The Iron Range Engineering (IRE) Model for Project Based Learning in Engineering

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Abstract
In the heart Minnesota's Mesabi iron range, a new model for engineering education has been funded and began delivery in January 2010. The IRE (Iron Range Engineering) model is a project-based-learning (PjBL) model in which students work with industry or entrepreneurs on design projects with a focus on producing graduates with integrated technical/professional knowledge and competencies. Students at IRE are upper-division mechanical engineering students, enrolled at Minnesota State University Mankato, who are mostly graduates of Minnesota's community colleges. IRE students do not take classes;100% of their learning is done in the context of the industry/entrepreneurial projects. The PjBL model readily lends itself to regional economic development making the IRE program an education/economic hybrid system.

Overview
Since the publication of *Engineer 2020* [1] (and before) there have been numerous calls for a new-look graduating engineer. With guidance from some of the most respected leaders in engineering education, the IRE model has been developed to utilize industry-based project-based-learning (PjBL), outcome-based assessment, just-in-time interventions, self-directed learning, and emphasis on reflection to graduate engineering practitioners with integrated technical/professional competency.

Educating Engineers: Designing for the Future of the Field [2] together with other recent research and reports on engineering education, make a compelling case for envisioning engineering education in a new way. The new Iron Range Engineering program explores a completely different way of approaching engineering education. Some of the characteristics of this new approach are:

> * Primary emphasis is on development of learning outcomes that have been spelled out in national reports, including *The Engineer of 2020*. This emphasis is contrasted with primary emphasis on coverage of topical material that characterizes many of the engineering programs throughout the world.
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> * Faculty members in the program invest heavily in developing abilities of students in the program to assess their development with respect to these outcomes. To support self assessment, faculty members articulate criteria with which development with respect to these outcomes can be evaluated.

* Learning activities are organized around externally-sponsored projects. Each semester, students manage projects in which they perform engineering functions such as design, development, research, testing, etc. for local and regional industries and entrepreneurs. Faculty members use the projects as contexts for developing competencies and learning subject matter.

* This contextual problem based learning model provides an exciting environment for synergism between education and economic development. Learning by working on externally sponsored projects from industry and inventors, the innovation process is moved into the undergraduate education process and allows for more globally competitive regional industries and the promise of new hi-tech start-up companies.

* Students complete course and graduation requirements by exceeding or meeting levels of competencies with respect to clearly articulated outcomes using a modified Bloom's Taxonomy.

Rationale Supporting Need of "New Look" Engineer
The evidence for needing and the calls for a new model of engineering education are extensive. These calls have come from a wide variety of sources, such as:

- The National Academies of Engineering (NAE) in *The Engineer 2020* and *Educating the Engineer of 2020* publications:

  "If the United States is to maintain its economic leadership and be able to sustain its share of high-technology jobs, it must prepare for this wave of change. Although there is no consensus at this stage, it is agreed that innovation is the key and engineering is essential to this task; but engineering will only contribute to success if it is able to continue to adapt to new trends and provide education to the next generation of students so as to arm them with the tools needed for the world as it will be, not as it is today." [3]

- The National Science Board (NSB) in *Moving Forward to Improve Engineering Education*:

  "The Board feels that a continuation of the status quo in engineering education in the U.S. is not sufficient in light of the pressing demands for change". [4]

- The leaders in engineering education through several American Society for Engineering Education (ASEE) Journal of Engineering Education (JEE) Articles:

  "Converging on a view of engineering education that not only requires students to grasp traditional engineering fundamentals, such as mechanics, dynamics, mathematics, and technology, but to also develop the skills associated with learning to imbed this knowledge in real-world situations. This not only demands skills of creativity, teamwork, and design, but in global collaboration, communication, management, economics, and ethics." [5]

"In view of the broadening and rapidly shifting scope of the engineering profession, it is imperative to shift the focus of engineering curricula from transmission of content to development of skills that support engineering thinking and professional judgment. Future engineers will need to adapt to rapidly changing work environments and technology, direct their own learning, broaden an understanding of impact, work across different perspectives, and continually revisit what it means to be an engineer. Traditional approaches to engineering education (chalk-and-talk lectures, individual homework, three years of "fundamentals" before an introduction to engineering practice) is incompatible with what we know from decades of cognitive and classroom research". [6]

The need for change is not new and should be considered part of the continuum of change our society is going through. The same need existed in the middle of the 20th century in the United States as summarized in:

- President Barack Obama's Remarks at the April 27th, 2009 National Academy of Science Annual Meeting:

  "A half century ago, this nation made a commitment to lead the world in scientific and technological innovation; to invest in education, in research, in engineering; to set a goal of reaching space and engaging every citizen in that historic mission. That was the high water mark of America's investment in research and development. And since then our investments have steadily declined as a share of our national income. As a result, other countries are now beginning to pull ahead in the pursuit of this generation's great discoveries ... That's why my administration has set a goal that will greatly enhance our ability to compete for the high-wage, high-tech jobs of the future –- and to foster the next generation of scientists and engineers. In the next decade –- by 2020 –- America will once again have the highest proportion of college graduates in the world. That is a goal that we are going to set." [7]

It is in the context of a defined need for change, the call for change, and the *Educating the Engineer of 2020's* call for system level approach that the IRE model was developed.

Rationale Supporting IRE Model

The same sources that have called for a change in engineering education have also given directions for this change that led to the aspects of the IRE model of student empowered development of technical and professional knowledge and competencies in context of industry sponsored project-based learning.

The call for engineering education to be **student empowered** (or centered) **development of** competencies is summarized in the:

- *Educating the Engineer of 2020* focus on the need for student focus in the curriculum development:

  *"Pursue Student-Centered Education - One should address how students learn as well as what they learn in order to ensure that student learning outcomes focus on the performance

characteristics needed in future engineers. Two major tasks define this focus: (1) better alignment of engineering curricula and the nature of academic experiences with the challenges and opportunities graduates will face in the workplace and (2) better alignment of faculty skill sets with those needed to deliver the desired curriculum in light of the different learning styles of students." [1]

The focus on **technical competencies** has been a hallmark of engineering education, but the need for **professional competencies** to be addressed as an equal are more than evident in the:

- *Educating the Engineer of 2020's* recognition that "the disconnect between the system of engineering education and the practice of engineering appears to be accelerating. This is due to the explosion of knowledge, the growing complexity and interdependence of societal problems, the worldwide reach of those problems, and the need to operate in a global economy" [3]
- ABET Criterion 3, program outcomes; where out of the 11 outcomes that programs must demonstrate their students attain, the following 7 have a professional component to them [8]:
  (c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
  (d) an ability to function on multidisciplinary team
  (f) an understanding of professional and ethical responsibility
  (g) an ability to communicate effectively
  (h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
  (i) a recognition of the need for, and an ability to engage in life-long learning
  (j) a knowledge of contemporary issues.

The IRE model is designed to specifically meet the model of engineering education being called for by those leading the way for engineering education to meet the engineering needs of the future.

Description of Revolutionary Model for Engineering Education in the United States
The IRE model was delivered for the first time starting in January 2010 in Virginia, Minnesota as a collaboration between Itasca Community College and Minnesota State University Mankato.

The IRE Model is:
Student empowered **development of** technical and professional **knowledge and competencies in context** of industry/entrepreneur sponsored project-based learning, leading to regional economic development

Project-based-learning (PjBL):
In an adaptation of the Aalborg Model of PjBL (Figure 1), IRE students combine learning of technical information with the execution of engineering design projects (note: this model is 100% project based and does not include traditional courses).

Entering students are community college graduates or transfer students from other universities who have all completed lower division requirements for a BS in Mechanical Engineering. The IRE model is the four semester upper division portion of a student's education. Graduates will be conferred a bachelors degree in mechanical engineering. Students execute one to two project cycles per semester.

During the proposal stage, students, in collaboration with faculty and clients, develop two plans: a design "work plan" which details the entire execution of the deliverable to the client; and a "learning plan" which addresses professional learning objectives, technical learning objectives, and the learning modes that will be employed to meet the objectives (self-directed learning, peer-directed learning, faculty-directed learning, and external expert-directed learning as well as methods for formative assessment and reflection).

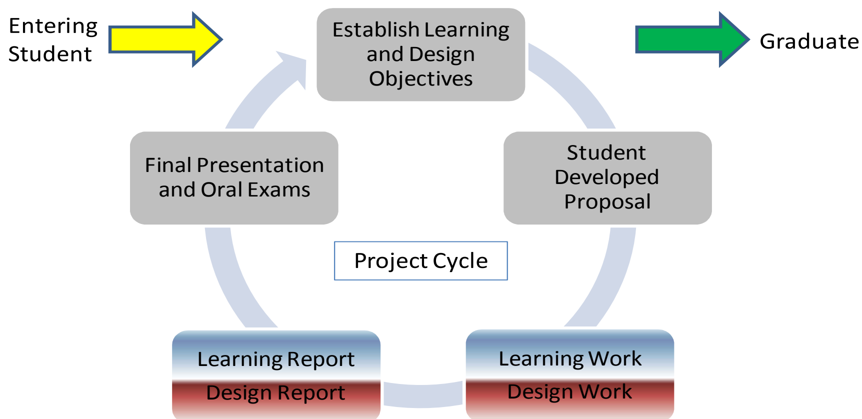

Figure 1. An adaptation of the Aalborg Model of PjBL for use in the Iron Range Engineering Program [9]

Projects are industry or entrepreneur sponsored. IRE is located in the heart of Minnesota's Iron Range. Within short driving distance there are five iron mines, two coal generation power plants, a wind-turbine farm, two paper mills, a new precious metals mine, and proposed steel mill. The managers and engineers in these industries have embraced this program and committed to providing projects, project guidance, technical expertise for student learning, and assistance in assessment. As an example of a project – In Spring 2010, an IRE student group designed and implemented a condenser performance test to be applied to the power generation condenser on a 400 MW power plant. The performance test will give several indications of efficiency both before and after the condenser is retrofitted. The results of the testing will give Minnesota Power vital information on the cost savings and payback period. To perform the project, the student group 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. A technical report was published and five oral presentations were made.

As another example of the PjBL model effectiveness, four design projects were entered into a statewide business plan competition with over 1000 total entries. The IRE program placed 3 of the four in the top 10 in their respective divisions, with one placing in the top 3 as a finalist.

Technical and Professional Knowledge and Competencies:
The IRE developers have broken technical and professional knowledge and competencies down into a finite number of measurable outcomes. For each outcome, a continuum from novice to expert using Bloom's 2D taxonomy (see Figure 2.) is being applied.

In the beginning of each student's first semester, she works with faculty to establish her individual starting point on each outcome. In this way, the IRE model recognizes each student's different starting points and empowers all students to build on their strengths and overcome their weaknesses as they navigate their education. To graduate, each student has to attain "work ready" competency.

Student empowered design and monitoring
A guiding principle for the IRE model is that students own the responsibility for their learning. At the beginning of each project cycle, students identify which outcomes will be addressed during the project. Working with faculty, they determine which learning modes will be applied and determine what types of evidence they will need to acquire to demonstrate outcome attainment by the end of the project cycle. Each project cycle concludes with the presentation of two reports - a design report for the deliverable and a learning report that reflects on the learning process and provides evidence of outcome attainment. In addition to written reports, there is a student presentation made to faculty and external clients. The final presentation includes an extensive oral exam session in which students demonstrate their understanding of technical engineering knowledge gained and competencies acquired. At the conclusion of each project cycle, students have a new view of their levels of knowledge and competencies.

Brief History
In March 2009, the Minnesota Iron Range Resources Board (a group of eight members of the Minnesota State Legislature) decided to establish a new engineering program on the Iron Range in Minnesota. The program is the result of five years of planning and development by a small team of engineering educators from across the country. This group sought to use the new knowledge on how people learn to empower students to take ownership of their education and gain their knowledge and competencies, with special emphasis on the professional competencies as they are articulated in ABET a-k and Engineer 2020, in the context of learning engineering by practicing engineering side-by-side with engineers.

Iron Range Engineering is an extension of Itasca Community College Engineering in Grand Rapids, Minnesota. The ICC Engineering program, under the direction of Ron Ulseth, reached national prominence in engineering education through building learning communities, and providing an outstanding foundation in the first two years of an engineering program.

Today the IRE program is directed by Dr. Dan Ewert who comes to IRE after 19 years at North Dakota State University, the last 7 as a department chair. IRE has two distinct advisory boards - one from industry which provides significant input on how IRE meets the region's engineering and economic needs and another advisory board from academia that includes engineering education experts who provide guidance on learning outcomes, concrete expectations for when students have achieved competency levels, how students should be assessed with respect to learning outcomes, how progress with respect to these learning outcomes is made transparent to the students, what processes should be in place to support assessment, student learning, student development, and student growth, etc. The IRE Academic Advisory Board meets monthly to provide developmental guidance. Members are: Dr. Sheri Sheppard, Stanford University; Dr. Jeffrey Froyd, Texas A&M; Dr. Denny Davis, Washington State University; Dr. Thomas Litzinger, Penn State University; Dr. Edwin Jones, Iowa State University and St. Thomas University.

Knowledge Dimension	Process Knowledge							
	Conceptual Knowledge							
	Factual Knowledge							
		No Exposure (0)	Remember (1)	Understand (2)	Apply (3)	Analyze (4)	Evaluate (5)	Create (6)
	Cognitive Dimension ==>							

A. Factual Knowledge: The basic elements that students must know to be acquainted with a discipline or solve problems in it.

Aa. Knowledge of terminology

Bb. Knowledge of specific details and elements

B. Conceptual Knowledge: The interrelationships among the basic elements within a larger structure that enable them to function together.

Ba. Knowledge of classifications and categories

Bb. Knowledge of principles and generalizations

Bc. Knowledge of theories, models, and structures

C. Procedural Knowledge: How to do something; methods of inquiry, and criteria for using skills, algorithms, techniques, and methods.

Ca. Knowledge of subject-specific skills and algorithms

Cb. Knowledge of subject-specific techniques and methods

Cc. Knowledge of criteria for determining when to use appropriate procedures

1.0 Remember: Retrieving relevant knowledge from long-term memory.
- 1.1 Recognizing
- 1.2 Recalling

2.0 Understand: Determining the meaning of instructional messages. Including oral and graphic communication.
- 2.1 Interpreting
- 2.2 Exemplifying
- 2.3 Classifying
- 2.4 Summarizing
- 2.5 Inferring
- 2.6 Comparing
- 2.7 Explaining

3.0 Apply: Carrying out or using a procedure in a given situation.
- 3.1 Executing
- 3.2 Implementing

4.0 Analyze: Breaking material into constituent parts and detecting how the parts relate to one another and to an overall structure or purpose.
- 4.1 Differentiating
- 4.2 Organizing
- 4.3 Attributing

5.0 Evaluate: Making judgment based on criteria and standards.
- 5.1 Checking
- 5.2 Critiquing

6.0 Create: Putting elements together to form a novel, coherent whole or make an original product.
- 6.1 Generating
- 6.2 Planning
- 6.3 Producing

Figure 2. Bloom's 2D Taxonomy as utilized to chart student acquisition of technical competency through oral exams, design reviews, portfolio assessment, and the presentation of other evidence. At graduation an "A" student is expected to have an average 4.5 across all technical and professional competencies.

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