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Robotics and Mechatronics Engineering Framework to Develop a Senior Capstone Design Project: A Biomedical Mechatronics Engineering Case Study

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Abstract

The capstone design project for engineering students is the pinnacle of the undergraduate engineering education process. The design projects exist to both demonstrate the students' capabilities that they have learned throughout their education and bridge their education to industry standard practices. Given the significance of this project to young engineers, it is important to take the opportunity to appropriately challenge the students in their projects to optimize the time and effort that the students have put into their education and projects. The benefactors of the engineering education system are the students, universities, and industries. In the case of the engineering education system, the benefactors are not only those who depend on the quality of the system but are also those who are the greatest influences on the education system. The Universities provide the framework and environment for students to challenge themselves and reach their potential as engineers while the industries dictate the expectations of young engineers.

The discipline of engineering is well known to be one of accumulated knowledge and experience. The common practices of engineers are built upon their predecessors and the current engineers work to continue this growth. Students rely heavily on the experience of their advisors to bridge the gap between ideation and creation of the capstone projects. Adding the experience of non-engineering disciplines adds another dimension to the types of engineers bred out of the engineering education system. This paper proposes an optimization of the existing capstone design project framework to accommodate the growing demand for multidisciplinary skill sets. The focus of this optimization is the utilization of accumulated knowledge and experience through experts who would act as advisors for the students. This optimization is a call to universities and industries to strategically invest the time and experience of professionals in the engineering education system and the students. This optimization would open up opportunities for students to learn and practice multidisciplinary projects as well as prove a student's ability to adapt and apply their skills to any industry.

Introduction

While the engineering education system breaks down the discipline of engineering into subdisciplines, such as electrical and mechanical engineering, it is not realistic to expect a project group to be made up of monodisciplinary engineers. Real-world problems demand a range of expertise and perspectives to develop the optimal solution. In addition, experienced engineers deviate from one another based on the direction of their career and the area of expertise that they have trained. The natural progression of engineers is to become interdisciplinary as other disciplines slowly merge with the original to create a specialty. With the addition of groundbreaking discoveries that create new disciplines of their own, such as computers, it becomes that much more demanding for engineers to adapt quickly to integrate new disciplines into their work. All projects begin as multidisciplinary as they utilize the accumulation of interdisciplinary specialties to solve new problems. But as these projects progress, it is natural for the engineers to integrate the new disciplines into their own as well as bring in new engineers who pick up the newly defined discipline. The nature of a multidisciplinary engineering project is to mutate into a new interdisciplinary study. As this cycle has gone on for centuries, the complexity of practical engineering skills continues to grow.

The universities that implement the engineering education system struggle to keep up with the demand for engineers who can hit the ground running once they enter the industry. Some courses must be taught to engineering students who are in an entirely different discipline than their own. For example, mechanical engineering students must have a certain level of programming and electrical skills. These skills have become standard for mechanical engineers but are limited to avoiding dulling their fundamental mechanical engineering principles. While this makes mechanical engineering interdisciplinary, the response to the unbalanced disciplines is to create an entirely new interdisciplinary field that draws from the same disciplines but has a different balance. This new interdisciplinary field is named mechatronic engineering. The problem is that continually adding more interdisciplinary fields is not sustainable for the engineering education system [1]. The engineering education system already struggles with organizing the courses into an undergraduate program. In the case of mechatronics, the three fundamental disciplines in electrical, mechanical, and software do not necessarily complement each other which forces students to lean towards one of the disciplines as their specialty.

An example of a discipline that can be included in many variations of multidisciplinary projects is biomedical engineering. Biomedical engineering is already a complex interdisciplinary field that has gone through the evolution of a multidisciplinary collaboration mutating into an interdisciplinary field. This means that biomedical engineering is a standalone industry due to its development and relevance. Being a very complex interdisciplinary discipline, its addition to a multidisciplinary project adds exponential complexity as it brings a nuanced fusion of all of the original collaborators during its multidisciplinary phase. Assuming that this trend continues, engineering education cannot account for every possible combination of every possible fusion between disciplines [2].

The goal of this proposal is to offer a better way to prepare students for multidisciplinary projects and the demand for various interdisciplinary engineers that await them in their careers. Rather than teaching interdisciplinary fields as if they were a single discipline, it would be more natural to simulate the industry project environment by challenging students to collaborate on multidisciplinary projects. This seeks to allow each student to find their specialty rather than trying to generalize an exponentially growing interdisciplinary domain. The proposal is to encourage multidisciplinary capstone projects with the assistance of university and industry advisors. This allows engineering students to become familiar with their discipline and all of its facets, and then bring their expertise to a multidisciplinary project where they will naturally absorb parts of the other disciplines to complete the project.

Barriers to Multidisciplinary Capstone Projects

The greatest barrier to implementing this proposed multidisciplinary capstone project is the need for the presence of experts in the other disciplines that make up the multidisciplinary domain. While a group of mechatronic engineering students and their mechatronic advisor can bring their expertise, it is unrealistic for the students to test their understanding of their discipline while also trying to learn enough about the other disciplines to create a quality capstone project. As is done in industry multidisciplinary projects, the team must have contributors from various disciplines. While implementing the capstone project course, it is important not to forget its purpose. The project is testing a student's capabilities within their discipline. To maintain that purpose while also challenging students in their collaborative efforts, the other disciplines must be used as a control group. This control group would need to be made up of advisors who can provide both a realistic problem for the students to solve and guidance. The greatest challenge is for the students to operate as if they were one team of a much larger group. This means that their system is a subsystem that must be compatible with the purpose and functionality of the greater system. A greater system needs to be established by the advisors to give the capstone project appropriate minimum success criteria. The minimum success criteria is the validation metric of the capstone project. Traditionally, students work with each other and their advisors to set the expectations of what the system must accomplish for the project to be considered a success. The additional complexities of a multidisciplinary application will likely result in minimum success criteria that are inappropriate, whether being too complicated or too simple.

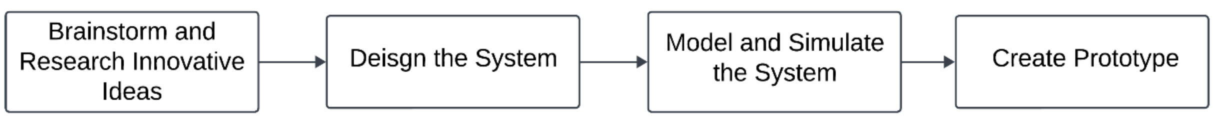

Fig 1. Basic Engineering Capstone Project Framework [3]

Another barrier to multidisciplinary projects is the stress that the project would put on the fundamental engineering capstone project framework. Figure 1 shows the standard framework to complete an engineering capstone project. The steps to the engineering capstone project framework are brainstorming and researching innovative ideas, designing the system, modeling and simulating the system, and finally creating the prototype [3]. The framework is designed to guide students through a realistic collaborative engineering project. Each step serves to challenge students to apply their knowledge to real problems by changing their mindset from academic theory to realistic application [4]. While the framework is sound in theory, each step becomes more challenging as the complexity of a multidisciplinary project dwarves a monodisciplinary project. The first step alone, brainstorming and researching innovative ideas, becomes a much greater challenge when the students need to understand the role that their subsystem will play in the greater system and how they will go about applying their discipline to the project. The project must be administered in a way that keeps the demand of the greater system simple allowing the students to focus on a more complex subsystem based on their discipline but relative to the greater multidisciplinary system.

Case Study: Biopharmaceutical Manufacturing Test Bench

The case study's capstone project serves as an illustration of how an attempt at a multidisciplinary project can lose its direction without a proper control group of disciplines. The "Biopharmaceutical Manufacturing Test Bench" was a capstone project that sought to break into the field of vaccination manufacturing as the COVID-19 incident has insighted awareness to the need for innovation in biopharmaceutical manufacturing. The idea was to embark on a multidisciplinary capstone project where a mechatronic subsystem could be implemented into a greater system made up of the disciplines of manufacturing and biopharmaceuticals.

While the idea was strong and the students were motivated, the project lacked a vital resource in advisors from the other disciplines. The lack of advisors meant that the students had to go out and research the biopharmaceutical manufacturing industry as quickly as they could to ensure that the project could be completed in time. The students had a timeframe of 1 semester to narrow down the area of biopharmaceutical manufacturing they wanted to insert their mechatronic system, identify the needs of the subsystem relative to the greater system, design the subsystem, model the subsystem, and then create the prototype. This project had a lofty goal to accomplish in one semester and it proved to be too much for the students. The time it took to go down the rabbit of interdisciplinary webs that make up biopharmaceutical manufacturing forced the students to make a rash decision to maintain their timetable. While the students appropriately followed the framework to complete the capstone project, the specifications of the subsystem that the students chose were not compatible with a greater biopharmaceutical manufacturing system. The students were able to complete their project in time while demonstrating adequate mechatronic skillsets, but the project failed at incorporating a multidisciplinary domain. Not only did this project fall short of the multidisciplinary aspirations, but it also squandered an opportunity for students to address the need for the optimization of vaccine manufacturing and distribution [5]. This shows that the execution of the framework steps and the inclusion of multidisciplinary advisors is vital for the proper implementation of a multidisciplinary capstone project.

Student Motivation and Opportunity

For students who wish to explore the capabilities of mechatronic applications, many creative project ideas and collaboration are considered during the brainstorming process. During the brainstorming process, students need to consider the feasibility of the project and will often choose a project that can be confidently completed with the resources provided rather than take a risk on a more challenging project. This is very limiting on the potential of what the capstone projects could be in terms of what the students could learn through the experience that they would gain through various challenges and hardships brought about by a more advanced project. The best form of education for engineers is practice. There is no better time for students to practice practical skill sets than during the capstone project process [6].

To properly conduct a multidisciplinary capstone project, the students must take responsibility for their efforts and demonstrate a willingness to grow and adapt. Students will have the opportunity to exercise their ability to learn and adapt to large-scale collaborative projects. The students must learn to work with each other while also reaching out for help from those who are more experienced. It is an excellent exercise to identify valuable resources and take advantage of the opportunity to draw from a professional's experience. Demonstrating both tangible and intangible skills allows a student to set themselves apart. As the capstone project is the peak of the engineering education process, it is also a student's opportunity to prove their competency and ability to adjust to the next level of engineering.

University Motivation and Opportunity

A university is in a unique position that stands between hopeful engineering students and professional engineers working in industry. The university's responsibility is to provide the environment and resources for a student to acquire the necessary skills and knowledge to become a professional in their discipline. The quality of the university's administration of the engineering education system can be measured by the competency and capabilities of the young engineers leaving to work in various industries. The capability to administer an effective multidisciplinary capstone project would best fit the expectations of the ABET. The ABET has a set of criteria for the skills that engineering students should have as they finish school. These outcomes are an accumulation of experience and skills throughout the education process and cannot be simplified to a single course. As the capstone project serves as a final demonstration of the skills of engineering students, there is no better place to provide students with a true challenge that demands the utilization of the expected student outcomes. One example of a student outcome that can only be observed through practical usage is the ability to communicate to a diverse audience. A multidisciplinary capstone project would open the opportunity for students to demonstrate an ability to communicate with both engineering and non-engineering advisors, fulfilling an ABET student outcome criteria. As the ABET has many criteria for the overall engineering program, the multidisciplinary capstone project offers a complex engineering problem that acts as a catalyst for greater educational practices [7]. To better the reputation of the university and future graduates, it is in the best interest of the university to bring its students to the highest level of competency using the resources available to the university. Students are allowed to prove their industry readiness through their quality and industry-applicable capstone projects [4].

In addition to a university's motivation for administering a multidisciplinary capstone project, there is plenty of motivation for the professors who will act as the multidisciplinary advisors for the project. A professor's motivation is likely to lie within the professor's research or field of study. One motivational factor is for non-engineering professors to be connected with engineering students whose capstone project aligns with an area of research being studied by the professor. While many engineering students choose to move on to industry after graduating, some choose to stay for a post-graduate degree. The capstone projects are often reflections of the interests of the students. If there is an opportunity for a group of students to work with a non-engineering professor, then the students could not only expand their interest in a multidisciplinary field but also learn about the professor's work and expertise. In addition, the professor would also have opportunities to have the multidisciplinary capstone project involve the development of useful equipment or experimentation related to the professor's research. As these examples demonstrate, the relationship between students, professors, and research can vary but the opportunity for the university to connect interest groups could greatly benefit all those involved.

Universities are also places where a large number of experts of varying disciplines come to collaborate, teach, and research. In essence, the nature of the university opens the opportunity for multidisciplinary collaboration through a communication line between students and advisors. The current framework of the capstone project allows for communication between engineering departments when a project needs the expertise of another engineering discipline, but with the growing diversity in multidisciplinary projects, there needs to be a greater framework for expertise contribution from non-engineering departments. Communication lines could take many different forms depending on the state of the university. For example, once the capstone project topic and the required disciplines have been decided, the students could reach out to designated advisors of the relevant discipline and request a meeting to unfold the project idea and receive any relevant information or guidance towards the project. Collaboration between the departments could raise awareness of the potential effect that a field like robotics could have on a non-engineering discipline. In addition to awareness, collaboration could also allow engineering students to design and create useful instruments or testing benches for other disciplines allowing for greater research opportunities.

Industry Motivation and Opportunity

Multidisciplinary projects in general have been a hot debate topic for many decades. Whether in politics, large corporations, or innovation, there are always delays and mistakes due to miscommunication, misunderstanding, clashing agendas, and many other nuances throughout the project. Every industry works towards effective collaboration on large projects, often by separating the project into subprojects. The challenge is that the subprojects still need to be aware of how their project fits together with all of the other subprojects. This is a very relevant subject for all industries to consider. There are many reasons why an industry would invest in a multidisciplinary capstone project. One motivation for industries is to obtain a larger sample size of controlled collaborative projects. Narrowing in on the performance of a single project and why the project ended up, the way that it did provides an endless amount of material to examine to implement change. The second motivation is that industries can get a close look at a student’s ability and willingness to collaborate with others, especially with those who work in different disciplines. A third reason is that an industry can present a segment of a large project to the students to look for future engineers to plug into the ongoing multidisciplinary project.

Another benefit for industries is raising awareness of an uncommon or advanced interdisciplinary field and technology. Students are often made aware of the opportunities in fields directly related to their discipline, however, it is not as common for a student to be prepared for an interdisciplinary job right out of college. In addition, students often share experiences and interests. Getting students interested in the interdisciplinary field would propagate more opportunities for industries to obtain valuable engineers [8]. In the case of biomedical engineering, the once multidisciplinary projects became a discipline of its own. Now universities offer degrees ranging from minors to graduate degrees to accommodate the growing interest and need for specially trained biomedical engineers [9]. As robotics is being applied to various fields regularly and diversly, it is not feasible for a university to create new fields for every nuance of interdisciplinary engineering. A workaround is the capstone project in which the industries could get their hands on bright young students before they graduate and influence their engineering background with industry expertise.

There are many opportunities for industries to get involved in capstone projects. The first is industry sponsorships in which the industry invests time, money, and resources while providing the students with a problem to solve. This will allow the industry to have direct influence over the direction of the project. Students can communicate with the industry to learn about the industry standards to design a system closely related to the actual technology used in the industry. Another way for industries to be involved is if they partner with the universities to offer guidance to students who wish to explore a project within the industry's expertise. The university would provide a connection between the students and industries so that students can familiarize themselves with the industry standards and expertise.

Conclusion

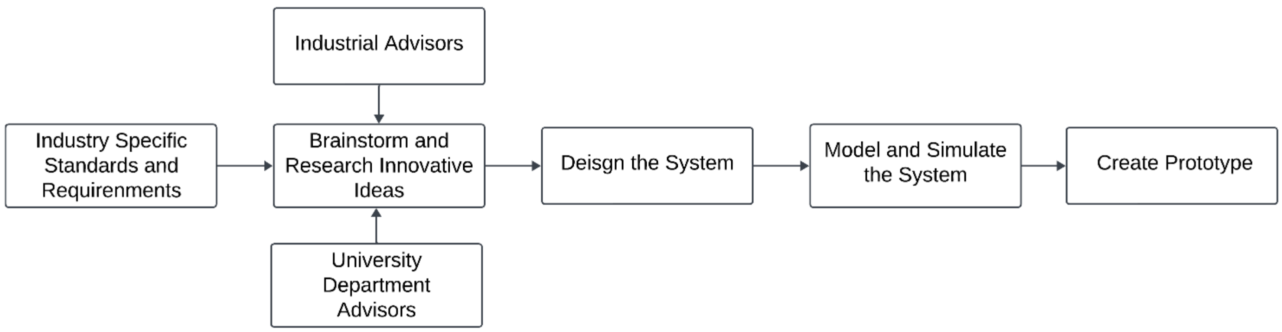

Fig. 2 Multidisciplinary Capstone Project Framework [3] [10]

The engineering education system has maintained a standard of engineering practices that ensures the quality of engineering design and creation. The framework for engineering education has survived the test of time as the fundamentals of engineering have proven to be effective, however as times change the method of implementing the framework can become inefficient or infeasible. Figure 2 shows the proposed optimization of the general engineering capstone project framework. The new framework includes industry-specific standards and requirements as well as advisors from industry and various university departments to assist the projects through communication lines provided to the engineering students. Figure 3 represents the relationship between the symbiotic relationship between university, industry, and student interest in multidisciplinary capstone projects. Each party involved with the proposed framework has something to give and receive from the other parties. With the assistance of the advisors, multidisciplinary projects can overcome the barriers to entry by ensuring that the students are allowed to fully display their capabilities on a multidisciplinary application without being hindered by the nuances of the specific industry. While the mechatronics engineering discipline is used as an example of a foundation to build a multidisciplinary capstone project, any engineering discipline will fall under the same course of action. The foundational discipline would serve as the focus of the project; however, the multidisciplinary industry would demand a greater level of specialty that would never be found in a single engineering discipline. Using biomedical engineering as an example, any multidisciplinary project applied to the biomedical field must satisfy the standards of the industry set by various third parties for the safety of the patients. The consideration of industry standards requires a big-picture point of view that allows students to think realistically as they design their system and determine its feasibility [10].

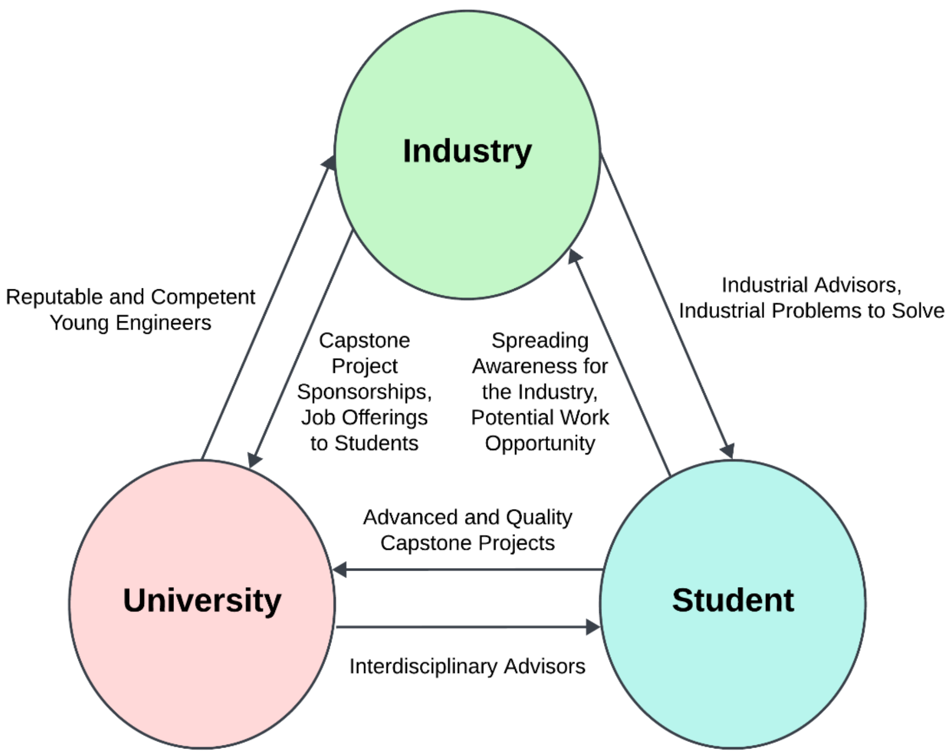

Fig. 3 Benefits of Collaboration between Universities, Students, and Industries

Between the existent training period for junior engineers and the growing number of interdisciplinary fields, the number of experts in a particular interdisciplinary field cannot keep up with the demand. As an interdisciplinary field is being born, the collaboration of various disciplines is enough through multidisciplinary efforts. But as the field grows and becomes the foundation for further progress, the need for specialists in the interdisciplinary field grows. The harder it is to find the experts the greater the need to create more experts in that field. As universities have already encountered difficulties with fusing various disciplines due to the demand for various interdisciplinary engineers, it becomes necessary to find a new way to prepare young engineers for the ever-growing field of engineering. This is the opportunity that students, universities, and industries have through a multidisciplinary capstone project. Raising awareness for interdisciplinary needs and creating component and moldable young engineers serves to benefit all beneficiaries of the engineering education system.

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