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Lizabeth Schlemer has been teaching at Cal Poly, SLO for 18 years. She is a graduate of Cal Poly herself, and she holds a Masters in Industrial and Systems Engineering and an MBA from University of Southern California, and a PhD in Educational Research from University of California, Santa Barbara. She has 10 years of work experience at Unocal Corporation where she held positions of increasing responsibility. Most of her current research activities center around engineering education and enhancing engagement through valid contexts like project based learning and community service. She teaches a wide range of subjects from Engineering Economy to Facilities Planning and Design. She has developed good relationships with local industry and provides her students with opportunities to participate in real projects for real clients.
Design projects with out-of town companies

Abstract

The capstone design class in the industrial engineering department at California Polytechnic State University, San Luis Obispo (Cal Poly) includes projects with companies. The projects are large ambiguous facilities design problems that allow students to incorporate many aspects of the IE curriculum. For the past 15 years students have been participating in these projects with local companies. Over the past several years, companies from out of town (200 miles to the north in Mountain View or 200 miles to the south in Oxnard) have participated. These out of town companies have presented certain logistical issues, but they have proven to be quite beneficial to the students, the program, and the companies. This paper will discuss lessons learned and illustrate through student assessment the benefits of these activities.

Introduction

One of the comments we hear from companies who hire our Industrial Engineering (IE) and Manufacturing Engineering (MfgE) students is that they “hit the ground running.” Employers report that the students are familiar with projects and problems outside the well-defined textbook type. They are familiar with the complexity of dealing with various stakeholders and conflicting motivations. They understand the need for excellent communication skills and solid technical expertise. It is not only the practical nature of the education here at Cal Poly but that the students gain experiences working with real companies on real projects. Over 80% of our students gain some of these skills through the typical internship or co-op where they spends three to six months doing paid work at a company location. We find when student return to school, they are more engaged and motivated to learn. In addition, every one of our students works on projects with companies in their classes1,2. As early as the freshman year students apply work measurement techniques and continuous improvement principles on a small-scale project with local companies. Sometime an entire class, like the project management course, will compete to develop a solution to a company-supplied project. Some senior project students work with companies on complex problems that the company never has time to address. And finally the capstone design class in IE has every students work in small team (4 to 5 students) on a unique project for a real client. There are approximately 80 students who take this capstone design course each year. That means there is a demand for between 16 and 20 projects each year. This project-based course has been taught in this way since 1995. That means our students have worked on over 200 projects. Although many companies are pleased with the project experience and participate in multiple projects, it is often a challenge to get these projects lined up, especially in a small community like San Luis Obispo. Starting in 2006, we experimented with doing these projects with companies out of the area. These have proven successful for the students and the companies.

The advantages of Project Based Learning (PBL) for students learning are many3. Students learn to work on teams, they are able to see the culmination of a larger problem than they could have done alone, and they often achieve better design solutions. Several researchers at the University of Madrid4 found that PBL used in the design of electronic systems increased interest in electronics, increased academic performance, and produced better design solutions. In addition,
situational factors were found to influence the outcomes of PBL activities for junior engineering students\(^5\). These situational factors include the type of project selected, the learning of the individual student, and the ability of students to adapt to working under time pressure.

Learning that requires students to solve “real life” challenges are shown to improve the quality of the learning environment in both cognitive and emotional domains\(^6\). Recent review and recommendations include the practice of engineering in an authentic context\(^7\). If structured properly, authentic projects as a context for learning engineering potentially meets many of the human goals within the Ford and Nichols Taxonomy of Human Goals: Integrative social relationship goals, self-assertive social relationship goals, affective goals, cognitive goals, task goals, and subjective organizational goals \(^8\). The result can be synergistic improvements in motivation for learning \(^9\).

Engagement is often cited as an important component of learning in PBL. In the Civil and Chemical Engineering school at RMIT, researchers\(^10\) examined the factors that effect engagement in a PBL environment. They examined first year engineering students and identified factors that helped students engage in a project. The first factor is that students need “interesting work.” The second is that students must understand the structure of the problem with clearly defined expectations. Thirdly, students work best when they feel connected to other students in their groups.

Maleki\(^11,12\) addresses many aspects of using industry based projects in the capstone design course in Industrial Engineering. Many of the aspects of project selection and establishing learning outcomes are well developed in his work. All of the projects are with local businesses. Schilling and Klamma\(^13\) also discuss the process of projects done with industry in a computer science course. The difficulties and successes are discussed and summarized. They have developed several guidelines for their projects successes.

This paper will describe the course at Cal Poly and the use of out of town projects, descriptions of the specifics of several successful projects, the methods used to increase the probability of success, and an assessment of effectiveness from the student’s perspectives.

**The Course and Projects**

IE students at Cal Poly are required to take 196 quarter units to complete their degree in IE. One of the last courses student take is a facilities design and planning course. The course is four units taught over a 10 week quarter. Students meet for three hours a week in a lecture setting and three hours a week in a lab class. The lab portion is usually scheduled from noon to three o’clock. There are two main components of the course: the lecture where the students learn many topics pertaining to facilities design, and the project where students apply the facilities topics and many other subjects learned throughout their curriculum. The class time is split fairly evenly between the project and the lecture. With much of the lecture front loaded and the project back loaded. This works well as the students have a complete background on facilities planning during the first part of the course and can spend many hours on the project near the end. Students are graded on their performance on a final exam and on the project. Below (Table 1) are the learning objectives of the course. Of the 60 hours spent in the classroom, approximately 25 hours are
spent on lecture and in class learning. The remaining time is spent either visiting project locations, working on the projects, or meeting with the instructor in individual group meetings. The group meetings with the instructor usually occur once a week and lasts for about half an hour.

Table 1 – Learning objective for Facilities Planning and Design Course

- Apply the topics throughout the IE curriculum to a facilities project.
- Understand topics that fall under the umbrella of facilities.
- Work with a client in a professional manner preparing quality memos, reports and presentations.
- Leave the course proud of the work you’ve done.

As a capstone design course, several important ABET\textsuperscript{14} requirements are covered in the course. Table 2 listed the outcomes assessed.

Table 2 - Abet outcomes achieved though the capstone design course in Facilities Planning an Design

| (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 teams |
| (e) | an ability to identify, formulate, and solve engineering problems |
| (f) | an understanding of professional and ethical responsibility |
| (g) | an ability to communicate effectively |
| (k) | an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice |

The projects require that students learn all aspects of facilities\textsuperscript{15} and also draw on many topics from their curriculum. Facility design is ideal for this because almost everything that happens in a facilities takes up space. Everything has to be thought through. For instance, the inventory methods affect the floor space required for that inventory. If a factory can incorporate just-in-time principles the quantity and type of inventory on hand impacts the layout. In addition, if there is an inspection process, the method of the inspection determines the workstation design and the placement of the workstation in the facility. This makes facility design an ideal umbrella topic to cover most aspects of Industrial Engineering.

For more than fifteen years students have worked on projects for local companies. The students work in teams of four to seven students to produce an improved facilities design expressed in a report and a presentation. Clients are usually small manufacturing firms in the San Luis Obispo County. Typically these firms are so small that they would never have had the opportunity to see IE topics applied in a systematic manner by knowledgeable individuals. An overwhelming number of the clients have been pleased with the results. Table 3 is a partial list of companies and projects. Some of these companies have hired IE’s after realizing the contributions IE’s can make to a company’s efficiency. In addition, most companies have implemented at least some of the recommendations made by these students.
<table>
<thead>
<tr>
<th>Company</th>
<th>Location - CA</th>
<th>Company Type</th>
<th>Project Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>C&amp;D Aerospace</td>
<td>Santa Maria</td>
<td>Aerospace</td>
<td>Redesign of an assembly cell</td>
</tr>
<tr>
<td>Hardy Diagnostics</td>
<td>Santa Maria</td>
<td>Biomedical</td>
<td>Design layout for a new location</td>
</tr>
<tr>
<td>Dioptics</td>
<td>San Luis Obispo</td>
<td>Distribution</td>
<td>Design new warehouse</td>
</tr>
<tr>
<td>Road Home</td>
<td>San Luis Obispo</td>
<td>Non-Profit</td>
<td>Design a homeless shelter/campus</td>
</tr>
<tr>
<td>Left Coast T-Shirt</td>
<td>San Luis Obispo</td>
<td>Screen printing</td>
<td>Re-layout production floor to incorporate new machine</td>
</tr>
<tr>
<td>SLO Roasted Coffee</td>
<td>Los Osos</td>
<td>Food</td>
<td>Design new layout to incorporate new packaging process</td>
</tr>
<tr>
<td>UVS Thrift Store</td>
<td>San Luis Obispo</td>
<td>Non-profit</td>
<td>Re-layout and methods improvement</td>
</tr>
<tr>
<td>New Life Church</td>
<td>Arroyo Grande</td>
<td>Non-Profit</td>
<td>Design of new youth center</td>
</tr>
<tr>
<td>Jamba Juice</td>
<td>San Luis Obispo</td>
<td>Retail</td>
<td>Redesign of retail location</td>
</tr>
<tr>
<td>Wasco</td>
<td>Santa Maria</td>
<td>Electronics</td>
<td>Design of a new facility</td>
</tr>
<tr>
<td>Corbett Canyon Winery</td>
<td>San Luis Obispo</td>
<td>Winery</td>
<td>Re-layout of a bottling line</td>
</tr>
<tr>
<td>Fountains of Living Waters</td>
<td>Santa Maria</td>
<td>Wholesale</td>
<td>Layout of a new facility</td>
</tr>
</tbody>
</table>

Cal Poly is on a quarter system so the time is very short to accomplish these projects. Although many think that the quarter might be too short to accomplish these things, it is actually ideal for working with companies. Companies generally want quick results, which is sometimes difficult in an academic setting. Some of the other projects done in the college of engineering are constrained quite a bit with a start only in September and a finish in June. Most problems in companies need a quicker turn around. In the facilities class we can start a project in late January and deliver results in early March. Along the way student teams spend 400 to 500 hours on the project.

Although most projects are still done in the local community, over the last few years we have been working with companies all throughout California. Haas Automation in Oxnard, CA, has hosted eight project teams. Summit Steel Works in Mountain View, CA had a group working on a new facilities design. We worked on several projects with Diamond Foods in Stockton, California and MLM Logistics in Los Angeles. There are many advantages to working with these companies. For the students these opportunities are more like real work experience. Students love working with Haas Automation because when listed on their resume, potential employers see the project and the company as a solid real life experience. The companies really like to have these students as they can keep their company’s name in the mind of the students and they can even treat the project like an extended interview.
Case studies of successful projects

To get an idea of the types of project two successful projects are described below. The first is a redesign of a work cell at Haas Automation in Oxnard, and the second is a complete facilities design for Summit Steel Works in Mountain View, CA.

Haas Ball Screw Assembly Area Redesigns

One of our Industrial Advisory Board members is from Haas. Hass designs and manufactures CNC machines. It has an excellent reputation and the quality of their products is unparalleled. He indicated that his company often has projects that are on the “back-burner” and these might be ideal for our students to address. We began these projects in 2009, and since then have completed 8 projects with 2 additional executing this quarter. This particular project had five students work on improving the efficiency in 1200 square foot work cell. The work cell assembles ball screws used in many of the company’s most common machines. Issues that needed to be addressed included material handling of the awkwardly shaped ball screw along with consideration of the precision nature of the part. The inventory control issues within the work cell and the ergonomics of the workers were all issues addressed in the design. The students develop three alternative designs. The cost and sophistication of the material handling equipment separated the three alternatives. Students had to research and cost out all the equipment and present benefit cost analysis with the indicated recommended layout. Figure 1 shows a three-dimensional scale model that the groups presented to the company. Students spent 450 documented hours on this project.

Summit Steel

Summit Steel is a small metal manufacturing company located in Mountain View California. The owner is an alumni of Cal Poly. The company generally does prototypes or small batch job shop activities for local businesses in the areas. Recently they had the opportunity to examine manufacturing modular homes used in disaster recovery. The company wanted to investigate the possibility of developing a new facility to
manufacture the aluminum structures. A student team of six was tasked with developing a complete manufacturing plan including machinery, material handling equipment, process description, inventory control procedures, quality control recommendations, ergonomic considerations, and economics. This project was a complete look at a start up facility. They started with drawings of the parts (which changed daily) and a facility, and delivered the first iteration of the production layout. Figure 2 shows the layout as developed. Students presented these results along with a simulation of the manufacturing process. Students spent 680 documented hours on this project.

**Structure for success**

Over the years we have developed some important aspects of the project execution. These have become even more important as we expand to companies out of the area. Below are several important areas of attention necessary in order to increase the probability of successful projects.

**Visit prior to initiation of the project**

A visit to the company prior to the initiation of the project is essential for the instructor and the company. For the instructor, the visit will give a context to help students with project definition and execution. The key people involved at the company will also see the dedication that the instructor has to the course and project. The company personnel can ask questions and investigate any issues that might come up.

**Fully Disclose Client’s obligations**

It is important to set expectation for the client companies. It might have been a long time since the company has dealt with students. Clients need to know that there actually are “stupid questions” and the students will probably ask them. It is important to prepare the companies for what might be an overwhelming nature of the student’s uninformed questions and requests. Part of what the students are learning is that the case studies or problems in the book are not real. That when companies deal with problems, they often must collect data themselves or they have to make decisions in the absence of any enough information. The time commitment from the company’s point of view needs to be clearly defined. If students are going to come up with a good solution within the 8 weeks they will need the company’s cooperation. The company has to allow students access to employees, documents and visits. The companies are also told they must participate in two presentations, one half way through and one for the final results. For out of town companies, the interim presentation is done via an online collaboration software. We have used Elluminate® several times with success.

Companies are also asked to reimburse students for travel to and from the company site and for supplies necessary for the production of a report and a 3D model. (Figure 3). Usually $500 will cover all these expenses.

Lastly, the instructor should balance the warnings about student’s stupid questions
and the time requirements with a display of the past reports. Many of these reports are in excess of 100 pages with complete analysis of flow and space, and cost justified. The students really do quite an amazing job and this should be communicated to the clients. The companies are actually getting quite a valuable service.

**Initial tour of the facility**
Student groups go on a tour of the facility during the second week of class. There are up to eight projects in any one quarter with as many locations. Because of this the instructor cannot attend every tour so the students are briefed on how to handle themselves and required to do research ahead of time on the company and the products. The initial project definitions are usually very short and leave room for the students to develop their own project charter after the initial visit. This gives them the chance to incorporate project management into the course. The tours are usually done during the lab portion of the class. For out of town companies this requires a bit of coordination as the students may have to miss an entire day of class. This is usually not a problem at the beginning of the quarter.

**Interim presentations**
Approximately half way between the initiation of the project in week two and the final presentation in week ten, the students give an interim presentation to the client company. When the company is out of the area this presentation is done via conference call or collaboration software. We have used Elluminate® for this in the past. The presentation usually covers three main issues. First, the students should reiterate the project definition and deliverables. This insures all stakeholders agree on expectations. Secondly the students discuss any analysis they have done or display data they have collected. Before this presentation student groups have typically made several visits to the company to collect data. And lastly the students leave time for questions or data they are still in need of. One of the surprising things for students working with companies is the difficulty in getting the data they desire. This is also one of the advantages to working with real problems. Both communicating data needs and collecting data themselves is an important skill.

**Empowering Teams**
Using some of Daniel Pink’s motivational techniques, we stress the meaning of the work these students are undertaking. It is communicated to them that it is not just a project, but also a representation of Cal Poly, the IME department, and the reputation of the instructor. They know that they will be letting down many if they do not perform excellently on these projects.

Discussion about the about the projects and the client during weekly meeting with the groups is encouraged. We talk about team functioning and content analysis. Sometimes conflict resolution is also addressed.

![Figure 4 - Student team at final presentation](image)
Some time is spent discussing the process and normalizing difficulties. Each team is handled differently depending on their personality and needs. Sometime the team is prodded to work harder, other times the team is encouraged that they are on the correct path. The goal is to hold high expectations while empowering the students to achieve excellent results.

Recoding Time Spent
Each individual is required to track the time they spend on the projects and report this each week. By the end of the project, individual time commitments average 80 hours with between 400 and 500 hours per team. This practice has helped establish the required commitment and shows teams and members when they are not conforming to the requirements in an objective fashion.

Final results
Deliverables always include a final presentation that usually takes an hour with time for questions, a comprehensive report, and a 3D Physical model of the recommended layout. Sometimes students and clients alike discount the value of the physical model before the presentation, but without fail the model is a highlight of the presentations.

Another technique used to increase the probability of success is that the students must give a practice presentation to the instructor several days before the final presentations. During this presentation the students are critiqued on slide format, presentation delivery, content clarity, and organization. These practice presentations usually last at least two hours and often results in the students having to completely re-do some of their work. Even though this is sometimes disappointing for the students, without fail students feel the practice presentation was often the most beneficial part of the project. These kinds of direct feedback on their communication skills are hard to come by in a class setting.

Assessment
Students who have participated in projects with out of town companies were queried as to the benefits. Fifteen students responded to the survey and every one felt that the experience was beneficial and were glad to have worked on these projects.

When asked why they decided to volunteer for these projects instead of working on a project in town, students expressed interest in working for a well known company and that they thought it would help their resume. The surprising thing was that most of the students expressed an interest in the project because of the challenge it offered.

Not surprising, the most difficult part of the project was the distance. Several students didn’t mind the distance because the projects were close to their home. Some of the difficulties reported occur in any project like data availability and communication with the client.

Table 4 below are some comments from the survey from the students. Also included is a word cloud (Figure 5) of the open-ended comments form the survey. Some times these word clouds (www.wordle.net) give insight into the salient features. In this case the word “experience” is prominent indicating the desired value was achieved.
Table 4 – Comments from Students

<table>
<thead>
<tr>
<th>Comment</th>
</tr>
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<tbody>
<tr>
<td>Haas is a great company to work with on projects. They understand what Cal poly IE’s can do and are very willing to share information. Willingness to share information is probably the key for out of the area companies.</td>
</tr>
<tr>
<td>Very valuable experience</td>
</tr>
<tr>
<td>I was happy with the result, and I found that it helped my development of IME concepts through real life application of what we learned in the classroom.</td>
</tr>
<tr>
<td>Working with Haas (and other companies) through IME courses help tie in course material with hands-on experience. It is definitely a great preparation for internships and positions in the real world.</td>
</tr>
<tr>
<td>Provided excellent experience to understand the complexities of small businesses and real-world work environment.</td>
</tr>
<tr>
<td>The experience gained on this project has been main topics in interviews and helped me get a summer internship.</td>
</tr>
</tbody>
</table>

Conclusions

The benefits of project based learning are well documented. Many schools are located at a distance from major industries and therefore do not have as many opportunities for real projects for real clients. This paper describes a process used at Cal Poly, San Luis Obispo to provide students with real life projects with companies several hours away from the university. The benefits are clear and the obstacles are surmountable.
References


2. Schlemer, Lizbeth and Mimnaugh, Faith, “Using Sports Coaching Techniques to Enhance Project Based Learning Instruction,” ASEE Zone IV meeting in Reno, NV, March 2010


