# The Iron Range Engineering PBL Curriculum: How Students Adapt to and Function Within PBL

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## ABSTRACT

Iron Range Engineering is a unique complete-PBL curriculum for upper division students. Rather than studying *about* engineering in traditional engineering courses, IRE students *solve complex and ill-structured industry problems* in mining, milling, and manufacturing industries. To support students' transition to PBL and to facilitate deep approaches to learning technical and professional competencies required for the engineers of the future, faculty have created a variety of structures. This paper describes IRE's PBL implementation and reports the results of a qualitative study of their students.

## INTRODUCTION

Engineering education in the United States is a domain where the application of PBL is gradually growing (Litzinger et al, 2011). Although many implementations are for single courses, or portions of a course, one program -- The Iron Range Engineering program -- has recently implemented an *entire* upper division engineering curriculum using semester-long industry-based PBL. Iron Range Engineering (IRE) represents a unique model for an undergraduate problem-based learning (PBL) engineering program. Rather than studying *about* engineering in traditional engineering courses, IRE students *solve complex and ill-structured industry problems* in mining, milling, and manufacturing industries. A majority of their learning activities are organized and indexed by these industry projects.

This paper describes IRE's PBL implementation and reports the results of a qualitative study of their students; we examine their perceptions of the pedagogical activities that aid in their adapting to and succeeding in the PBL curriculum as well as what they see as the primary barriers. We then analyze these data for the primary emergent themes and discuss how these relate to the literature to help inform future PBL implementations in engineering.

## Background Literature

### PBL and Its Use in Engineering Education

PBL is an instructional methodology with the following characteristics (Hung, Jonassen, & Liu, 2008): *problem-focused*, where students learn by addressing authentic, ill-structured problems; content and skills are *indexed by the problems*, rather than as a list of topics; *reciprocal relationship* between knowledge and the problem; *student-centered*, where what is learned is determined by student intention rather than faculty objectives; *self-directed*, where students assume responsibility for generating learning issues and processes through self- and peer assessment; *self-reflective*, where learners monitor their understanding and learn to adjust strategies for learning.

According to the engineering degree accreditation organization in the U.S., ABET, learning to identify, formulate, and solve engineering problems is an essential learning outcome for any engineering graduate (ABET, 2010). Engineers are hired, and succeed for their ability to solve problems. In addition, due to extensive globalization and rapid changes in engineering and technological know-how, engineering students must demonstrate life-long learning skills in seeking out and applying new knowledge and continue to develop their problem solving skills. (Adams & Felder, 2008).

Several engineering degree programs have implemented PBL for all or part of their curricula. The first full implementation was the Chemical Engineering program at McMasters University in Canada, followed by Aalborg Linkiping, Rosilde and Maastricht Universities in Europe and numerous engineering programs in Australia (e.g. Monash University, University of Southern Queensland). In the United States, Worcester Polytechnic Institute requires all undergraduates including engineering majors to complete at least two synthesizing projects in addition to required credits (Litzinger et al, 2010).

**Student reactions to PBL**

Although all learners new to PBL face challenges, there may be specific challenges for engineering students. When Nasr and Ramadan (2008) implemented PBL in an Engineering Thermodynamics course they noted that, ".. students are formulae-driven. Effective methods need to be employed to discourage students from reaching out for quick equations to plug and chug in" (p. 22). Engineering students may also have difficulty applying prior knowledge from earlier coursework to PBL problems. Students in an engineering communications course spent more time than instructors anticipated trying "to find new information to find a solution to a problem, as if it were just one discrete task, and much less in contemplating how what they were being asked built on previous knowledge and experience" (Mitchell & Smith, 2008, p. 136). Johnson (1999) reported that students in a PBL hydraulic engineering course complained that the projects were vague and requested clarification, suggesting a discomfort with ill-structured problems. Engineering students develop learning strategies that help them to succeed in traditional engineering courses. Those strategies often conflict with the intellectual requirements of PBL activities (Yadav, Lundeberg, Bunting,& Raj Subedi, 2011).

Engineering students are not alone in their resistance to PBL. Authors have noted that PBL experiences must be planned carefully if they are to avoid common learning pitfalls. Researchers have studied PBL group dynamics (Wilkerson, 1996), peer leadership in groups (Palmer & Major, 2004), and the role of tutors/instructors in facilitating PBL learning (Savin-Baden, 2000). In PBL settings, students may feel disempowered by assessment methods that do not match their PBL experiences (Savin-Baden, 2004). In addition, the PBL problems must be 1) intrinsically motivating, 2) provide adequate structure to match the level of student experience with ill-structured problem-solving tasks, and 3) provide adequate challenge to encourage a deep approach to learning (Mauffette, Kandlbinder, & Soucisse, 2004).

## Methods

**Institutional Context**

The IRE program resides in Virginia Minnesota and is a collaboration between the Itasca Community College (ICC) and Minnesota State University Mankato. IRE is an upper division, team oriented, PBL program organized by industry-mentored design projects, rather than topic-based courses. For example, in a recent semester, an IRE student team designed and implemented a condenser performance test to be applied to the power generation condenser on a 400 MW power plant. To solve the problem, students learned cycle analysis, conduction heat transfer, convection heat transfer, heat exchanger design, engineering economics, evaluation theory, and studied the environmental implications, all in the context of a real deliverable for a major client. The IRE program formally started its PBL program with a cohort of 14 students in January 2010.

Each problem is comprised of several stages: scoping the problem, selecting competencies appropriate to the project, (chosen from 16 core technical competencies in mechanical or electrical engineering or student-proposed advanced competencies that students must complete in order to matriculate), developing learning plans to acquire competencies, developing design plans to solve the problem, implementing and documenting both learning and design activities, completing oral exams to demonstrate competency attainment, and a series of design presentations throughout the cycle. As with all PBL programs, IRE students assume a large degree of responsibility for their own learning. At the beginning of each project cycle (Figure 1), students identify which learning outcomes or competencies will be addressed during the project. Each outcome is classified using the newer version of Bloom's taxonomy of cognitive outcomes (Anderson & Krathwohl, 2001). Working with faculty, students then determine what learning activities to employ and what types of evidence are needed to demonstrate outcome attainment. Learning activities include self- or peer-directed learning, one-on-one faculty directed learning, or industry engineer-mentored learning.

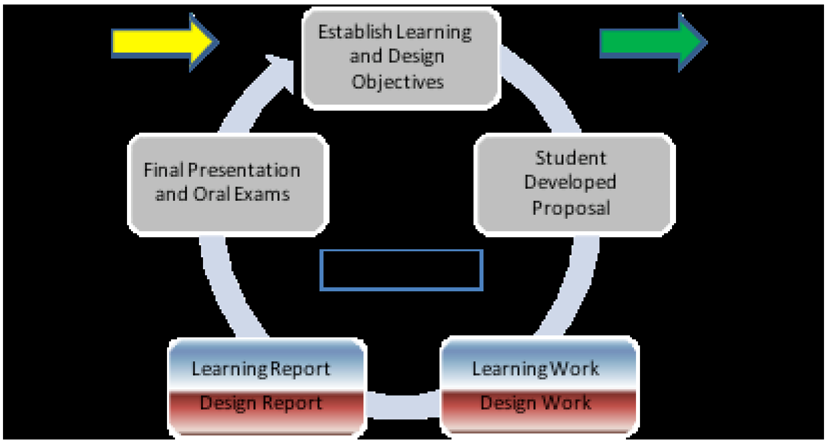


Figure 1. IRE Learning Cycle

Throughout the semester, students engage in a variety of assessment experiences including problem sets, laboratory experiments, written exams and oral exams in which they demonstrate their understanding of technical engineering knowledge on core and advanced competencies. The student also provides evidence, via independent or group projects of their ability to apply technical knowledge to a real problem. Problem solutions can also be used by students to demonstrate higher order analytic, evaluation and creative cognitive skills. Each problem cycle concludes with the presentation of two reports: a design report for the deliverable to the industry client, and a learning report that reflects on the learning process and provides evidence of outcome attainment. In addition to written reports, student teams present a final design review to their faculty and peers that is formally evaluated. They then present their final design to the external clients.

**IRE Students**

To date, students have been recruited predominantly from a nearby two-year college as well as from other two-year colleges in the Minneapolis – St. Paul, MN metropolitan area. The first cohort of 14 students will graduate in December 2011 with a B.S. in General Engineering with joint emphases in mechanical engineering and electrical engineering. A second cohort (10 students) began in September. Demographically, IRE students are 16% female, 4% non-Caucasian, 60% first generation college, and 72% qualified for United States federal aid. Students function as cohorts, going through the program together.

**Data Collection and Analysis**

Data for this analysis are from semi-structured interviews with thirteen IRE students. The majority of the sample (n = 10) were purposefully selected so as to ensure representation of both student cohorts, women and under-represented minority students, and students who completed their first two years at varying institutions. The remaining interviews (3) were with student volunteers.

Over a two day site visit, Authors Marra and Palmer conducted individual recorded interviews with students that lasted approximately 45 minutes each. We used a semi-structured interview protocol that probed student experiences on choosing IRE, their previous postsecondary educational experiences, their perceptions of the PBL curriculum and their plans for future work and education. We triangulated student interview data with: students comments from a publically available blog; observations of students working in their project teams and in faculty-led learning conversations; and interviews with faculty and one industry partner. We conducted the faculty interviews by telephone prior to and after the site visit and reviewed the student blog after coding interviews.

We analyzed these multiple sources of data in stages. First, the two primary researchers coded the 13 student interviews individually. We then consulted on our separate coding and created a collaborative coding structure. From the 13 interviews we developed the major themes outlined in our results section below. We clarified and further elaborated the themes by reviewing the student blog entries and by triangulating results with the faculty and industry partner interviews. At the last stage, we reconfirmed and documented the main themes by returning to the student interviews to find supportive quotations. Due to the small number of females and minorities in the program we use non-gendered labels for quotations.

**RESULTS**

One of the struggles in implementing PBL curricula is helping students to transition from traditional pedagogies to this new way of learning. The IRE faculty recognize that this is a challenge students may face and have built in structures that may help students with this adjustment.

**Industry Project Scaffolds**.

Students are initially assigned to industry project teams based upon their strengths and learning needs. Students found that peer teams functioned in both positive and negative ways. For instance, this student clearly reported learning from peers in the context of the teams. “Once that step was done, we went back and explained .. like I explained to the group how I did my portion then someone else would explain how they did their portion.. we kind of taught each other ...”. But in other cases teams didn’t function as effectively. Although teams create a contract that outlines expectations for participation, some students still experience being “stuck” in a particular role multiple times over several team experiences – and in some cases a gender bias emerged as female students took on the majority of report writing responsibilities. Others reported that the perceived intensity of the industry project led them to each do his or her own part and then combine the pieces to meet the deadline, limiting truly meaningful collaboration.

Teamwork is one component of the strong sense of community amongst IRE students. Another aspect is the community building activities -- such as group camping trips --- that are scheduled throughout the year to help students engage with each other in multiple roles and contexts. Although this is no longer the case, students in the first cohort were required to live on campus in close proximity of one another. Overall, students experience an intense and intimate relationship with one another and with faculty. As such they can be susceptible to some of the negative aspects of highly cohesive groups such as "group-think". The benefits, however, include a very open environment where students willingly give and accept constructive feedback without the barriers often seen in student interactions.

**Learning Scaffolds**.

Student-developed learning plans help them to both take ownership of their learning and to realistically manage their time. For core competencies, an initial set of content areas provide students with an outline of learning expectations that match their outcomes to traditional engineering degree programs. This helps students to be confident that, in the end, their technical expertise will be competitive with student from other institutions. Learning plans for advanced competencies are negotiated over a period of time between the student and the faculty. These learning plans are often tailored very specifically to address a technical issue in their industry problem and are also used by students to develop expertise in an area of personal interest.

Students and faculty discuss and reflect upon the metacognitive aspects of learning primarily through examining Bloom's taxonomy. While students may initially only mimic the outlines of the taxonomy as they describe levels of learning, eventually students grow to appreciate the importance of reflecting on not only what they know, but how deeply they have learned it. As one student wrote in their student blog:

"To understand anything of course, begins with factual knowledge ... What is important though... is that we understand the concept of metacognitive learning and the role it plays in this program. ... only now am I starting to see how reflection on learning activities truly plays a key role in retaining learned material and dealing with the unknown through relation."

Students are also able to tailor their learning activities to take advantage of a variety of resources. While some students still rely on traditional learning strategies such as textbook content, other students use peer discussions, internet resources, faculty learning conversations, workshop-style learning events, and industry expert mentors to actively engage with technical content.  For example, students in one team we observed discussed their conceptual understanding of a technical equation with their faculty advisor prior to a scheduled meeting with an industry mentor to present their work in progress.  The faculty member was able, in real-time, to help students develop alternative pathways for constructing a mathematical model of the real-world problem.

**Assessments of Learning**.

Faculty generally require two or three assessment measures to triangulate the student's understanding of technical material.  Some students found the oral examination assessment method to be helpful, noting that this type of assessment was in alignment with PBL pedagogical activities. This student describes how orals require you to more deeply understand the tested content.

"When you are talking about it, you have to know what's going on... it's not just memorization and learning most of what you need to learn right before a test and then probably forgetting it a week after..."

These same oral exams, however, were described as an impediment by others. Several interviewees remarked that students "crammed" for orals – invoking memorization learning strategies to reach what the program describes as "level 2" (conceptual) learning. This level must be demonstrated in order to earn a minimal grade in the program – a "C".

Some said their strategy was to make sure to pass the oral exam for their competencies to guarantee that minimal grade, and then if time permitted move on to the more meaningful leering outcomes associated with levels 3 and 4. Students additionally remarked that this most commonly occurred for competencies not associated with industry projects, and that students' lack of time management skills may also play into this phenomenon.

**Self-selection into PBL**

Although pedagogical factors are clearly significant in terms of helping students to adapt and be successful in their PBL studies, the IRE students are somewhat unique as they have self-selected this non-traditional engineering program. Nine of interviewees had attended a two-year college at which one of the founding IRE faculty has taught pre-engineering courses using open-ended problems for many years. These students consistently mentioned positive prior experiences with these problems as a factor in their decision to attend IRE.

“There’s the lecture learning and there’s project-based learning and I’d put ICC somewhere in between... I’ve always been a fairly independent student....I learn at my own pace, so the opportunity to do that here was great...”

These open-ended problems were clearly not as ill structured nor as extensive as the industry problems students encounter at IRE, however they did serve to provide students with a taste of doing “real engineering” and of learning in student-centered ways.

**Student Predispositions**.

Our conversations with students revealed that student pre-dispositions combined with their past experiences with traditional educational activities may both help them to choose to attend and adapt and succeed in an PBL curriculum. For instance several students indicated their preference for “hands-on” learning and desire to avoid typical lecture-based classroom settings.

At a surface level these comments may seem not terribly remarkable – after all, many students will express a dislike of lectures -- but they may also be an indication that these learners have some awareness of themselves as learners that accelerates their adjustment to IRE and makes the PBL method a good fit for them.

Students’ previous educational and life experiences will color the way they react to PBL. For one IRE student, prior family and work experiences were an important part of his transitioning to and succeeding with PBL. This student described working in the family construction company and was coached by his dad to listen to more experienced co-workers and ask “a lot of questions”. This student explained that those skills have serve IRE learners well where it is necessary for students to take charge of their own learning.

**Access to Faculty.**

As our discussion of scaffolds illustrates, faculty interactions with students are a critical. We note that the IRE program does not employ “tutors” that are often used in PBL programs. Students rely on access to IRE faculty and project managers (adjunct faculty who have industry experiences) for the “tutoring”, coaching and guidance that are critical for their success in a PBL curriculum. Students are on campus at a minimum five days a week for eight or more hours a day; they work individually and in teams to make progress on their learning competencies. When they get stuck, they turn to faculty for guidance.

“As far as individual learning goes [faculty] have been a great help. I like to do alot of individual work but I’ll run into just bumps in the road that I can’t quite make it past easily, so to have them to fill in those holes a little bit, make them a bit shallower makes it a bit easier to get over the top of them and move on...”

However, because students’ learning is not structured in “class time”, students need for faculty time and attention are detached from a daily schedule and arise unpredictably, based on the pace of their learning and their individual problem-solving processes. Students commented consistently on their desire for more and more frequent faculty interaction. IRE faculty are aware of this issue and taking steps to address it. One strategy currently being employed is the use of Smartboard and Skype technologies to provide increased access.

**DISCUSSION AND IMPLICATIONS**

After twelve or more years of practice at learning in traditional formats, tertiary-level students may have mixed reactions to a PBL pedagogical. Engineering students may have even more difficulty with the transition than students in other disciplines because their foundational courses in math and science have rewarded them for rote memorization and focus on solving equations that lack connection to real world contexts. The IRE program successfully addresses many of the typical forms of student resistance through thoughtful curricular design and implementation.

As a complete implementation of PBL, students continuously engage in PBL rather than encountering it in a single course in the midst of traditional teaching methods. Students select the program because they are motivated to engage in PBL for the entirety of their upper division learning. Faculty have formulated multiple ways to scaffold students immersion in the semester problems while also supporting students to engage in deep approaches to learning the technical material that is the hallmark of quality engineering programs. Promotion of multiple modes of learning, encouragement to engage in metacognitive reflection, assessments that match their PBL experience, and a deliberate focus on building community were some of the many aspects of this program that facilitated student success.

Necessarily in a PBL curriculum, the industry problems are a major focus of students' learning, and as the literature suggests, the nature of that problem is significant both in terms of students' motivation and their success. Students affirmed the importance of the quality of their industry problems in their discussions of the IRE program. As might be expected, the degree to which problems were aligned with required technical competencies and student interest varied. When problem were strongly aligned, students found that they were more deeply engaged in learning and that their ability to manage their time was improved.

The IRE program continues to battle aspects of the traditional tertiary level education system that constrain how PBL is implemented. The architects of this program must still work within a curriculum approval system that favors pedagogies that align with traditional approaches. Additionally, students still predominantly focus on learning within a semester calendar that does not necessarily coincide with the realities of industry needs. Faculty are also limited by a reward system that places demands on their time that compete with full attention to the students' emerging problem-solving needs.

## CONCLUSIONS

The IRE program is uniquely designed to immerse upper division engineering students in a completely problem-based curriculum. Although both students and faculty are continuing to adapt to the challenges inherent in this non-traditional approach, our study indicates that both are fully engaged in the process and – most importantly – students perceive they are developing engineering skills that will be directly transferable to their future employment.

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