A COMPARISON STUDY OF PROJECT-BASED-LEARING IN UPPER-DIVISION ENGINEERING EDUCATION

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ABSTRACT

A new model for engineering education was launched in January 2010 in northeastern Minnesota. The Iron Range Engineering (IRE) model is a project-based-learning (PBL) methodology that focuses on producing graduates with integrated technical and professional knowledge and competencies. A unique and important element of the IRE model has 100% of IRE student learning taking place in the context of industry projects. Students at IRE are upper-division engineering students who transferred from Minnesota community college lower-division engineering programs. To understand the impact that IRE methodology may have on preparing engineers with the competencies needed for the future workplace, a comparison study has been developed to investigate the extent to which students in integrated applied models are affected. The curriculum model and comparison study are described within this paper, along with preliminary results on student development and engagement.

INTRODUCTION

The Iron Range Engineering (IRE) program and this project are a collaborative effort between Itasca Community College and Minnesota State University, Mankato (MSU). The investigators are evaluating the effects of project-based-learning (PBL) in engineering education. The evaluation is approached from four different perspectives: the cognitive development of the student, the technical competency of the student, the professional competency of the student, and the motivation of students to learn.

The study focuses on the IRE students enrolled in the newly established Iron Range Engineering program in northeastern Minnesota. This program is a project-based-learning model in which students work with industry on design projects while developing integrated technical and professional knowledge and competencies. Students typically begin their education at one of Minnesota's community colleges for introductory engineering, math, and science courses and then continue their studies at IRE for the final four semesters of the students' upper-division engineering education. In the IRE program, students do not take classes. Instead, they spend their upper-division years working on industry-driven projects and obtaining core engineering knowledge through a guided independent study model. Graduates earn a bachelors degree in general engineering with an emphasis in mechanical, electrical, chemical, or biomedical engineering based on their project focuses and interests. The first cohort of 13 IRE students will graduate in December 2011, 9 more will graduate in Spring 2012, and the third cohort of 23 students began the curriculum in August 2011. Given the preliminary success of the first students, the developers, industry partners, faculty, students, and academic advisory board of the IRE program believe this new teaching and learning design is revolutionary for engineering education in the United States.

This paper describes the background information supporting the model, the IRE approach, the assessment strategy, and preliminary results addressing cognitive development and student engagement. The investigators on this project have developed a strategy that uses a wide variety of proven tools to gauge the extent of student development of knowledge and competencies. The results of this study will provide useful evidence to engineering programs wishing to establish project-based-learning cohorts and to engineering programs that have strong industry-based contextual co-op or internship emphases. In addition, the study will lend information regarding "best practices" to academia in general, supporting the notion of learning engineering design and practice in a contextual environment.

SUPPORTING BACKGROUND

The calls for a new model of engineering education and the evidence for its need are extensive. These calls for a new engineer have come from a wide variety of sources, such as: The National Academies of Engineering (NAE) in "The Engineer of 2020":

> It is our aspiration that engineering educators and practicing engineers together undertake a proactive effort to prepare engineering education to address the technology and societal challenges and opportunities of the future. With appropriate thought and consideration, and using new strategic planning tools, we should reconstitute engineering curricula and related educational programs to prepare today's engineers for the careers of the future, with due recognition of the rapid pace of change in the world and its intrinsic lack of predictability (NAE, 2004, p. 51).

Leaders in engineering education through American Society for Engineering Education (ASEE) Journal of Engineering Education (JEE) articles, for example:

> 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 (Adams and Felder, 2008).

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 "Educating the Engineer of 2020" (NAE, 2005):

> Some 50 years ago, such debate led to the introduction of the engineering science model of engineering education. It produced engineers who "practiced" differently, and that led to many new products and technologies that were developed more rapidly and were of higher quality than those developed by the semi-empirical methods that were then the norm for engineering practice. Today, the practice of engineering needs to change further because of demands for technologies and products that exceed existing knowledge bases and because of the changing professional environment in which engineers need to operate (NAE, 2005, p. 13).

The same sources that have called for a change in engineering education have also given directions for this change. The student-driven IRE model focusing on the development of technical and professional knowledge and competencies in the context of industry sponsored project-based learning is one response. The call for engineering education to be driven by empowered students in their development of competencies is summarized in the National Science Board's report "Moving Forward to Improve Engineering Education". This report suggests that the best approaches to engineering education are "Using student involvement in the design of the curriculum" (NSB, 2007, p. 15). In addition, "Educating the Engineer of 2020" focuses on the need for a focus on students in 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. (NAE, 2005, p. 24)

THE IRON RANGE ENGINEERING EDUCATION MODEL

The IRE model in the United States addresses the calls for change in engineering education. The primary emphasis is on the development of learning outcomes, contrasted with primary emphasis on coverage of topical material that characterizes many of the engineering programs throughout the world. The learning in the IRE model is 100% project based and is targeted at the development of a technically sound, highly professional graduate who possesses high levels of problem solving ability and has experience in engineering design. In an adaptation of the Aalborg Model of PBL (Figure 1), IRE students combine learning of technical information and professional development with the execution of engineering design projects. A guiding principle for the IRE model is that, throughout the projects, students own the responsibility for their learning through the projects while obtaining the technical and professional knowledge and competencies which have been defined for the program.

Project Cycle

The core of the IRE model is the learning that takes place around engineering design projects. At the beginning or "proposal stage" of each project cycle, 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). Students execute one to two project cycles per semester.

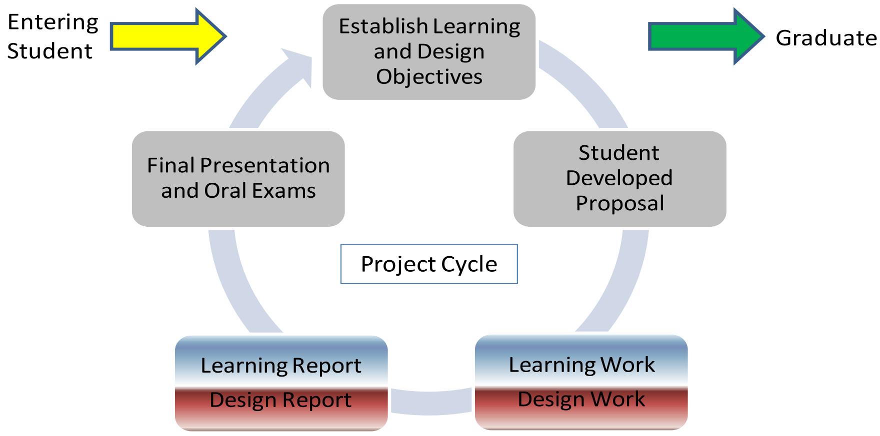

Figure 1. Iron Range Engineering Program Model of PBL: Adapted from the Aalborg Model of PBL (Kolmos, 2004).

Each cycle concludes with the presentation of two reports: a design report for the deliverable and a learning report that reflects the learning process and provides evidence of outcome attainment. In addition to written reports, a student presentation is made to faculty and external clients. The final presentation includes an extensive oral exam in which students show their understanding of technical engineering knowledge and the competencies acquired. At the conclusion of each project cycle, students have a new view of their levels of knowledge and competencies.

Technical Competencies

For each technical competency, assessment is done on a continuum, from novice to expert, using Bloom's modified taxonomy (Krathwohl, 2002). During the student's first semester, her individual starting point is established through working with faculty. 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. Each semester students achieve eight technical competencies. For core competencies (eight mechanical and eight electrical), there is a fixed syllabus. For advanced competencies, students work with faculty to develop a personalized syllabus. In all cases, a technical competency consists of the development of knowledge through deep learning activities (Litzinger, 2011). Upon starting a project and meeting with industry clients, students identify which core and elective competencies best meet their individual and project needs. Some technical competencies are learned early in the semester as necessary background knowledge. Others naturally develop during project execution and are learned later in the semester. To graduate, students must attain "work ready" competency in core and advanced competencies.

Throughout the learning process, students have multiple interactions with faculty, learn through self-study and in peer groups, and tie their learning to their projects. Students regulate their learning through organization of new knowledge, evaluation of quality of learning, and making in-progress changes to learning based on those evaluations. Each week, students meet with faculty in a “Learning Review” to discuss progress, impediments and plans for learning in the upcoming week. Students take oral and written exams, and provide evidence of deep learning for each competency. Students complete course and graduation requirements by exceeding or meeting levels of competencies based on clearly articulated outcomes.

Professional Competencies

At the beginning of the IRE experience, students also identify all of the professional competencies or attributes that are expected of them by graduation. Working with faculty, they gauge their baseline in each attribute. Each semester, faculty provide learning activities in leadership, learning about learning, team work, communication, personal responsibility, professional responsibility and the entire spectrum of executing the design process. Through reflection, personnel evaluation by project mentors, client feedback, peer feedback, and faculty evaluation, students track their advancement towards their graduation goals. At the end of each semester, students write improvement plans for the next semester including specific activities aimed at enhancing their performance.

Through PBL, industry interactions, and significant metacognitive activity, students develop advanced problem solving skills, deep technical knowledge in the fundamentals of engineering, advanced knowledge in selected disciplines, and a well developed set of professional skills such as writing, speaking, project management, leadership, conflict management, and ethical decision making. The expectation is that these experiences will lead IRE graduates to meet the ABET a-k student outcomes (ABET, 2009) at levels much higher than in traditional US programs.

COMPARISON STUDY

The purpose of the evaluation is to determine how effective the project-based IRE learning model is at meeting the call to develop a technically competent, professionally competent, and learned engineer in comparison to a traditional engineering education model. If successful, a cohort-based approach to the IRE model could be readily incorporated into other university departments and/or co-op and internship programs in the United States. The IRE faculty recognize that curriculum-wide PBL is more common in Europe and other parts of the world.

Study Goals and Expected Outcomes

Several goals and outcomes have been established to evaluate the effectiveness of the IRE model as compared to traditional engineering education:

Goal 1: Evaluate cognitive development of students in:

a) evaluate changes in learners' perceptions of their skills and attitudes with respect to self-directedness in their learning.

b) determine changes in the relationships between learners' study processes and the structural complexity of their learning.

c) assess changes in learners' motivational orientations and use of different learning strategies.

d) track changes in learners' cognitive and affective perspectives.

Goal 2: Evaluate ability of engineering learners to acquire technical knowledge through PBL:

a) evaluate changes in learners' abilities to develop conceptual knowledge using concept inventories.

b) investigate changes in learners' abilities to acquire technical knowledge using oral examinations and Bloom's 2-D taxonomy.

c) apply portfolio assessment to qualify student acquisition of technical knowledge as they learn.

d) assess student achievement and learning in areas of design processes, and solution assets (intermediate and final design products) to quantify knowledge acquisition.

Goal 3: Evaluate ability of engineering learners to acquire professional competencies:

a) assess student achievement and learning in areas that include teamwork and professional development to quantify professional competency acquisition.

b) qualify satisfaction of industry with respect to abilities of students' and graduates' to demonstrate desired professional attributes.

c) apply portfolio assessment to qualify student acquisition of professional competencies.

Goal 4: Study impact of PBL environment on student interest-level and motivation to learn:

a) quantify changes in student engagement as they learn.

b) assess changes in learners' motivational orientations.

c) track student interest level and attitudes through learning sequence.

Study Approach

A combined case and comparison study approach is being used to investigate the cognitive development of the student, the technical competency of the student, the professional competency of the student, and the motivation of students to learn. The study will involve three groups, each with cohorts for the next three years as shown in Table 1. The project began in full in Fall 2011 with Cohort B being the students who entered in August 2011. Cohort A is composed of students who began before August 2011. Limited research is being done with Cohort A. The preliminary results described in this paper are for Cohort A.

	Brief Description	Year 0	Year 1	Year 2	Year 3
Iron Range Engineering PBL group (IRE group)	Juniors and Seniors at IRE who have transferred from other institutions; majority from ICC	Cohort A	Cohort B	Cohort C	Cohort D
Minnesota State University, Mankato comparison group (MSU group)	Juniors and Seniors at MSU; majority started at MSU as Freshmen		Cohort B	Cohort C	Cohort D
Itasca Community College (ICC) graduate/transfer student comparison group (ICC group)	Juniors and Seniors at various regional institutions who completed first two years at ICC		Cohort B	Cohort C	Cohort D

Table 1. Group and Cohort Descriptions.

The IRE group will be the focus of the case study while the MSU group and ICC group will be used for the comparison study. Each cohort is a class of students who will begin their program with the same expected time to graduation. In years 1-3, each cohort will be assessed pre-intervention, during intervention and post intervention.

Data collection will begin with a baseline study of each of the groups at the beginning of their junior year (pre-intervention) and then continue with multiple day workshops held each spring at the end of the academic year. The tools being used bridge the spectrum of the goals of the project and are described next. In order to establish rigor and credibility for the study, parameters such as triangulation of data sources and multiple researcher analysis will be employed as described by Darke, et al. (1998).

Research Instruments:

Self Directed Learning Readiness Scale (SDLRS) is a method for evaluating an individual's perception of their skills and attitudes that are associated with self-directedness in learning (Guglielmino, 1977).

Study Process Questionnaire (SPQ) determines the relationship between students' study processes and the structural complexity of their learning (Biggs, 1978, 1987).

Motivated Strategies for Learning Questionnaire (MSLQ) assesses college students' motivational orientations and their use of different learning strategies (Pintrich, 1991).

Transferable Integrated Design Engineering Education (TIDEE) consortium developed an integrated system (IDEALS) for assessing outcomes related to students' personal capacity, teamwork, design processes, and solution assets (Davis, 1999).

ABET Outcome Portfolio Analysis (PORT) was developed by faculty at Itasca Community College for a structured review of student attainment of ABET criteria based on articles of evidence for demonstrating competency in each criterion.

Concept Inventories (CI) are multiple choice instruments narrowly focused on learner understanding of essential conceptual knowledge (Reed-Rhoads & Imbrie, 2008).

Full Length Practice Fundamentals of Engineering Exam (FE): Practice exams from Professional Publication Inc. (PPI) will be used as part of a mock FE exam to assess student attainment of technical knowledge.

PRELIMINARY RESULTS

Preliminary evaluation of the model using Cohort A has focused on goals 1 & 4 for the IRE group using the SDLRS, MSLQ, and SPQ evaluation tools. Results are shown in Table 2.

Cohort	Cohort Starting Date:	SDLRS		MSLQ		RSPQ			
						Year 1		Year 2	
		1st Year Data	2nd Year Data	Motivational Beliefs	Self-Regulated Learning	Deep Approach	Surface Approach	Deep Approach	Surface Approach
Generation 1	Fall 2009	206	218	4.8	4.4	29	23	34	28
Generation 2	Fall 2010	222	N/A	4.7	4.3	38	22		
Generation 3	Fall 2011	244	N/A						

Table 2. Preliminary Data for Cohorts A and B

The *SDLRS* is a self-report questionnaire with Likert-type items designed to measure the complexity of attitudes, skills, and characteristics that comprise an individual's current level of readiness to manage his or her own learning. The adult average is 214 with 202-226 for an average range and 227-290 for an above average range. IRE students in generation one started with a below average mean of 206 and have shown an increase in their skills and attitudes that are associated with self-directedness in learning to 218 in year two. Generation one is still in the average range, but as a group is above the adult average. Interestingly, as the IRE learning model, student learning goals, and outcome expectations have become more clearly defined through program assessment and modification, each of the following generations of students show an increase in their skills and attitudes associated with self-directedness in learning. The generation three group (Cohort B), which is starting this fall, has self-identified in the "above average" range.

The Motivated Strategies and Learning Questionnaire assesses college students' motivational orientations and their use of different learning strategies. There is no significant difference between generation 1 & 2 students of cohort A in both sections of the questionnaire in their first year in the program. In addition, generation one students had no significant difference in both sections of the questionnaire when reevaluated in their second year. It appears the IRE program has no measurable impact on student motivation orientations or learning strategies.

The Study Process Questionnaire (SPQ) evaluation of the IRE student complexity of learning structure shows similar results to the SDLRS evaluation. As the IRE learning model has developed, it appears that the generation 1 cohort has increased the complexity of its learning structure from year one to two. In addition, the generation 2 cohort has benefited by starting out with a higher level of complexity in the learning structure.

As the IRE model matures, initial results show that students within each generation and from one generation to the next are increasing in their a) identification with self-directed learning and b) motivation towards using deep learning strategies. However, the IRE model does not currently appear to impact students' motivational orientations and their use of different learning strategies. It will be important to evaluate generation 1 students' motivational orientations and their use of different learning strategies as they graduate and start their careers.

FUTURE WORK

Ongoing evaluation of goals 1 & 4 will need to continue in order to monitor the progress of each generation as they move through the program and enter the profession. Further work is needed to collect and compile the data for evaluating goals 2 and 3 and to develop the comparison groups at MSU and ICC. The collection of this data in combination with interviewing program graduates and their employers will provide evidence for the success of the IRE model of engineering education.

CONCLUSION

According to the literature, there is a need in the United States to change engineering education to meet the changing needs of society and the ever increasing amount of knowledge and technology related to the field. Preliminary findings indicate that the new IRE program may provide insights on best practices in the use of PBL in the United States engineering education system. Initial student results and feedback from program partners and sponsors indicate the potential for this program to serve as an example of how to successfully develop the engineers needed to meet the needs of the 21st century.

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