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Design of a Power Substation: Technical Learning in the Context of an Industry-Sponsored Project

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Abstract

Iron Range Engineering (IRE) is a project-based, non-traditional engineering program in which students gain technical expertise in the context of multidisciplinary, industry-based projects. In spring 2012, a team of IRE students completed a multidisciplinary project for Essar Steel Minnesota LLC. The project required students to complete the basic design of a power substation for the main pelletizing plant. The students did not have any prior experience designing power substations. The technical and professional skills needed to complete the project were gained in the course of the semester. This paper describes the program, using this project as an example of learning in the context of industry-sponsored projects.

Introduction

Project-based learning (PjBL) is an effective pedagogy that has been used successfully for over 30 years. It started in medical schools and continues to be accepted in engineering disciplines[1]. PjBL has been defined and described in various ways[2]. PjBL refers to many instructional approaches in which much of the learning and teaching occur in context of open-ended projects[3].

PjBL is a model that motivates students to learn technical content, practice professionalism, conduct research, integrate theory and practice, and apply knowledge and skills to complete projects[4]. With this approach, the selection of open-ended problems or projects for students is important to inspire creativity and self-motivation. This approach requires mentors to facilitate learning and provide necessary resources to ensure students are given opportunities to manage their time and to practice self-directed learning[5,6]. Ultimately, PjBL promotes students to design, solve problems, make correct decisions, research and usually work together as a team to deliver a solution or product[7].

Iron Range Engineering (IRE) is an entirely project-based engineering program: students do not participate in traditional lecture classes; instead, students acquire their technical/professional learning in the context of industry projects. IRE students earn Bachelor of Science in Engineering degrees, with emphases along a spectrum between what might be traditionally called mechanical and electrical engineering[8,9,10].

Essar Steel Minnesota LLC (ESML), owned by the multinational Essar Group, is one of IRE's industry partners. ESML initiated and sponsored a project for IRE students in spring 2012. The project involved the complete design of a power substation for the ESML mining plant. A team of six IRE students, from various disciplines, was formed to complete the project. The project provided opportunities for a great deal of experience both in professional and technical learning

for the students. Professional experiences included, but were not limited to, continuous interaction with industries, multiple presentations, extensive technical writing, and teamwork. The students were also able to interact with engineers from the ESML and benefited greatly from the engineers' experience. Technical learning consisted of 3-phase power systems, ac fault analysis, industrial grounding, etc. In this paper we describe the program structure, program strengths and weaknesses, and how students gained their technical learning in the context of this industry project.

Project overview

The project was to design a power substation for ESML's main pelletizing plant. The client (ESML) defined the project deliverables as follows[11]:

- Basic electrical and lighting layout
- Electrical grounding system
- Construction materials
- Basic architectural design
- Basic roof design including loading from wind and precipitation
- Heating, Ventilation, and Air Conditioning (HVAC) design

Additionally, the design needed to follow the most up to date version of the National Electric Code (NEC) and include a layout of the electrical equipment. Moreover, the size of the building needed to be appropriately dimensioned to house the aforementioned equipment layout. The substation building needed to be designed to contain the following medium voltage electrical equipment: 20 medium voltage circuit breakers, 14 transformers, 7 medium voltage variable frequency drives, and several motor control centers that would be controlled remotely. To minimize the risk of equipment damage during a fault occurrence, an appropriate electrical grounding system needed to be designed.

The team completed the design in May 2012. The basic design included equipment layout, foundation and structural analysis, grounding and fault analysis, heating and ventilation planning, lighting, and cable sizing. Each aspect of the design met local and national codes and regulations. The substation was designed to house the required 13,800-volt switchgear, in addition to the corresponding power transformers and variable frequency drives. The physical design of the building included the foundation, roof truss specifications, and wall and roof type. Dimensions were selected based upon the equipment layout and accessibility of equipment to personnel, in accordance with Occupational Safety and Health Administration (OSHA) regulations. In addition to meeting OSHA standards, the design also met Minnesota Building Code, American Society of Civil Engineers (ASCE) specifications, and the International Building Code. The HVAC and insulation characteristics of the building were designed to handle the extremes of northern Minnesota weather (i.e., summer temperatures that can exceed 90° F and winter temperatures that frequently dip below 0° F). The design of HVAC was a challenge because housing so many transformers and variable frequency drives in close proximity would generate large amounts of heat; hence the heat elimination system needed to be robust. Table 1 presents the multidisciplinary aspects of the project.

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Table 1. Overview of the multidisciplinary aspects of designing a power substation

Engineering Discipline	Project Areas	Examples
Electrical	Electrical equipment layout Fault Current Analysis Grounding system Lighting	clearance requirements, grounding system, switchgear specifications, VFD, circuit breaker ratings, Lighting requirements
Mechanical	Cable tray HVAC	Cable tray specifications, heating and cooling design,
Structural	Structural and Foundation Analysis	Building footings, walls, roof
General	Codes and Regulations	NEC, Building Codes, OSHA, NFPA, floor spill containment

Project Outcomes

Desired learning outcomes were defined based on ABET student outcomes. The ABET student outcomes associated with the project are as follows:
The team applied engineering principals to achieve the best possible design that met and exceeded expectations of the clients (Outcome A). Some of these principals included calculating fault current, designing roof and foundation, and computing total heat and cooling loads. The students designed and conducted experiments, such as measuring ground resistivity, experimenting with continuity principle (used to design HVAC), heat transfer analysis of cooling a transformer, and thermodynamic analysis of a refrigeration cycle. These experiments were necessary to gain required knowledge of the project or to prove that the design met the needs of project (Outcome B), and they usually involved use of modern engineering tools and techniques (Outcome K). The project involved multiple designs in various areas, such as HVAC, grounding, lighting system, cable tray, and roof and foundation (Outcome C). This project was multidisciplinary, and the students from multiple disciplines worked as a team to complete the project (Outcome D).

The first phase of the project was to understand what exactly ESML needed, formulate the problem, conduct research and experiments, and finally propose solutions (Outcome E). A big portion of the project deliverables was four to five presentations made both to the client and other peers at the program, and the writing of several technical reports. After each presentation, the team received feedback from the faculty and peers on the content and delivery of the presentation and their technical writing skills. Each section of the final technical report was reviewed and graded by the team mentor (Outcome G). One of the deliverables was the contextualization document that reports what significance the final design might have on the environment, health and safety concerns, economics, ethics, etc. (Outcome H). Based on the technical evidence and submitted documents, these outcomes were evaluated, and the faculty mentor made sure that each team member achieved these outcomes.

Iron Range Engineering Program

In the heart of Minnesota's famous iron range, an innovative model for engineering education was launched in January 2010. A satellite program of Minnesota State University- Mankato, IRE is a PjBL program in which students work intimately with industry partners on design projects or entrepreneurial projects of their own that might lead to start-up companies. IRE is a 2+2 program in which students complete their freshmen and sophomore years at another institution (mostly local community colleges) and transfer in to complete their junior and senior years completely immersed in a multidisciplinary engineering team environment.

The objective of the program is to generate graduates armed with not only technical knowledge but also professional and leadership skills required to succeed in today's complex, global economy, as well as to bring further economic expansion to the area. At IRE, the majority of students' learning occurs while completing industry- sponsored projects following roughly a 40 hour-per-week experience in an engineering-type office/lab setting where students learn engineering design through actual practice and managing engineering projects for industry clients. Students manage the acquisition of their technical competencies by learning and applying the engineering concepts in the context of their design project. This approach varies significantly from traditional lecture-based curriculums.

The structure of IRE curriculum is shown in figure 1. The curriculum comprises 60-credits: 28 professional and design, and 32 technical credits. The 32 technical credits include 6 mechanical core, 6 electrical core, 4 general engineering core, and 16 elective credits. Each competency equals one technical credit. Examples of electrical core competencies include AC Circuits, Digital Logic, Electronics, and Signals& Systems; Heat Transfer, Fluid Mechanics, and Mechanics of Materials are examples of mechanical core competencies. The elective competencies are structured by a student and an instructor one-on-one as an independent study, according to the student's interest or his/her project goals. Although the core competencies are well-structured and matched with the subjects commonly taught at traditional institutions, elective courses are incorporated to facilitate students' learning in the context of their design projects. IRE students earn a Bachelors of Science in Engineering (BSE) after completing all 60-credits. Moreover, they are able to earn an emphasis in specific engineering areas if they complete 12 out of 16 elective competencies in a specific discipline such as mechanical, electrical, biomedical, etc.

IRE students, alongside their instructors, design their own syllabi including what they will learn, technical evidence of that learning, and when they will deliver their technical evidence. This empowerment promotes the interest level and motivation of the student, and leads to the ability for deeper learning and longer retention of the material. Along with technical learning, design coursework is integrated into the curriculum as students complete their industry projects. This program aims to prepare engineers who are able to understand issues that transcend disciplinary boundaries and to be able to offer effective solutions.

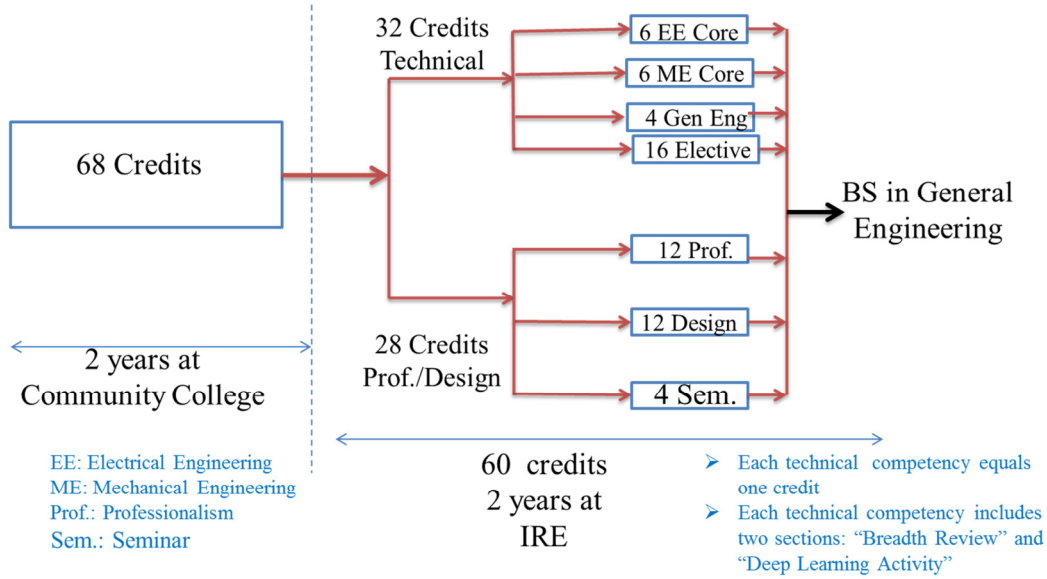

Figure 1. IRE Curriculum

Technical learning in the context of project

Each team member registered for eight technical competencies in the course of the semester, with each competency worth one credit. Some of these competencies were core competencies and were mandatory to be enrolled in. The rest were elective technical competencies in which the students enrolled and completed in order to gain knowledge and skill required to complete their design project. This type of learning helped the team reinforce learning while working with subjects that related to real world engineering project. The following is the description of project-related competencies taken during spring semester 2012 by the team:

Three Phase power systems & AC Fault Analysis
These competencies helped students learn how to calculate fault currents that could occur at the substation and allowed the team to suggest switchgear ratings and circuit breakers amperage based upon these calculations.

Heat Transfer, HVAC (Heating, Ventilation, and Air Conditioning)
The heating, ventilation, and a refrigeration system installed in the building was directly related to these competencies. A significant amount of heat is generated within the indoor power substation by transformers and Variable Frequency Drives (VFDs). Additionally, the substation may experience 40 below zero during winter in northern Minnesota. By completing these competencies, the students learned how to design and make a recommendation for a proper HVAC system. The learning accomplished from these competencies involved various concepts such as air flow through a ventilation system, heat generated by equipment, and heat lost from the walls and roof.

Engineering Graphics
The main deliverable of the project for the client was a set of detailed engineering drawings. The client wanted the team to explain all aspects of the design by standards blueprints. The learning

accomplished involved the integration of materials, structures, electrical, lighting, air conditioning, heat loading, and safety into several blueprints of the design. Through this competency, the students not only learned engineering drafting, they also gained knowledge of generating various technical drawings.

Industrial Grounding

One of the project deliverables was the recommendation for an electrical grounding system. The objective of this competency was to help students design a grounding system for the substation. The students learned how to calculate and measure the resistance of several types of soil and based on the results make recommendations for a proper grounding system.

Industrial Safety & Electrical Safety

These competencies were beneficial in helping the team to understand and learn safety code from several different sources. The iron ore mine is governed under the Mine Safety and Health Administration (MSHA) regulations. National Electric Code (NEC) regulations govern the distances between electrical equipment and structures, between the pieces of equipment, fire protection, mechanical and structural safety. Structural code from the American Concrete Institute (ACI), American Society of Civil Engineers (ASCE/SEI), the International Building Code (IBC), and the Minnesota State Building Code, were followed while designing the building structure. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) code were followed while designing the HVAC system for the building.

Structures & Foundation

In these competencies, the students learn how to calculate the roof loading due to equipment loading, environmental loading, and the weight of the roof itself. This was used to choose the correct roof joists. The thickened edge slab was designed by using these calculations. This included the point loads from the joist system, the weight of the wall, and the reaction force from the supporting soil.

Table 2. Elective competencies enrolled by each team member

Student A	Student B	Student C	Student D	Student E	Student F
HVAC* I	AC Fault Analysis	Heat Transfer	Structure	Foundation Design	AC Fault Analysis
HVAC II	Industrial Grounding I	Engineering Graphics	Electrical Safety	Engineering Safety	Industrial Grounding
Engineering Graphics	Industrial Grounding I	Industrial Safety	HVAC	HVAC	Heat Transfer
	Electrical Safety	HVAC	Three Phase	Three Phase	
	Engineering Graphics	Mechanic of Material	Heat Transfer	Heat Transfer	

* Heating, Ventilation, and Air Conditioning (HVAC)

Discussion

This project is an example of learning in the context of an industry-sponsored project. The project was defined by the ESML engineers who provided excellent technical mentorship for the students. Two major factors that played an important role in the project success were (1)

excellent relationship between the IRE program and its industry partners, (2) the structure of IRE curriculum. The program did not ask for any financial support for completing the project, instead only technical mentorship was requested. Therefore, the team had an excellent opportunity to learn technical contents from well-experienced engineers by working closely with them on the projects. Additionally, the IRE curriculum is structured to facilitate learning in the context of project. As part of curriculum, each student must enroll in 16 elective competencies during their junior and senior year at IRE, taking 3 to 4 elective competencies per semester. The elective competencies, similar to independent study in traditional institutions, are developed by students and the instructors to help students gain knowledge and skills required to complete the project. This allows students to gain credits for their learning. The assessment is based on student's evidence of his/her learning. Each team member enrolled in few elective courses in spring 2012 (table 2) and developed learning plan to achieve the goals of the project.

This project is a proof that learning in the context of industry-sponsored project is an effective approach that has been helping students learn and apply technical contents. The following is a few strengths of the program:

- Students motivation: during the initial meetings with the client (ESSAR engineering department), the project was well scoped and the team mentor divided the project into several sections. The goals and tasks of each section were defined in the first week of the semester. Then, the students were required to choose a couple of sections that match with their interests or their educational goals. We believe that giving options to each individual increased his motivation. The team mentor avoided mandating any work or any section to students.

- Retention of knowledge: the team members were interviewed and asked technical questions on their sections in spring 2013, one year after completing the project. All team members retained the information very well and answered the technical questions correctly. A possible reason for recalling the information after one year is that the students focused on the meaning and applications of material and not the facts. This approach is different than lecture-based class in which students learn the facts and memorize the contents.

- Skill development: the team performed a number of professional activities. They prepared and gave five technical presentations about their project and wrote a number of technical documents. In addition to technical learning, the team learned and practiced a variety of other professional skills such as teamwork, time management, self-directed learning, peer-evaluation, peer-teaching, etc. Although students can develop these skills in a traditional setting, the program structure and curriculum facilitate and promote these skills and make it easy for students to learn and practice.

In spite of the program success, a few weaknesses are worth mentioning:

- Whereas in traditional setting knowledge is built layer over layer and simple to sophisticated, IRE students only gather information relevant to their projects. Therefore, they may not be fundamentally as strong as other students at traditional institutions.

- This program works very well for students who are highly motivated. Non-motivated students not only fail the program, they demotivate other students.

- Although combining technical learning and project work help students to save time, PjBL is a very time demanding approach for both students and faculty. The team claimed that they spent 50 hours per week on the project. In addition to his teaching and research duties, the faculty mentor also spent more than 10 hours per week to facilitate the students' learning, keep track of project progress, and provide resources for the students. In addition to the faculty mentor, external experts, i.e. ESSAR engineers, helped students learn the concepts and practice.

- Because students' learning differs from traditional instruction, the evaluation of student knowledge and achievement is a difficult task for faculty. Faculty require students to gather evidence of their learning and to participate in oral examinations, in addition to using other methods of assessments such as practical examinations, concept maps, peer assessment, self-assessment, facilitators/tutor assessment, and written reports.

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