

Integrating Graduate and Undergraduate Education with Real World Projects

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Abstract - This paper discusses three case studies where graduate students worked alongside undergraduate students on projects suggested by local companies. In the first case, graduate students were assigned to work in teams with undergraduate students, and later continued the project to fulfill both company expectations and publication of a conference paper. In the second case, a graduate student who had previously completed a course continued working with the instructor on a thesis with an industry case study. The master's student proposed the involvement of a new student team the next time the course was offered, and the team worked in a separate, but related area of the company. In the third case, a senior graduate student became the teaching assistant instructor for an undergraduate level course. A company project was used to fulfill graduate student independent study credits, as well as a team project for the undergraduate course. The educational advantages and benefits of these models for undergraduate students, graduate students, and faculty advisors will be discussed in this paper.

Index Terms - project-based course, graduate education, mentor, undergraduate teams.

INTRODUCTION

The practical application of academic lessons in undergraduate and graduate engineering education can be critical to a student's comprehension and retention of course material. Real world projects offer unique opportunities for the application of knowledge and theory obtained in the classroom by engineering students. These projects benefit the students and industry sponsors involved to create a corporate-academic relationship. These relationships are vital for universities to develop partnerships for future collaborative efforts and to promote the importance of engineering education.

Opportunities to develop realistic projects with local companies can be cultivated with persistence and communication. Often, projects evolve from formal coursework which fosters an interest to solve a local company's problems. In other cases, company problems stimulate an interest into academic research in search for a solution. We present three case studies of successful student group projects that developed through instructor-student-company interaction. Each case evolved from different stimuli to create excellent models for the future integration

of graduate and undergraduate education with real world projects.

There have been several instances in the engineering education literature where faculty have teamed graduates and undergraduates to work on engineering and design research projects. Some of the teaming methods include teaming one graduate student with another undergraduate student, for the purpose of mentoring the undergraduate and promoting graduate studies [1]. Another innovative instance includes the use of "Vertically-Integrated Projects" (VIP's) that combine research and development activities for undergraduate students that join VIP teams consisting of graduate students and faculty [2]. This idea is based upon the concept of the engineering student possibly contributing to a research project over several semesters and getting the opportunity to contribute significantly to research. Our methods presented in the following case studies differ based upon the formation of the research teams, and in the last case, demonstrate how a graduate teaching assistant can direct students in an engineering course to perform complementary research on her own graduate research project, and build her own skills of directing research and design.

Many universities have implemented senior capstone design courses that are based on industry or real-world inspired projects, particularly since the adoption of ABET 2000 criteria. Rose-Hulman University has taken this one step further by replacing the M.S. thesis requirement with a structured design course that teaches both graduate and undergraduate students "how to design" [3] and also integrates a service-learning component to fulfill community needs [4]. Middleton and Branch [5] discuss the problem of having undergraduates on capstone design teams who have problems with project management and team dynamics. To address this problem, a graduate seminar course in Project Management was developed at the Colorado School of Mines where a graduate student leads one of the undergraduate senior design teams and fills the role of engineering manager.

Prince, Felder, and Brent [6] examined the ongoing debate of whether faculty research can be used to improve undergraduate education. Proponents argue that there are synergies that exist between research and teaching, and that there are benefits to the undergraduates who are involved with programs such as National Science Foundation sponsored Research Experience for Undergraduates projects. Some of these benefits include increased retention, improved

recruitment for graduate programs, cognitive gains for students who participate, and increased satisfaction. Shortfalls may include that only some undergraduates are able to participate, and that some opponents argue the realities of synergies between research and teaching and the subsequent gains for participants.

This concept can be extended to encompass whether graduate student research projects can also be used to improve undergraduate education. Alternatively, the question could be asked of whether undergraduate education can be used to enhance graduate education. For example, Phillips and Murphy [7] discuss the fact that most engineering graduate students do not receive any formal training in topics that will prepare them for academic positions. Most new faculty members have not been trained in the art or science of teaching, including the psychology of learning. They describe a team teaching approach that pairs a graduate student with a faculty mentor to deliver courses at the University of Michigan. Another initiative at the University of Michigan has been a course specifically designed for graduate students preparing for academic careers, entitled "Teaching Engineering" as well as seminar programs offered through the University of Michigan Center for Research on Learning and Teaching.

CASE STUDY 1

Evans Findings Company is a manufacturing facility for high speed stamping and deep drawn metals parts located in East Providence, RI. The University of Rhode Island (URI) Department of Industrial and Manufacturing Engineering and Evans have developed a unique partnership over the last several years by providing students an opportunity to apply the mathematical analysis they learn in class to practical applications. During recent concurrent courses in **Industrial Engineering Design II** and **Manufacturing Systems: Analysis, Design and Simulation**, undergraduate and graduate students teamed up on different projects to help local companies solve problems related to the course material. One group was selected to work with Evans Findings to analyze and propose a solution to a problem they were having with scheduling their production lines. Assignment of group members to projects was based primarily on student interest and having an equal ratio of undergraduate-to-graduate students on each project. Additional factors considered included the student's academic major, student capabilities based on past performance and the lack of outside class schedule conflicts between group members. In the case of the Evans' project, two graduate students were teamed up with two undergraduate students; all from the Department of Industrial and Manufacturing Engineering.

I. Problem Background

Evans is primarily a make-to-order (MTO) operation but have a few customers that place make-to-stock (MTS) orders. The contract terms of their major MTS customers require them to maintain an on-hand inventory of

approximately one-quarter of the estimated annual usage (EAU) to satisfy orders without inventory exposure. Evans has experienced difficulty in the past using commercial material requirements planning (MRP) tools to manage their production processes for MTS orders. These programs provided some benefits but were too generic for their specific manufacturing environment. In addition, it proved to be difficult to extract relevant information from the myriad of available output data. Despite their committed investment, Evans found the burden of maintaining an MRP system was not cost effective for a moderately small business like theirs. Evans' president and chief engineer asked the URI students help them model their manufacturing systems in a customized software application such as a database or spreadsheet.

II. Model

The purpose of developing a model design of the manufacturing processes was to provide a description of the expected work in process (WIP) inventory levels at selected monitoring points, such as the beginning and completion of assigned workstations. The expected WIP inventory levels were then adjusted by date to determine the required inventory levels that would prevent exceeding the scheduled delivery dates.

In conjunction with the model design, the software application was designed to ensure that the customer requirements were on track to be satisfied. A traditional method of systems design was used for the software application to include identifying the need, converting needs requirements to system requirements, designing the database/spreadsheet and user interface, and building, testing and implementing the software application.

One of the early steps in the design development activity was to create a vision of how the software application would interact with the manufacturing system model. Since the president had specific wants based on his vision of the output display, it was the student team's job to interpret his vision into system requirements, develop the engineering design solution using modeling and analysis tools and package the solution into a feasible simple-to-use software application. A physical black-box architectural framework capable of performing the functional requirements was developed to identify the required inputs, outputs and processes that needed to take place.

III. Results

The group project at Evans was instrumental in solidifying many of the concepts taught in class. The students gained valuable exposure to real manufacturing operations and realized the value and difficulty of measuring WIP inventory levels throughout a facility. Evans primary objective of creating a manufacturing model of their facility was completed. One of the graduate students in the group went on to develop a spreadsheet application around the model as part of an independent study course during the following summer, further fulfilling the needs of the company and

bringing the project to completion. In-house engineers and a regular consultant were then prepared to further adapt and implement the software model. The resulting paper was subsequently accepted at the Industrial Engineering Research Conference (IERC 2008), sponsored by the Institute of Industrial Engineers [8].

CASE STUDY 2

A graduate student from the College of Pharmacy enrolled in statistics and manufacturing courses from the Industrial and Manufacturing Engineering Department to fulfill a portion of his Ph.D. coursework requirements. The student had already completed his Doctor of Pharmacy and M.S. degree in Biomedical and Pharmaceutical Sciences at the university, and was continuing for a Ph.D. in the same field. He decided to complement his knowledge of pharmaceutical coursework with classes related to manufacturing and performance improvement, and ultimately decided to pursue a second M.S. degree in Manufacturing Systems. With the help of a faculty advisor from the College of Pharmacy, XYZ Pharma was identified as a case study location for his thesis research in the Industrial and Manufacturing Engineering Department, provided that a pseudonym was used to protect their anonymity in a highly competitive industry.

XYZ Pharma primarily serves as an over-the-counter contract manufacturer, producing over 100 human and veterinary products. The company is comprised of a 25,000 sq. ft. production facility and a 75,000 sq. ft. detached warehouse building. The facility has the capacity to produce oral products such as liquids and suspensions, and topical products including gels, creams, liquids, adhesives and more.

While completing his Master's thesis research work, the graduate student realized that XYZ Pharma could benefit from the involvement of more students. He had previously completed a **Lean Systems** course where graduate students and undergraduate students who are fulfilling professional elective requirements are able to propose projects that relate to local companies, part-time employment, or even extracurricular interest areas. The master's student proposed the involvement of a new graduate student team the next time the course was offered, and the team worked in a separate, but related area of the company.

I. Problem Background

At the start of the graduate student's research for industrial engineering, the XYZ Pharma management estimated that they were slightly behind schedule with meeting customer deadlines, but felt that they were one of the more reliable and capable contract manufacturers in their market area. Unlike many other manufacturers with dedicated manufacturing equipment and personnel, XYZ Pharma is a self described pharmaceutical "job-shop". At any given point they are manufacturing between five and seven different products simultaneously throughout the production facility in various formulation, filling and packaging areas.

Due to the high volume of products being manufactured and the need to meet deadlines, the overall maintenance of the facility is lacking. While there is an employee dedicated to cleaning and waste removal, large amounts of cardboard boxes can be found throughout the facility. Additionally, empty chemical containers and drums can be found in large numbers, 60-90 at any given time, waiting for recycling and obstructing loading dock access. The drums were often stacked three high, exceeding heights of 12 feet, which could be a safety hazard. Material handlers must frequently move raw materials and finished goods multiple times to access blocked pallets.

Another area contributing to the inefficient movement of materials to and from the facility was the ineffective usage of the company's delivery truck. The truck was primarily used to make "milk runs" between the warehouse and the manufacturing facility, to supply raw ingredients and remove finished goods for shipping. The "milk run" truck is not always full and occasionally leaves the production facility empty, even if the production building warehouse is congested. Excess raw ingredients and components often remain in the production warehouse area multiple days after their use.

II. Model

The graduate student developed a model that integrated lean manufacturing techniques, discrete event simulation, and design of experiments to help identify possible performance improvement opportunities for XYZ Pharma. One particular manufacturing process for a topical gel was modeled and simulated. This approach was developed into the graduate student's thesis and several subsequent publications.

In the Lean Systems course, the annual team project in this course is to apply lean manufacturing principles to a non-manufacturing environment. Although XYZ Pharma is a manufacturing facility, they are not a traditional manufacturer, given that they are making FDA-regulated products in a batch environment on a contract basis. The graduate student discussed with the professor the suitability of having a Lean Systems team work at the facility concurrently to help the company deal with their disorganized warehousing activities. A team of three students was assembled and began to look at warehouse bottlenecks, value stream maps of the current and potential future states, kanban, facility culture, 5S activities, standardized work, and visual factory techniques.

III. Results

The graduate lean team proposed a number of possible solutions to the company's material handling and flow problems. Warehouse implementation of 5S to facilitate the removal of empty cardboard and barrels would yield immediate benefits and promote process improvement.

After the warehouse is cleaned and processes are preliminarily redefined, visual factory techniques will simplify worker's roles and identify problems earlier. Further, cross-training will give employees an understanding

of the system and how their actions impact others. Finally, a Kanban approach will drive the flow of raw materials and packaging components to the specific machine and remove empty cardboard and barrels to appropriate disposal. These lean techniques would drastically reduce inventories and create more free space. This would also result in a safer environment, with improved “cleanability” and access for operators.

The suggestions by the team were utilized as supporting information to the thesis and publications of the first graduate student working with the company [9]. The proposed improvements were presented to the company’s senior management, where they were positively received and will be considered for future improvements.

CASE STUDY 3

Electric Boat is a large defense contracting company with several local facilities which has developed long-term relationships with many departments at the University of Rhode Island. Regular collaborations between the company and the university include sponsorship of senior design projects, involvement with faculty research projects, internship hiring, and visits to the local industrial facilities by students and faculty alike.

In this third case study, faculty assigned a senior graduate student teaching assistant to be the primary instructor for a very small section of an undergraduate level stochastic methods operations research (OR) course, with support from faculty members who had taught the course in the past. The student was also interested in using independent study credits to fulfill part of the doctoral degree requirements. An industry-based problem from Electric Boat provided the means to accomplish both undergraduate and graduate level educational goals simultaneously.

The primary goals for the graduate student included: (1) gaining experience applying both simulation and queuing theory methods to a real-world system design problem and comparing results, (2) testing the capability of a traditional manufacturing system stimulation package (ProModel) to model complicated transportation and distribution networks, (3) gaining experience directing undergraduate students in an industry-sponsored project.

The undergraduate goals for this project included not only learning to work in systems design teams and to work with engineers at a local company, but also to learn typical system design techniques and methodologies and practice these concepts on a real-world project. The project also emphasized engineering problem-solving techniques, like understanding scope, objectives, and model assumptions when considering different approaches to the same problem using two different methods.

I. Problem Background

Recent contact with this local company had revealed their desire to obtain the industrial engineering department’s help in redesigning dirt parking lots and traffic patterns within

and between lots, thereby providing a safer and more efficient transportation environment for their employees and other local businesses. Initially, the graduate student and faculty advisor met with the company together and reviewed their parking system problem. Observations and preliminary data collection indicated that many employees blatantly ignored traffic controls, traffic flows, and even curbs while rushing to exit the dirt lot at the end of each shift. The company was concerned for the safety of the drivers and pedestrians, and wanted recommendations for improved traffic flows when they ultimately paved this lot.

The student proposed the following course of action to the faculty advisor. Prior to the beginning of the semester, the graduate student conducted a literature review of research related to parking system design. The graduate student wrote a 12-page literature review and prepared a synopsis of parking design procedures, relevant to the specific employee parking system design problem. The design manual covered such topics as employee parking lot design [10], the use of stochastic methods to design a parking lot [11], and how to compare parking lot designs [12]. Once the semester began, the graduate student presented the design synopsis/guide to undergraduate students in the OR course in an easy-to-follow slide presentation. The design guide included information on demand planning and estimation, capacity planning, design efficiency, flow design, environmental impacts and safety, which are all critical components to understanding stochastic system design for any type of problem. This parking problem thus was very representative of typical system design problems. In addition, the design guide also presented specific feature designs components, relevant to parking systems including module, lighting, security, signage, snow-removal, and drainage space considerations. The undergraduate students read the design material as an assignment and took an in-class quiz on the material. The undergraduate students began to use the information contained in the design guide to help them design and test a parking system for the employer. This involved visiting the company, collecting data on current parking lot usage, analyzing the usage data statistically, and developing a computer simulation model to test the students’ parking lot designs.

II. Model

The undergraduate students in the class worked together to collect arrival and departure data for current traffic patterns and estimated logical arrival and departure distributions for each parking lot based upon future demand estimates given by the employer. The students used MS Excel to analyze and present graphical data, which builds on the statistical analysis theory and practice previously obtained in their Probability and Statistics for Engineers courses. The students used the design guide to build a parking lot layout in AutoCAD, which students had previously learned to use in a junior-level Computer Tools for Engineers course. The students then developed and built a simulation model that

would test their proposed parking system design layouts. The students were able to import their AutoCAD drawing into ProModel™ simulation software, add arrival distributions, designate parking locations, and build path networks for automobiles to move upon, based upon the imported AutoCAD layout. Their proposed new design represented best practices for parking lot design and also adhered to the industrial park regulations where the facility is located. Their parking layout was also modular in nature, which facilitated easy replication of parking spot dimensions with standard sized aisles and islands.

Although the undergraduate students incorporated location building, arrivals, and path networks in their model by the end of the semester, several key features were missing from the model. There were some logic problems that related to how the cars would enter and leave certain aisles in the new parking lot, the model did not incorporate two-way traffic, and did not incorporate more difficult logic that would represent capacitated flows and conflict resolution between automobile traffic. For example, when a car pulls out of a space and into a lane of traffic, there must be a standard amount of space, given on-coming vehicle speeds, for the vehicle to exit the parking space and enter traffic flows that are leaving the parking lot. This all affects the capacity of lanes and the time to empty the parking lot at the end of shifts. Given that building a simulation model with advanced features was not a requirement of this basic stochastic operations research course, however, the students had done a good job on the project, given their project scope.

III. Results

To correct some of the inconsistencies and incomplete features of the simulation model, the graduate student continued to work on the project after the undergraduates had completed the course. The graduate student presented the revised simulation model to the company, and it was well-received. The company planned to use some of the recommendations of the team in their future paving of this dirt parking lot, as soon as capital expenditure funds became available, and demand required it. Time had to be set aside in several classes to discuss the project and approaches. So a trade-off must be made and managed between gaining experience designing a real stochastic system, and the depth of conceptual knowledge gained through lecture time in class. The project did not include civil engineering students, which could have expanded the scope of work into topics such as drainage design, pavement design, pavement markings, or other traffic controls

ADVANTAGES

These models all offer significant educational advantages to the undergraduate students, graduate students, and faculty advisors. For the graduate students, their course projects become learning opportunities that also help them make progress toward degree completion. Often, the class projects are able to be integrated into their theses or dissertations, or turned into conference papers following the completion of

the course. This helps the graduate students to understand the process of writing and publishing academic articles prior to the completion of their own primary research work, and builds their resumes for their eventual job search process. They take on supervisory roles to the undergraduate students which helps them prepare for eventual roles as faculty advisors.

For the undergraduate students, they are able to work on real-world problems with industry. In Case Study 3, at least, engaging in a team project with a company is not generally a component of the class, which has previously been more traditionally taught with textbook readings, lectures, homework assignments, and exams. From a logistical point of view, undergraduates are able to share rides to company facilities, divide up project tasks, when appropriate, and seek the guidance of a more senior graduate student who becomes an unofficial or official team leader. The undergraduates are also able to develop relationships with graduate students and come to understand the process of obtaining advanced degrees. They are exposed to the research that the graduate students are completing and may begin to consider graduate school in their own future. Both undergraduates and graduate students who are working on the company project for the purposes of the class requirements are able to see the more intensive level of research being conducted by the primary graduate student.

For the faculty advisor, there are many practical advantages. After initial contacts are developed, the graduate student project leader can serve as a daily point of contact for the local company during the course of the project. This eases time commitments for the faculty advisor. The graduate students often own cars and can provide rides to undergraduates who live on campus and might not otherwise be able to become involved with projects at local companies. The faculty member can schedule one common meeting time with all students involved, which can include both an update on research progress, practical updates on the progress at the local company, and addressing any problems being encountered by either the undergraduate or graduate level students. Much of the information that faculty advisors need to pass on to students regarding report writing, finding and properly citing references, maintaining company relationships, or engineering content for the project is best presented when all students are together.

CONCLUSIONS

These three case studies have revealed many of the educational advantages of integrating graduate and undergraduate education through the use of projects inspired by local companies. The undergraduate students are able to work on real-world problems with industry, which exposes them to future job opportunities in their engineering fields. They are also able to develop relationships with graduate students and come to understand the process of obtaining advanced degrees. They are exposed to the research process and may consider graduate school for their own future. For the graduate students, their course projects help them make

progress toward degree completion while gaining experience as a mentor or instructor for the undergraduates. The projects may be integrated into their theses, or turned into conference papers later. For the faculty advisor, there are many practical advantages such as reduction of off-campus time commitments at the local company and easy coordination of company visits and research team meetings. There is also the personal satisfaction of simultaneously coordinating teams of students at different levels of their educational journey.

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