

Applying Design Based Research to New Work-Integrated PBL Model (The Iron Range Engineering Bell Program)

Bart Johnson¹, Ron Ulseth² and Yuezhou Wang³

¹ Itasca Community College, United States, Bart.Johnson@itascacc.edu;

² Iron Range Engineering, United States, Ron.Ulseth@ire.minnstate.edu;

³ Iron Range Engineering, United States, Yuezhou.Wang@ire.minnstate.edu

Abstract

A new project-based model of engineering education is being developed to deliver an upper-division (final two years of four-year bachelor degree) experience. The experience is centred on students working directly in industry through engineering apprentice (cooperative education/internship) employment. Students will work in industry, completing projects, for the last two years of their education while being supported in their technical and professional development by professors, facilitators, and their peers through use of digital communication. This new model focuses on learning being more imbedded in professional practice, in contrast to the more traditional model of engineering, where the learning about the profession is done in the abstract of a classroom. The learning experience is designed to open doors for greater access to engineering education. Developed for community college graduates (entering students who have completed first two years of engineering bachelor requirement) in the United States, the program will serve a more ethnically and gender diverse student body. The innovative new model focuses on the development of transversal competences, a new set of teacher roles in PBL, industry-university collaboration, curricular design, continuous evaluation of practice, use of e-learning, and the students' learning processes. The program pilot starts July 2019. This paper will describe the new model, the design-based research method being used, report on the steps completed to date, introduce new sets of data on the new model, analyse the data, evaluate its impact, and result in the next iteration of design improvement. It will primarily focus on program development and the research approach for evaluation of the education model.

Keywords: Professional development, University-industry partnership, Practice-ready engineer, Work-integrated, Transversal skills

Type of contribution: research paper

1 Introduction

The past few decades have seen steady and frequent calls for changing and improving engineering education to meet the societal needs of today and the future (National Academy of Engineering, 2004; American Society for Engineering Education, 2015; Martin, Maytham, Case, & Fraser, 2005; Almi, Rahman, & Purusothaman, 2011; Hasse, Chen, Sheppard, Kolmos, and Mejlgaard, 2013). Emphasis is on the development of the whole engineer with an increased emphasis on the design and professional attributes and transversal skills, in addition to the traditional technical ability needed by engineers (Sheppard, Macatangay, Colby, & Sullivan, 2009). The new program focuses on developing more practice ready engineers through a student active learning experience centered on engineering practice (Lindsay & Morgan, 2016). Similar to how human-centered design is changing engineering practice to involve solutions based on the human perspective at all steps, the experience-centered engineering education of

the new upper-division program will involve the student gaining engineering practice perspective at all steps.

The new program is the Iron Range Engineering “Bell Program” and is inspired by two models recently named as emerging engineering education world leaders in a report published by the Massachusetts Institute of Technology (Graham, 2018). These models are the Iron Range Engineering (Johnson, 2016) and Charles Sturt University (Lindsay & Morgan, 2016) models in the U.S. and Australia respectively. Iron Range Engineering (IRE) is a project-based learning model that utilizes ill-structured, complex problems directly from industry (Ulseth, 2016) and Charles Sturt University (CSU) is a model that uses extensive cooperative education apprenticeships and on-line technical learning (Morgan & Lindsay, 2015). The Bell program draws its structure from CSU and its learning strategies from IRE. The Bell model is separate from the IRE model but being co-located under the same Iron Range Engineering administrative umbrella.

In October 2017, the Iron Range Engineering model was awarded the ABET Innovation award (ABET, 2018). The ABET Innovation Award recognizes vision and commitment that challenge the status quo in technical education. It honours individuals, organizations, or teams that are breaking new ground by developing and implementing innovation into their ABET-accredited programs. It is from this groundbreaking, award-winning model, that the new co-op model will be developed, being done so by the same development team.

The research of this educational innovation needs to be both formative, refining the model as it develops, and at the same time add to the theoretical body of knowledge on engineering education. Collins, Joseph & Bielaczyc (2004) proposed the design-based research approach of *progressive refinement* for developing a new curricular model. They described progressive refinement as when the “design is constantly revised based on experience, until all the bugs are worked out. Progressive refinement in the car industry was pioneered by the Japanese, who unlike American car manufacturers, would update their designs frequently, rather than waiting years for a model changeover to improve upon past designs”. This type of design-based research (DBR) approach will provide the kind of rapid response that is needed and will include reflective practice approaches among the students involved, faculty, and the researchers (Brown, 1992). Design-based research (DBR) is recognized for its potential for developing an understanding of the organizational development and enhancing the professional practice (Andriessen, 2007; Romme, 2003; Van Aken, 2005) which are important parts of curricular development. This paper continues the study of the program development (Johnson & Ulseth, 2018) and focuses on the first evaluation of the new proposed model as part the DBR process. It specifically focuses on the evaluation by prospective students and a national group of community college faculty of the proposed model with the specific purpose of design improvement for the model in preparation for the inaugural group of juniors entering the program in 2019. Reflecting the DBR approach, the structure for this paper is adapted from the Collins, Joseph & Bielaczyc (2004) recommendation for reporting on design research work with a focus on the Goals and Elements of the Design, Implementation Setting, Current Research Phase, Outcomes Found, and Lessons Learned.

2 Goals and Elements of the Design

2.1 Goals of the new model

Creation of more effective engineering graduates - industries have long been dissatisfied with graduates of traditional engineering programs. This dissatisfaction stems from the inability of new graduates to navigate the professional world. At Iron Range Engineering, this deficit has been addressed by allocating substantial

student time to both the application of technical knowledge in realistic settings and the practice of professional skills (Ulseth, 2016). The implementation of both the co-op experiences and the IRE strategies will provide the more fully developed and effective engineering graduate sought after by industry.

Diversification of the engineering profession – Especially in the United States, women, Hispanics, Black/African-Americans, and other minorities continue to be way underrepresented in the engineering profession as compared to their representation in society (NSB, 2018). Community college demographics, unlike traditional universities enrolling engineering students, are more aligned with societal representation in the United States (American Association of Community Colleges, 2018). The Bell model is being designed to enroll community college graduates in the upper-division (last half of bachelors) program. Thus, the goal is to have a more diverse student body and graduate pool entering the profession.

Adaptation of effective learning strategies created in the Iron Range Engineering model - In the 9 years of IRE operation, distinct models of learning for professional development, design, and self-directed were developed. These strategies include: highly developed model of reflection, professional responsibility curriculum, professional development plans, design and project management curriculum, technical development plans, seminar series, and an extensive communication curriculum. All of these curricular strategies are adaptable to the new model for effective engineering student development.

Very low net cost to the student - students will pay \$11,000 USD per semester for five semesters (intensive training plus two years of co-op) for a total of \$55,000. The student engineer will typically earn \$20/hr for 24 months of co-op for a total of ~ \$80,000 gross. Students who are able to live a college student existence during this timeframe will be able to graduate with near zero debt for the co-op portion of their education.

2.2 Elements of the design

The Bell program is the last 2.5 years of a 4.5 year bachelors of science and engineering degree. The first two years are completed at community colleges across the United States. Upon completing the entrance requirements into the program, the student will enroll for an on-site five-month intensive training experience (ITE). The ITE is followed by two one-year apprenticeships referred to as co-ops.

A cognitive apprenticeship (Collins, Seely Brown, and Holum, 1991) approach will be utilized to scaffold the individuals from their levels of competence at the entrance to the ITE to a prescribed level of competence upon completion of the ITE. Technical learning at the beginning of the ITE will be in a face-to-face on-the-ground mode with professors. As the ITE continues, the learning becomes more and more self-directed and more and more online until the end of the ITE where students are managing their own learning in an online course. Professors will facilitate technical learning throughout the 2.5 years. Learning coaches (facilitators) will guide students in their professional and design development throughout the ITE and the entire co-op experiences. The learning coaches will meet face-to-face via technology with the student engineers on a regular basis throughout the coop to provide guidance and support of the students' development.

Upon completion of the five-month intensive training experience period where they develop the high levels of self-directedness and professional responsibility necessary for success in a co-op placement, student engineers can either return to their home region or anywhere else in the country (or out) to complete a one-year co-op experience. After one year, they return to the home-base for one week of rigorous assessments, including the defence of student work, design capabilities, open-ended problem solving capabilities, professional acumen, and technical knowledge. Upon successful defense, they go back for a second year of co-op placement followed by another round of exams and presentations. Successful defense at this point results in the awarding of a bachelor's of science in engineering. Figure 1 portrays this model.

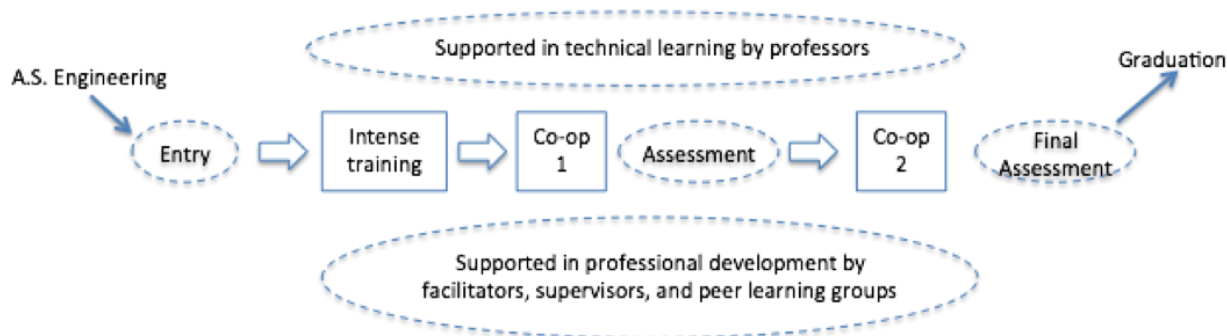


Figure 1. Graphic depiction of new model

This model utilizes unique strategies to integrate the development of the new engineer as a professional, technical, and creative person (Guerra, Ulseth, & Kolmos, (2017). The demand for engineering professionals is characterised by requirements of deep and solid interdisciplinary technical competences and communication and management skills. Changing engineering programmes (de Graaff & Kolmos, 2007) to meet these requirements can be addressed by different active learning approaches (Christie & de Graaff, 2017; Lima, Andersson, & Saalman, 2017). Several institutions of higher education have been addressing these requirements with project approaches to engineering education. Problem and Project-Based Learning approaches (Edström & Kolmos, 2014; Graaff & Kolmos, 2003; Helle, Tynjälä, & Olkinuora, 2006) have proven to be effective in making interdisciplinary connections between different subject matters, developing, in parallel, competences of project management, autonomy and communication (Lima, Dinis-Carvalho, Flores, & Hattum-Janssen, 2007).

Co-op education is a long established practice (Selingo, 2016) where students take a semester out of college to work as interns in engineering firms or industries. Students often find co-ops as the best part of their education, typically earn high wages while on co-op, very often more than \$20 USD/hr, empowering students to graduate from college with less college debt. There are several engineering colleges in the United States that employ required co-op education (e.g. Kettering University, the University of Cincinnati, and Northeastern University).

In traditional co-ops, students receive only nominal credit (1-3) for the co-op experience and thus put off their graduation by a semester for each semester of co-op. In 2016, Charles Sturt University (CSU) in Bathurst, Australia began their co-op based engineering education model (Lindsay and Morgan, 2016). The Charles Sturt model does provide substantial learning during co-op as well as full credit towards graduation. The new model described above is an adaptation of the CSU model with influences from other co-op models. In summer 2016, the founders of the CSU model visited IRE to identify unique PBL attributes of the IRE model that could be adapted for CSU.

The technical, professional, and design learning that happens during the Bell Program co-ops is a departure from all other US co-op engineering models and is centered on PBL methodology. In order to align the Bell model with PBL, we have used the 7 elements of PBL (Du, de Graaff, and Kolmos, 2009). The objectives are PBL centric and interdisciplinary. The problems the coops will solve are open and ill-defined and will consist of a major part of the students' learning. Technical, on-line, courses will support the project and there will be external facilitation as well as formative evaluation. This learning is what enables the students to earn full credit towards graduation for successful co-op completion as compared to other US institutions where full credit towards graduation is not awarded. Further, it will be facilitated as projects with industry-working team members.

3 Settings where Implemented

The new model takes advantage of three educational experiences:

1. Community college education (anywhere in the country)
2. The Iron Range Engineering models of professional and self-directed development (ITE at IRE campus in northern Minnesota)
3. Co-operative engineering placement (anywhere in the country)

There are approximately 300 community colleges in the United States that offer associate degrees in engineering. The demographic of enrolled students at community colleges is considerably different than at universities. Community college students are more diverse ethnically, more gender diverse in the STEM fields, and are older, thus bringing more life experiences to their education. Among community college students, 51% are non-white, the average age is 28, and 36% are first generation college students (American Association of Community Colleges, 2018). Further, women earn 42% of the STEM degrees awarded at community colleges (National Science Foundation, 2017).

The Iron Range Engineering (IRE) PBL program has developed unique and powerful models for creating professionally responsible, self-directed learners (Johnson 2016; Ulseth 2016). Over 10 published studies demonstrate the efficacy of these strategies and the advanced skill levels of IRE graduates (Guerra, Ulseth, & Kolmos, 2017). The strategies used at IRE serve as a cornerstone for the new program.

4 Current Research Phase

4.1 Methodology and method

When the design of the PBL program began in 2016 (Johnson & Ulseth, 2018), design-based research (DBR) was selected as the design and research methodology to guide the curricular development work. This work incorporates the four phases of DBR identified by Kolmos (2015): *design; implementation; data collection and analysis; and findings and conclusions*. The phases were adapted and combined with Andriessen's (2007) dual purpose of DBR model for this work as shown in Figure 2. The focus of the *program design* is *progressive refinement* through the problem statement; defining the design and learning objectives; planning (project management) of the curricular design, development of the curricular ideation and selection of a design for initial implementation; and ultimately a continuously reformed model with a curricular model improvement process. The focus of the *research design* is to establish the research questions; identify the learning theories applicable to the research work; design of the research work that influences the curricular implementation and improvement; and ultimately to disseminate what is learned and add to the body of knowledge on engineering education.

The research question for this phase of the program development is: "How do prospective stakeholders react to the prospect of the program and what input do they have to its development?" In the data collection section below, these reactions and inputs have been collected and analyzed. Improvements have been put in place and ideas are available to draw on for future iterations.

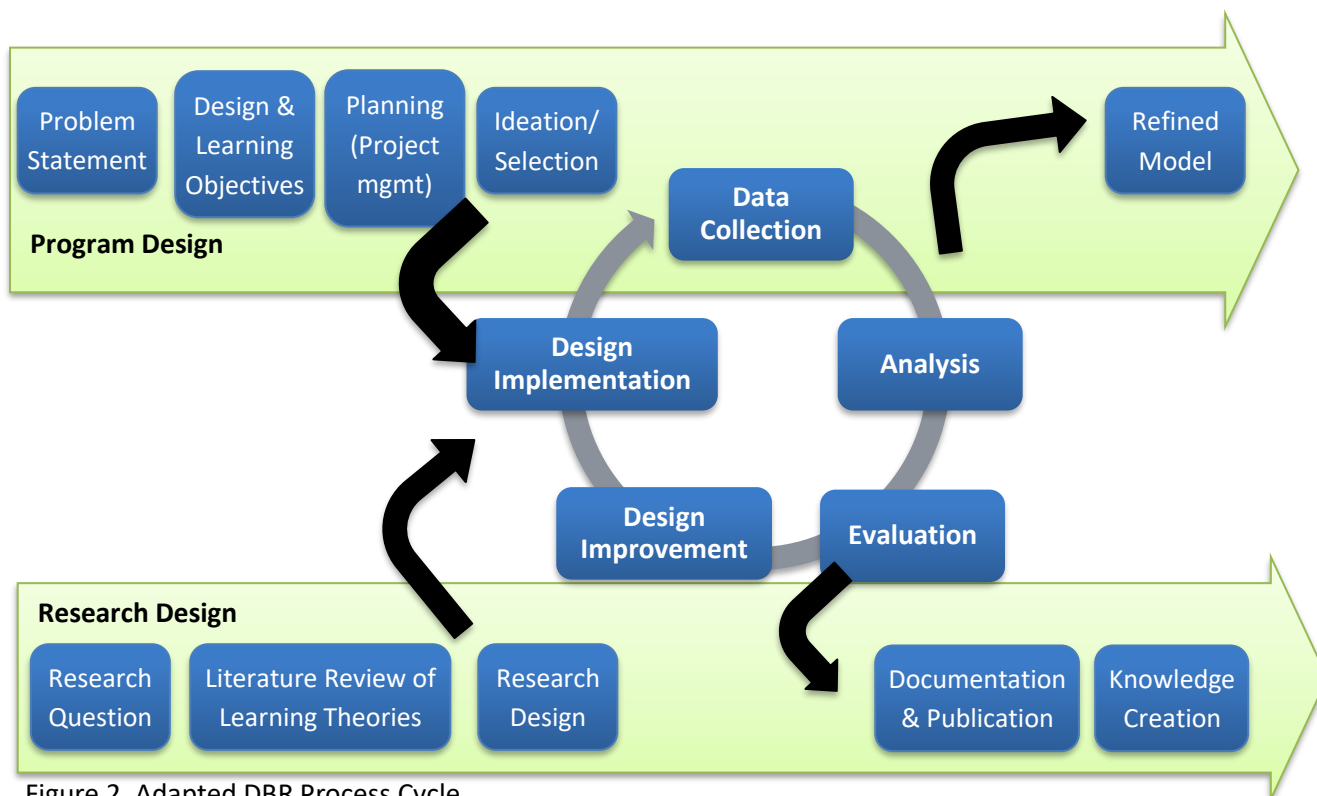


Figure 2. Adapted DBR Process Cycle

4.2 Data Collection

4.2.1 Faculty workshop January 2018

In January 2018, 30 faculty members from more than 20 community colleges (from which the initial students will likely come) were invited to workshop-based open discussion sessions about the intensive training and curriculum design. Their ideas, opinions and concerns were collected through poster presentations by small groups, paper feedback forms, and electronic feedback. The data was condensed and themes emerged.

First, prior to joining Bell Program, most students will experience a more traditional classroom setting. To ensure a smooth transition, the Bell program should provide an online orientation as a screening process to identify their motivation in remote learning. Some participants expressed support for a one-week orientation-type program for prospective students that would bring them to the Iron Range one year before matriculation to give them an in-person perspective on the Bell Program and provide a one-day project, active learning lab and online learning self-assessment. It could lessen some of the concerns about climate, distance, culture, and help the students to understand if the Bell Program is a good fit for their learning style and life plans after completing initial community college coursework. **Outcome: On-ground workshop and on-line orientation prior to enrolment would be of value to prospective students.**

Second, during the ITE, there must be a balance of technical learning and professionalism development. Each student will take a few competencies with a faculty to ensure a sense of community in a face-to-face setting. In terms of professionalism, students should complete a community-driven project to embrace inclusivity, diversity, ethics, learn from failures, as well as health and safety issues. Students will train to master job searching, resume writing, and interview skills, which help with co-op. Similarly, samples of student-written syllabi and best work could increase exposure, prepare students for the Bell Program, and

more broadly help advance experiential learning as a pedagogical tool for engineering. **Outcome: Suggestions for ITE topics and strategies.**

Third, the method of assessment throughout the two-year co-op experience is vital to the progressive refinement of the program. In co-op periods, students should document their weekly learning progress via an e-portfolio submitted to on-site faculty who should also conduct short interview with their supervisor to confirm their performance. They are also encouraged to attend community webinars to share learning experiences. During their on-campus visit at the end of a semester, an assessment package will be assigned, including 8-hour open-ended problem solving exam, fundamental principles tests, and oral exams of their competencies. This multi-angle instantaneous assessment would help overcome the lack of communication in a traditional online education. **Outcome: Suggestions for learning/assessment strategies during co-op.**

Then, while reaching a consensus that the Bell Program is promising, owing to its unique PBL pedagogy, we have received more than 300 comments and questions regarding attracting prospective students and conveying the message to their local communities. One possible hurdle to market the program is the initial expensive tuition. While students eventually pay off loans by doing co-op, an estimation of financial stability should be explicit. Another common question is how to connect with local industry companies and search of available co-op opportunities. Some professional societies such as National Society of Black Engineers (NSBE), IEEE and Society of Women Engineers (SWE) have already established formal partnerships. These organizations could offer Bell Program students a first step in their professional career. **Outcomes: Need to have clear financial model for prospective students to understand. Need to have plan for connecting students to industry co-op partners.**

Finally, besides the interest from faculty, motivation of students ultimately dictates the success of Bell Program. Based on years of data on engineering students transferring to a university, community college faculty estimated that around 90 students would be interested in joining Bell Program as pioneers, provided they have a better understanding of the benefits of the program. **Outcome: 30 participating faculty members estimated 90 of their students per year would be interested in joining the new program.**

4.2.2 Student workshop May 2018

In response to the faculty workshop outcome advising an on-ground experience for prospective students, an on-site visit was developed and implemented. Students who wished to attend were identified through face-to-face or online interviews, with three questions being asked: (i) Benefits of joining the Bell Program; (ii) Anticipated accomplishments upon on-site visit; (iii) Types of engineer one would like to become. These questions were designed to help develop the program that better fits students' need.

More than two thirds of students' responses (N=30) for the first question listed hands-on skills and freedom of financial burden as the benefits. While the first benefit has been revealed with success through the sister program of Iron Range Engineering, the unique financial benefit to students could attract students, particularly in early phases as it pilots a new pedagogical model. To justify this attractiveness, we quantify the financial outcome for a hypothetical student. On the whole, the designated tuition for Bell Program is \$55,000 USD (5 months of intensive training plus 4 semesters). Assuming an hourly rate of \$20 and 160 hours of work per months, one could earn \$40,000 for a single year of co-op. It not only compensates all the tuition cost, but also offers a net income of \$25,000 upon graduation. **Outcome: potential students are attracted to the learning and financial aspects of the degree program.**

Regarding the incoming Bell Experience, most students would like to see the campus, facilities and community. Some also suggests a possible hands-on demo class. These requests can be addressed by existing IRE faculty. **Outcome: Suggested topics for Bell Experience.**

The response to the last question is rather diverse. Among 30 students, 12 are interested in Mechanical/Structural Engineering, 5 in Electrical Engineering, 7 in Chemical Engineering, 3 in Industrial/Aerospace Engineering and 3 are still unsure. Since the current IRE focuses mainly on ME and EE programs, the new Bell Program will consider to hire faculty and facilitators with wider scope of expertise.

Outcome: Diverse engineering interests of potential student body.

The data from these three questions was available prior to the one-site visit held in mid-May 2018. Developers used the knowledge to create the workshop which gave students the opportunity to experience the unique attributes of the Iron Range Engineering model that will become part of the Bell program as well as to meet similarly minded students from across the U.S. Upon completion of the event, all participants (N=38) completed an on-line exit survey identifying the attributes of the model that they found most appealing as well potential areas of concern or barriers. The data was compiled and analyzed. Following are the top three themes from each area with direct student quotes supporting the themes.

Positive Themes:

1. Most of the students from the Bell Experience are beginning to understand the importance of the work experience before receiving their engineering degree.

“I think this is a phenomenal and groundbreaking program in engineering schooling. So many schools just drill you on knowledge and it can be hard to see the true application of some concepts. Also, I think the cost is pretty reasonable for over 2 years of schooling, especially since the odds of getting a job increases drastically when you have experience from a coop.”

2. This event gave every student an opportunity to experience what it would genuinely be like to be a student enrolled in the Bell program. It opened the student’s eyes to some of the outcomes they would achieve by attending this program, and it allowed them to see if it was a good fit before making a decision to attend this program in the future.

“...I've never met a more welcoming group of people who are genuinely interested in us as individuals AND as a group. The fact that the time was taken to break the ice and get all of us talking to each other is such an important factor that really made this experience so much more valuable, all while instilling strong ideas of project management, teamwork, and professional development. Thank you for this opportunity of a lifetime.”

3. This event carried a lot of energy throughout, and many students were able to build confidence by working through them with other students from around the country. Many connections were made from the learning they were achieving at the Bell Experience to a working engineer.

“I feel as though I am leaving this experience with a more optimistic outlook on the program and it's sound like it's more my style in the way that I'm not really a fan of sitting in a classroom and learning, I'd rather be out doing things and experiencing the field.”

Outcomes: Students are attracted to model of learning. Students are attracted to content proposed in Bell model. The idea of a scholarship is of high importance to incoming students.

Suggestions to pay attention to:

1. Many students look at their financial situation in a variety of different ways. There is something about a scholarship that students hold in high regard. Even if it was built into the overall cost of the tuition, scholarships should be offered for students who are looking to attend our program.

“I have a scholarship in my community college and I am thinking about a university that I could apply for a new scholarship, but the Bell program has some advantages that interest me more, so I will evaluate my choice.”

2. The cost of this program is interpreted in a variety of different ways. For some of the students, there is a common positive theme of the price because they are able to see the income while working as a large advantage. For others, the sticker shock of tuition sets a barrier that they can't see through. They use this, and this alone, to compare to their other university options.

“The Bell Program seems to be an amazing option, but personally, my situation makes the cost of the program to be a great deal larger than my neighboring university.”

3. This program is a stretch for some students who have their eyes set on other accredited universities in their area. Some students will need more comfort in knowing that their education and degree is just as valuable, if not more valuable, than other disciplinary degrees.

“I feel like I am 90% sure I will apply to the program. The other 10% is holding me back because the program is fairly new, and I find it difficult to convince my family and friends that this is an accredited program. It's a leap of faith that I am still trying to warm up to.”

Outcomes: The program needs to better describe and market the financial impacts of student expenses vs. revenues i.e. tuition vs. co-op salary. The newness and unique attributes are seen as barriers to some prospective students.

5 Outcomes Found

The outcomes for the two data collection events (faculty and student) were **bolded** in the previous sections and are listed in Figure 3 below. Analysis of these outcomes results in three emerging themes: 1) there is substantial interest in the model by prospective students. 2) The financial sustainability aspect of having students make money to offset tuition costs, while macroscopically attractive to students as a concept needs to be more clearly communicated microscopically for students to prevent it from being a barrier to enrolment. 3) Quality ideas for the ultimate design of the program in terms of processes and strategies were collected from participants in both workshops.

- 30 participating faculty members estimated 90 of their students per year would be interested in joining the new program. (student interest)
- Need to have clear financial model for prospective students to understand. (financial)
- Need to have plan for connecting students to industry co-op partners. (strategy/process)
- Suggestions for learning and assessment strategies during co-op. (strategy/process)
- On-ground workshop and on-line orientation prior to enrolment would be of value to prospective students. (strategy/process)
- Suggestions for ITE topics and strategies. (strategy/process)
- Potential students are attracted to the learning and financial aspects of the degree program. (student interest)
- Suggested topics for Bell Experience. (strategy/process)

- Diverse engineering interests of potential student body. (strategy/process)
- Students are attracted to model of learning and content proposed. (student interest)
- The idea of a scholarship is of high importance to incoming students. (financial)
- The program needs to better describe and market the financial impacts of student expenses vs. revenues i.e. tuition vs. co-op salary. (financial)
- The newness and unique attributes are seen as barriers to some prospective students. (strategy/process)

Figure 3. Outcomes summary.

6 Lessons Learned

The data collected and analyzed provides much potential for immediate and long-term progressive refinement of the Bell program model. The most immediate example is the outcome from the faculty workshop suggesting that an on-ground student experience could be useful to expose potential students to the model and give them a much better basis on which to decide to enrol. This suggestion, made in January 2018 was implemented immediately and delivered in May 2018. The prospective students then provided much more useful data through surveys explaining their needs and impressions.

Refinements identified as needing immediate action relate to the recruiting and marketing of the potential student body for the pilot cohort. Barriers exist and need to be addressed with regards to the explanation of the financial model for students as well as perceptions regarding the newness/uniqueness of the model.

Longer-term knowledge was gained regarding the learning strategies and program processes for implementation in the pilot cohort. In particular, topic suggestions for the ITE, communication with industry partners, diverse engineering interests of potential student body, and a wide variety of suggestions for assessments and learning strategies. All of this data will be taken into consideration in during autumn 2018 when the development team creates detailed implementation plans for the pilot cohort.

Perhaps the most telling lesson learned comes from the high levels of interest and enthusiasm from the faculty partners and the potential student body. This evidence clearly communicates that there is an appetite for a model of this type in engineering education in the U.S.

7 Conclusion

A new model of engineering education is being developed. A description of the model and its origin have been provided and grounded in the literature. The developers of the new model were also the developers of the established Iron Range Engineering model in 2009. Those experiences highlight the need for a structured process of progressive refinement during the start-up phase of this program. Design-based research has been adapted to serve as the structured process. A research question at this stage was posed and data collected. The results of the DBR implementation come from two data collection events, a workshop of faculty partners from community colleges across the U.S. and an experience for prospective students. Those events are described and the outcomes have been identified/analyzed. The outcomes have already resulted in a shift in the trajectory of the program development and will continue to do so into the future. The outcomes further justify the appetite for such a model by the potential students and faculty.

Future iterations of the DBR implementation will take place during the remainder of 2018 and the first half of 2019. Data collection events will include program analysis by an external advisory board and test implementations of the curricular strategies with current Iron Range Engineering students and the new enrollees in the Bell pilot.

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