenges continue to be addressed through the department's continuous improvement model. The student experience changes that happen each semester come mostly in the form of new learning activities designed to address needs in enhanced student skills as identified by the students themselves, their teaching faculty, or industry stakeholders.

The teaching faculty spend much time taking part in professional development activities aimed at bringing emerging knowledge about how people learn into the student experience. This often results in changed approaches to achievement of student outcomes.

The Bell program, still in its infancy, is on a steep developmental curve. As the concept of work-based learning experiences combined with on-line technical learning matures, there is much potential for lessons from this implementation to be shared widely across engineering education and beyond.

As the future unfolds, the original change agents are fading away and new leaders are taking the program into a sustainable future. Because of the complex nature of the institutional partnerships, as well as the project-based, team-focused emphasis, these programs serve as innovative models for engineering education.

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