A Different Approach to Multi-Discipline Senior Design

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Abstract – Many faculty believe that Senior Design teams consisting of multiple engineering disciplines enhances the learning experience, produces superior designs, and represents a more real world experience. In our experience this is true in many cases. However, at times a given mix of engineering skills does not produce a quality learning experience for all students.

In this paper, we explore this issue from an experiential standpoint. In particular we focus on the interaction of industrial engineers on various senior design teams. We show both successful integration and not-so-successful integration of an industrial engineering student on a design team. We then present and demonstrate an alternative approach on how industrial engineering adds value to a senior design project. Two cases are presented in which teams of biomedical engineers design prosthetic devices in the first year, followed by teams of industrial engineers who design high volume production processes for the devices, including product design modifications. We believe through anecdotal evidence that the students using this approach obtained a superior senior design experience.

Keywords: Senior Design, multi-discipline

INTRODUCTION

Many faculty believe that Senior Design teams consisting of multiple engineering disciplines enhances the learning experience, produces superior designs, and represents a more real world experience. At Mercer University, this was generally found to be true. Supportive examples include teams whose represented engineering disciplines included mixtures of mechanical and electrical students, biomedical and electrical students, or computer engineering and biomedical, etc. However, it was regularly observed when an industrial engineering student is teamed alone with other engineering disciplines, the team dynamics break down. The lone industrial engineer on some multi-discipline projects added little value to the team, and ended up primarily acting as the project manager and budget analyst. On the other hand, teams consisting of predominately industrial engineers were able to more effectively demonstrate their design and analytical skills.

In this paper, we explore this issue from an experiential standpoint and demonstrate an alternative approach on how industrial engineering adds value to a senior design project. Two cases are presented in which teams of biomedical engineers design prosthetic devices in year one, followed by teams of industrial engineers who design high volume production processes and supply chains in year two. We believe through anecdotal evidence and a student questionnaire, that the students using this approach obtained an outstanding senior design experience.

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BACKGROUND

The Senior Design project at Mercer University is a two-semester capstone design course geared towards student demonstration of design, analysis, and building a prototype device for a real-world problem. Students self-form into teams of three or four, and choose their own project topic. The Senior Design instructor facilitates teaming of individuals who have not formed a team on their own. Project topics may be obtained from (1) regional industrial partners, (2) project of interest developed by a faculty, or (3) the student's own product idea. All projects have sponsors from faculty, local industries, entrepreneurs, or government agencies including NASA. The teams can consist of students from a single discipline, or can be formed from multiple disciplines. Each student has a faculty technical advisor in their specific discipline, to assure the project selected has the appropriate technical content specific to the discipline of each student. At Mercer, the Engineering disciplines include Biomedical, Computer, Electrical, Environmental, Industrial and Mechanical.

In the first semester, the student teams prepare a project proposal, create multiple alternative solutions, analyze alternatives, select the best solution, devise a test plan, and present a preliminary design review (PDR) of their product or process. In the second semester, the student team builds and tests the product or process, and presents a critical design review (CDR). This type of structure with two semesters for a senior design course is not uncommon [1]. Two semesters work well to allow enough time for students to design, analyze, build, and test.

Modern studies reveal that teams of diverse professionals can work well on multifaceted projects. The reasoning for using team approaches to development or design projects has remained fairly constant over time. Organizations apply the talents of many individuals in a team to: (1) Attain better solutions, (2) Divide labor, assign tasks to talents, (3) Integrate subtasks into a complete project, and (4) Meet completion time requirements. [1, 2] Teaming goals for senior design groups are similar. In many cases the differences between 'real world' design projects and senior design projects are the time frame of the project and ending point. Ultimately, many 'real world' designs are made for mass consumption and must lead into a production design and product, whereas most senior design projects typically end with a successful (or sometimes unsuccessful) prototype.

Difficulties of diverse engineering students and the managing faculty to navigate through the various engineering domains of each discipline represented on a team has been highlighted by many [3,4]. One recommendation for a model of interdisciplinary teams in self-managed work teams uses an instructor scaffolding model similar to what is currently implemented at Mercer. Ideally the instructor should demonstrate interdisciplinary characteristics such as valuing other disciplines and integrating disciplinary expertise. Little is mentioned about the appropriate timing of team member contribution to a project in the literature. This timing or sequencing of engineering disciplines is the topic of this paper.

PROBLEM STATEMENT

Mercer Engineering faculty are proud of their Senior Design course offering and believe it differentiates Mercer from many other Engineering schools. [5,6] They believe the senior design offering provides an invaluable experience and training for their Seniors.

While many Senior Design teams achieve their objective and produce successful projects, on occasion the instructors have observed teams that are not as successful, or have individual team members who have little to contribute or have a poor design experience. As instructors we discuss these observations and try to develop alternative approaches to lessen the potential of unsuccessful design experiences.

An example of an unsuccessful design experience that has been repeatedly observed is when an industrial engineer is teamed with a predominately biomedical, electrical or mechanical engineering team designing a physical prototype product. The lone industrial engineer (IE) ends up primarily acting as the project manager and budget analyst, leaving them with a less than satisfactory design experience. A recent industrial management student comment highlights this common observation. [7]

"*… I will be the finance lead in charge of keeping up with the budget and performing a detailed analysis of costs such as a return on investment and for a production run. My other roles include supporting the mechanical engineer and computer engineer ……*

…. I assisted in the revision of the schedule to include more details on tasks, developed merit criteria for design selection, and began research for designing a user manual for the device. In the next two weeks, I will be researching and evaluating weather data, developing a non-disclosure and confidentiality agreement……

"While I am performing all of my tasks, I do feel at times that my team members have more tasks to complete. … "

On the other hand, teams consisting of predominately industrial engineers (IE) working on manufacturing or process problems were able to adequately demonstrate their design and analytical skills. We believe these cases, of the lone IE having a poor design experience, were primarily due to the type and timing of the problem. Physical design problems with limited manufacturing or process design aspects typically do not require the capabilities IE's bring to a design project.

While IE's have a wealth of skills, their training is predominately oriented to process design and improvement as opposed to product designs. Senior design teams consisting of primarily industrial engineers tend to choose projects that focus on process improvements. On the other hand, teams of Mechanical, Electrical or Biomedical engineers tend to design functional devices.

Often, a lone IE on a product design team believes he can help by designing production processes, developing supply chains, or costing the production process. However, experience indicates that the timing of product design is such that little or no time is available for the IE to investigate process designs.

ALTERNATIVE APPROACH: FOLLOW-ON TEAM APPROACH

To ameliorate the situation stated above, Dr. Schultz and Dr. Vo have used an alternative approach to a traditional multi-disciplinary Senior design team. The approach is to use a design team of biomedical engineering students to design prostheses. And then in the next year, use a **follow-on** team of industrial engineering students to design the process and supply chain to produce the prosthesis. So while the product and overall engineering design benefits from having multiple disciplines, the students themselves function on independent single discipline teams where they can best demonstrate and utilize their capabilities.

An argument might be made that the product and process design teams should work concurrently. We tried this approach, but due to constant product design changes the process design team was at a decided disadvantage while attempting to develop concrete process designs.

A possible concern with this follow-on approach is that the product design team graduates prior to the next team starting (leaving the University). This reduces the ability of the process design team to communicate with them. This continuity issue was resolved by having the same faculty mentors involved in both projects.

CASE STUDIES

This approach of using **follow-on** IE teams to design the process and supply chain is demonstrated with two case studies. The first was a low cost below-knee prosthetic leg. The second was a universal prosthetic ankle.

Low cost below-knee prosthetic leg project:

The low cost prosthetic project began with a team of two biomedical and one mechanical student in the Fall 2008 – Spring 2009 senior design course. These students produced a simple low cost below-knee prosthetic which was to be used for a Mercer on Mission [8] trip to Vietnam. Note: Mercer On Mission is a unique blend of study abroad and service-learning that provides life-changing experiences for students through academic instruction, cultural immersion, meaningful service, and spiritual reflection.

In the Fall 2009 – Spring 2010 senior design course series, a team of 3 industrial Engineers took on the assignment to design a production process to mass produce this low cost below knee prosthetic. Whereas the original biomedical/mechanical design team manufactured most if not all the parts themselves in the machine shop, the industrials focused on developing a supply chain for many of the components. They successfully evaluated numerous suppliers and were able to find sources for all components. Their final supply chain resulted in a total material cost of $137.21 for the below-knee prosthetic.

The students designed a work cell layout, depicted in Figure 1. Figure 2 is a photograph of this assembly work cell built by the students. Figures 3, 4 and 5 are additional pictures of work in process at various stations along the assembly line. This assembly line consisted of 4 stations, and a takt time of 3.0 minutes. Thus staffed with 4 workers, their assembly line could produce approximately 18 prosthetic legs per hour, considering a few work breaks.

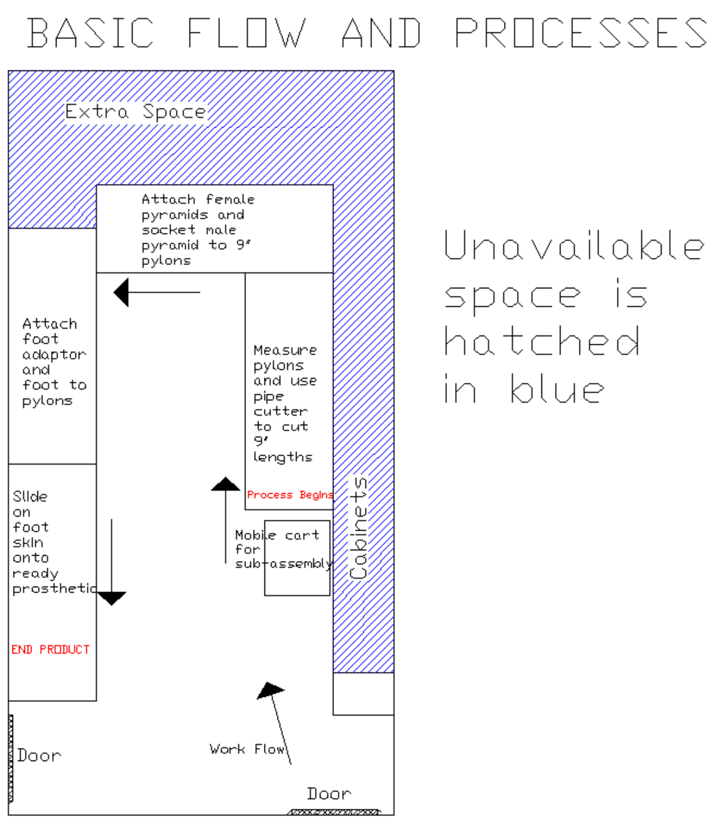

Figure 1. Work cell layout for the below-knee prosthetic.

Figure 2. Assembly work cell for the below-knee prosthetic.

Figure3. Screwing in bolt.

Figure 4. Fitting skin into foot.

Figure 5. Finished product.

Universal prosthetic ankle project:

The second project was the development of a prosthetic ankle by a team of two biomedical students and one mechanical student in the Fall 2009 – Spring 2010 senior design series. In the Fall 2010-Sping 2011 senior design series, a team of 3 industrial engineers took on the project of making minor modifications to the design and developing a high volume assembly process. Figure 6 shows an example of a prosthetic with this universal ankle.

Figure 6. Example of the universal prosthetic ankle.

The IE team developed a two station assembly process. Figure 7 is a picture of the lower ankle assembly station, and Figure 8 is the upper ankle assembly station. The assembly time for the lower ankle assembly was observed to be 43 seconds, and the upper ankle assembly was observed to be 77 seconds. Again, much of the effort was in developing suppliers and a supply chain. The material cost for the ankle components is $42.47, not including the foot itself. For large volume production, the material cost was estimated to fall to $27.50.

Figure 7. Picture of lower ankle assembly station.

Figure 8. Picture of upper ankle assembly station.

QUESTIONNAIRE

To evaluate how the students felt about this f**ollow-on** project approach, a questionnaire was sent to the students who participated in the case studies above. There were a total of 6 students, of which 4 responded to the questionnaire. All of these former students now have from 6 to 18 months of full-time job experience as industrial engineers. Two of the former students are working as industrial engineers at Robins AFB, and the other two are working as industrial engineers for manufacturing companies.

The complete questionnaire with responses is not included in this report, but is available upon request. Instead, we present complete responses for two of the questions and then summarize some common themes for the remaining questions.

Question 2 dealt with the overall senior design learning experience, while question 3 was used to determine if the project was representative of what an engineer does in practice. In general, all four students indicated they had a valuable and real world senior design experience.

2. Do you believe there was value in this learning experience? Please explain.

CM – *"Yes, because you learn professional skills. Most engineers that apply themselves can do equations and occasionally come up with a creative idea, but it is another whole realm for an engineer to create this idea and communicate it effectively. Even after having this experience, sometimes it can still be hard to communicate an idea effectively."*

SC – *"There was great value in this learning experience. The most valuable thing I gained was how to merge different engineering subject matter when trying to solve a problem. There is never only one solution, and therefore, it takes patience, rational thinking, and the ability to combine ideas into one."*

AL – *"Absolutely! Real world projects are never as easy as concepts learned in courses. Learning to manage communication, ideas, and opinions within the project was perhaps the most valuable learning experience. The idea of Project Management is a tough task to undertake."*

GM – *"Yes. It was a great opportunity to take the various knowledge and skills that we gained from our course work and apply it to a long-term project. The feasibility, budgetary, and review elements of the project accurately depict real-world project management situations."*

3. **Do you believe your experience was representative of what an Industrial Engineer does in the real world? Please explain.**

   CM – *"I believe it was. We started with a product, made changes to that product based on specifications of the customer and restrictions of our budget, designed how that product would be made, and then communicated how that product would be made to others. The only part that I do not feel was IE-esque was redesigning the ankle or finding the types of materials the ankle should be made out of. I know that determining what materials a product to be made out of is part of being an IE, but I feel that this project went somewhat beyond. "*

   SC – *"An Industrial Engineer is not subject to one particular job. The discipline is so diverse that there are several different avenues that one can choose. I do believe that my senior design project incorporated many of these attributes, though, including process improvement, time studies, ergonomics, cost analysis, and technical writing."*

   AL – *"Yes. IE's can have a wide range of skills, but often the most important skill they can have in the real world is using and applying a project management approach and leading/directing the project team. Often, the engineering solution is easy to draw up, but implementing a change or new approach requires another set of skills. Even if the final product isn't ideal, the process of following a project to its end (i.e. senior design) was a very valuable experience."*

   GM – *"Yes I do. In the real world an IE will be responsible for managing projects, interfacing professionally in business situations, testing design alternatives, and developing process improvements. Our senior design project gave us an exposure to these types of activities."*

Several of the questions were directed at the timing for designing the production process and supply chain. There was general consensus that the process design should not begin until the product design stabilized and that product designs are generally in flux during the two semester senior design course, impeding the ability to design a good process. Some students mentioned that being on a product design team might help influence designs that were more suitable to manufacturing, but that their personal experience for a capstone design experience might not be as fulfilling.

INDEPENDENT VERIFICATION

The quality of the "Mass Production of the Universal Prosthetic Project" was independently verified when the student design team placed second in the South East regional Institute of Industrial Engineering student paper competition. This annual competition provides a forum for industrial engineering students, from Universities across the South East, to demonstrate original student design and research work. A panel of 3-4 judges, from industry and academia, evaluate both a written and oral presentation when determining awards.

CONCLUSIONS

We have demonstrated a new and successful approach to using sequential, multi-disciplinary engineering teams to complete a 'real-life' project, where production is the final goal of the project. A team of biomedical engineering students followed by a team of industrial engineering students were able to successfully design, build, test, and produce a newly designed product, a prosthetic leg. The starting point and the ending point of each team were quite different, as in a relay race. However, the combined talents of both teams with different engineering disciplines were required for the project to be successful.

Different goals were required for each group, leading to the two different skill sets of the groups. The final accomplishment of the second group was better than if a single team had attempted this project, or if two teams had worked during the same semester.

A key element in the project success was using faculty and the instructor as the scaffolding between the groups allowing for the sequential scheduling of product design followed by the process design.

Each senior design team had an effective engineering experience appropriate for their specific engineering discipline. While difficult, this dual-project has yielded great results for the student and for the people who received the prosthetic legs produced.

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