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College-Industry Design Project Case Study: Process Heater Simulator

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Abstract

John Zink Hamworthy Combustion sponsored a senior design project at Oral Roberts University to improve a process heater simulator. The simulator is used in instructional demonstrations in John Zink Institute process burner courses. This was a unique partnership because the industry advisor was an adjunct instructor at the university and one of the university team members was an intern at the company before and during the project, working for the industry advisor. The industry advisor also taught all three senior design team members in two different mechanical engineering courses in their junior year. This capstone project involved redesigning a simulator which was originally a senior design project at two other institutions. The improved design corrected some of the original design issues and added many new features. The very close collaboration between the industry advisor and the university intern made this a particularly successful and award-winning project. However, despite the intimate working relationship, some of the project goals were not accomplished, in part because of increased scope. The paper discusses the three different versions of the capstone project at three different universities, the benefits of this arrangement, and the lessons learned from this effective partnership in comparison to more traditional industry-sponsored senior design projects.

Introduction

Industry and academia can collaborate to educate engineering students through capstone projects.[1,2] Some universities choose to partner with industry professionals to help teach senior design courses as part of the capstone projects.[3] These professionals are sometimes referred to as "Professors of Practice."[4] Many companies sponsor senior design projects to produce a product of interest while simultaneously educating students by allowing them to apply their knowledge and skills to an actual problem.[5]

Industry-sponsored senior design projects offer many potential benefits to universities, students, and the sponsors. Universities benefit from corporate sponsorship,[6] especially for prototypes, which are often expensive.[7] This added financial support often allows the projects to be larger in scope, which would otherwise be very difficult on a university budget. Students benefit from interactions with practicing engineers[8] and typically work on more practical and meaningful projects,[9] which are often multidisciplinary.[10] Industry-driven projects tend to have more realistic constraints and pressures relevant to future employment as an engineer, compared to student-driven or professor-driven projects.[11] Students also obtain potential employment opportunities for permanent jobs with the sponsor,[12] while some students decide they don't want to work with the sponsor after graduation based on their interactions with and knowledge of the company.[13] Students also receive experience that industry values by working on industry-sponsored senior design projects.[14] In some cases, students co-op or intern with an industry sponsor while working on their senior design project,[15] which was the case for the project described here. Some projects may be patentable[16] which benefits both the students and the industry sponsor. Students may have a chance to interact with industry standards and regulations[17] and sometimes even with the legal system and the local community.[18] Industry sponsors also benefit from involvement in these projects. They receive valuable work they may not have the time to do otherwise. They are also able to see how the students work on a real project, which is a type of extended interview, and may consider them for potential employment.

These benefits are best achieved through the right types of projects. Todd et al. (1993) provided some useful criteria for selecting industry-sponsored projects:[19]

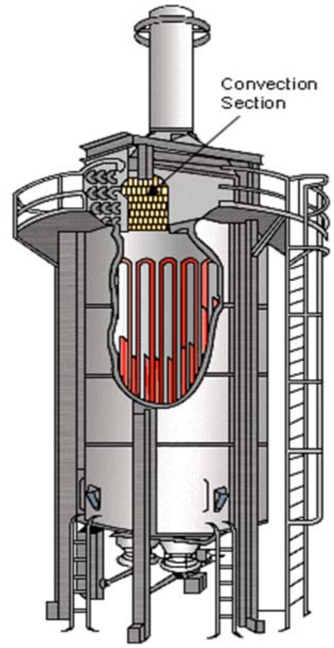
1. Should solve a specific need for the company.
2. Company should dedicate adequate financial and time resources to the project.
3. Project should not be of immediate need so there will not be unnecessary additional pressure on the students.
4. Projects should include both design and manufacturing.
5. Projects should not be classified or proprietary.
6. Projects should have an appropriate scope (neither too long nor too short).
7. Company should have product development experience so expectations are realistic.

The John Zink Institute (JZI) is the training organization for the John Zink Company, LLC (JZC) headquartered in Tulsa, Oklahoma. JZC makes industrial combustion equipment primarily for the hydrocarbon, petrochemical, and power generation industries. JZI provides continuing engineering education for engineers and operators using JZC equipment. JZI offers courses in Tulsa at the JZC headquarters,[20] at the client's site,[21,22] and online.[23]

Oral Roberts University (ORU) is a private Christian institution founded in 1963 in Tulsa, Oklahoma. It is primarily an undergraduate institution with approximately 3,200 students that offers an ABET-accredited B.S. degree in Engineering with emphases in Electrical, Mechanical, and Computer Engineering. ORU is approximately a 25 minute drive from JZC.

Process heaters are used in refineries and chemical plants to heat fluids, typically hydrocarbons.[24] There are many different kinds of process heaters.[25] Two of the most common are vertical cylindrical and cabin heaters. Vertical cylindrical (VC) heaters are of specific interest here (see Figure 1). They have vertical process tubes lining the walls and burners arranged in a circle on the floor firing vertically upwards. JZC makes process burners that are used in these process heaters. Both are discussed in some detail in the JZI process burner courses. Because of their importance in the operation of plants, some tools are available to help JZI students learn the fundamental principles of process heater operation, maintenance, and troubleshooting. Students attending courses in Tulsa get to see working pilot-scale process heaters in JZC's world class Research and Development Test Center.[26] An electronic process heater simulator has also been developed specifically for training purposes.[27] This tool is available to all JZI alumni and can be used over the Internet. This allows students to electronically tune a process heater without fear of causing an incident or impairing production, which would be concerns for inexperienced students attempting to tune an actual operating heater. In order to provide an additional learning tool, a small-scale physical process heater simulator was envisioned.

(a)



(b)

Figure 1. Vertical cylindrical process heater: (a) photograph and (b) drawing.

The capstone project discussed here involved designing and building a small-scale vertical cylindrical process heater simulator for demonstration purposes in the JZI process burner classes. This is a miniature version of the large scale vertical cylindrical process heaters used in many industrial applications such as oil refining. The demonstration may include, but is not limited to, the effects of burners being too close together, flame impingement on the process tubes, the effect of forced draft vs. induced draft, pollution emissions from different levels of premix air for combustion, the effects of different types of fuel, and several different flue gas flow control effects.

The process heater simulator described here is actually a third generation design. The first generation was completed by one mechanical engineering student at a university approximately a 1.25 hour drive from the company in the school year 2006-2007. While the finished prototype was functional (see Figure 2), it was not adequate for use as a classroom demonstrator. That version was constructed with a single burner and a helical coil, neither of which were representative of typical VC heaters in industry. Both subsequent versions had 3 burners and a vertical coil, which more accurately represents VC operations. The main purpose of the first generation project was to see if the original concept of a small-scale physical process heater simulator was feasible. That project met one of the important criteria as specified by Todd et al. that the project was not vital because the pilot-scale test heaters were available for demonstrations, although the electronic simulator had not yet been completed.

Figure 2. First generation process heater simulator.

Figure 3. Second generation process heater simulator.

The second generation of the process heater simulator was completed by a team of four mechanical engineering students at another university in the school year 2009-2010. The purpose of that project was to use the lessons learned from the first generation project to make a demonstrator suitable for the classroom with more features and a design that more closely resembles actual VC heaters. Since this was a much larger team, it was believed this goal was attainable. Three burners in a circle and a vertical coil were chosen for the design (see Figure 3). The second university is approximately a 2 hour drive from the company. This proved to be inconvenient for frequent, in-person progress meetings. One of the major lessons learned from both the first and second generation projects is the importance of communication.[14] As an example, the second design team ran out of money for some of the critical design components; as a result less expensive components were used to stay within budget. One specific example is the outer shell of the heater. The students chose to use plastic in place of quartz for the cylindrical shell because of the cost saving. However, the plastic was damaged over time by the heat from the burners. Had the students asked, the company would have been willing to provide additional funding to get the desired components.

One of the key design constraints for the second generation project was portability so the simulator could be transported by plane to training sites around the US. This created space and weight constraints, which also limited what principles could be demonstrated. It was decided to remove those constraints for the third generation simulator in order to demonstrate more phenomena. Note that the purpose of this paper is not to detail the third generation design, but rather some of the unique aspects of the project as compared to the first and second generation projects and other typical capstone projects.

Senior Design Projects

Nearly all of the latest ABET accreditation student outcomes (Criterion 3) for engineering programs are related to senior design projects.[28] These include:

(a) an ability to apply knowledge of mathematics, science, and engineering
(b) an ability to design and conduct experiments, as well as to analyze and interpret data
(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
(g) an ability to communicate effectively
(h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice An ability to apply knowledge of mathematics, science, and engineering

Even more specifically, Criterion 5 Curriculum states (p. 4) "Students must be prepared for engineering practice through a curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course work and incorporating appropriate engineering standards and multiple realistic constraints."

A major challenge in meeting these ABET requirements is finding realistic problems for engineering students to address. Some of the best projects often involve those provided by industry, which are typically relevant problems of interest to the corporate sponsors. Wall and Belknap (p. 5) recommended that industry projects "should not be mission critical, but rather well defined and within the available time, test equipment, and knowledge base resources of both students and faculty."[14] Based on two previous generations of senior design projects on the same basic topic, this was better accomplished in the third generation process heater simulator project described next.

Process Heater Simulator Project

The selection of the student design team was an important element in the success of the project. The lead author is an adjunct instructor at ORU and teaches a three-credit junior-level mechanical engineering course each semester. Prior to the adoption of the project, a top student enrolled in the adjunct's course was hired as a part-time intern to assist with a large project unrelated to the capstone project described here. During the internship, the possibility of a third generation simulator was proposed to the intern, who agreed to consider adopting this as his senior project. The intern enlisted the help of two classmates (who had also taken the adjunct's courses) and officially accepted JZC's corporate sponsorship offer the summer before his senior year.

The convenient proximity of the adjunct teacher and the intern in both the classroom and at the company fostered frequent and detailed project discussions. The student interned at the company on a part-time basis in the spring semester of his junior year, on a full-time basis in the summer before his senior year, and then again on a part-time basis throughout his senior year. This working arrangement proved to be beneficial in various ways. Many of the critical design decisions were finalized before the official start of the capstone project at the beginning of the students' senior year. This accelerated progress in all phases of the project. The simulator was assembled over the course of the senior year in the intern's office at JZC. Revisions were made on a regular basis concerning design, specifications, and construction details. Equipment was ordered through the company which reduced the typical university bureaucracy related to purchasing equipment and then getting reimbursed later by the industry sponsor. The location of the project in the intern's office allowed knowledgeable company engineers to more easily participate in the design process. For example, an element of the design involved inducing the flow of hot exhaust gases. The company's resident fluid flow expert was instrumental in helping the student team design a compact and cost-effective method for accomplishing that. Another advantage was the company's manufacturing expertise that allowed custom pieces to be easily fabricated.

A considerable amount of work was also done at the university. Most of the drawings and software programming were done at the university by the other two students on the team. Software development, 3D printing of some of the parts (not available at the company at the time), and some other hardware creation and modifications were also done at the university.

While the third generation project team used the knowledge learned from the previous project teams, very little of the actual hardware was re-used. The three Bunsen burners and the burner traversing system were the only major components from the second generation project that were re-used. This was not surprising because of the major change in the second generation constraint of having to be easily transportable by plane. Therefore, the project described here provided a significant design challenge for the team because a major restriction of the second generation was removed so more capabilities were now possible.

The initial substantial progress on the project the summer before the official start and the frequent communication between the adjunct and the intern increased the attainable project goals. The scope of the original plan for the third generation design was substantially increased as more and more capabilities were added to the simulator. This frequently happens in industry projects because of the continuous feedback nature of the design and improvement processes. Usually the two limiting factors that ultimately cause most projects to end are the budget and the deadline. In this case, there were clear schedule limitations created by the university's graduation eligibility policy. However, the budget was not nearly as confined. While a university-sponsored project would likely have had a fairly strict budget, potentially compromising quality and aesthetics, that was not the case for this industry-sponsored project. The primary objectives were the capabilities of the simulator and the professional image portrayed to JZI students. In the former objective, the simulator needed to be able to demonstrate the major operational principles of process heaters. Many things were done to help achieve the latter objective. For example, the sides of the simulator were made of clear acrylic so students could easily view the components inside. The JZI logo was professionally stenciled on the clear acrylic doors. The ductwork was professionally insulated with a polished metal cover by an outside vendor. Stainless steel and aluminum were used for some components, mostly for their aesthetics, as less expensive components could have been used. Figure 4 shows the completed third generation simulator.

(a) (b)

Figure 4. Third generation process heater simulator: (a) drawing and (b) photograph.

Figure 5 shows an example of the second generation unit being demonstrated in a JZI class. The fully completed third generation simulator was successfully demonstrated in a JZI class just after the capstone team graduated. It has subsequently been used in every process burner class held in Tulsa since its completion. JZI students have given very positive feedback on the simulator.

Figure 5. Partially completed simulator used in an actual JZI class in Tulsa, OK.

Lessons Learned

The importance of communication between the corporate sponsor and the student design team cannot be overemphasized. This was clearly seen in the results of the first and second generations of the simulator, compared to the third generation. While communication tools such as video conferencing make remote team meetings more feasible than ever, they are still not a substitute for regular face-to-face meetings. Real design projects of any significant complexity, especially involving students with limited relevant experience, need constant adjustments. Unlike most engineering courses where the solutions to complex problems are provided in the back of the book, real engineering problems seldom have such simple, singular, and well-defined answers. As project complexity increases, multiple design iterations become necessary during the course of the project.

The first generation project was started in 2006 and the third generation project was not completed until 2013. This demonstrates the complexity of this concept because multiple iterations over eight years were required to achieve the desired result. Information was learned during each capstone project that was used in subsequent projects.

Despite excellent communication, there were still some aspects of the third generation simulator that could not be accomplished. Even with the intimate working relationship, some of the project goals were not completed, such as collecting extensive operating data and automatically controlling the draft and excess oxygen. Some of this was caused by “scope creep” as new features and capabilities were added during the course of the project. Some of this could be attributed to mechanical engineering students assuming responsibilities outside their area of expertise. For example, trying to assemble the electronics and program the software to both control the equipment and to collect the data proved to be very difficult. This suggests the design team should have been multidisciplinary to include computer and electrical engineering students.

Conclusions and Recommendations

This was a unique industry-sponsored capstone project that had exceptional communication due to the industry project leader working as an adjunct at the university and one of the student design team members working as an intern at the company. This third generation project was a significant advancement over the previous two generations. The project met all seven of Todd et al.’s criteria for an industry-sponsored project,[19] although the increased scope proved to be too large to complete all of the objectives.

The evidence of the success of this project was a third place award in a regional ASME contest. The project was also featured in an article in the university’s engineering department newsletter and in the campus-wide newspaper. The students benefitted by getting the opportunity to work on a real-world project of interest with direct applicability to JZI. The company benefitted by getting a functional, top-quality simulator that is currently used to enhance training classes. JZI students benefit by having another tool to assist them in learning about process heaters. The university benefitted from the financial relief created by the corporate sponsorship and the positive image from having an award-winning student team.

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