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A New Approach to Capstone Design through Multidisciplinary Collaboration at Florida Polytechnic University

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A New Collaborative Approach to Multidisciplinary Capstone Design at Florida Polytechnic University

ABSTRACT:

As the complexity of engineering challenges continues to evolve, the importance of multidisciplinary collaboration has grown significantly. Capstone design serves as a culminating experience at the end of most engineering degree programs. Approaches to capstone design vary. Capstone projects can be industry-sponsored or internally funded, span one or two semesters, and involve single or multi-disciplinary teams. Florida Polytechnic University's Capstone Design Program introduces a pioneering, university-wide approach to the teaching and practice of engineering design by bringing together students and faculty from multiple disciplines in a cohesive, collaborative environment. This program leverages design thinking to guide students through the design process while integrating discipline-specific knowledge that informs the specialized roles of individual students and the broader understanding of what is expected from their peers in industry. This paper describes the history and development of this capstone program, details the integration of multiple disciplines at the student and faculty levels, and presents program outcomes. We aim to offer insights valuable to others interested in implementing a multidisciplinary capstone design program into their curriculum.

1 INTRODUCTION

Many engineering programs require some form of capstone design course at the end of an undergraduate degree program. The Accreditation Board for Engineering and Technology (ABET) requires a capstone design experience for all accredited undergraduate engineering programs [1]. Specifically, ABET criterion 5 states "a culminating major engineering design experience that 1) incorporates appropriate engineering standards and multiple constraints, and 2) is based on the knowledge and skills acquired in earlier course work" [1]. While required, the implementation of the course can vary widely between different programs. These differences include one- vs. two-semester sequences, internally vs. externally vs. unfunded projects, individual vs. group projects, single vs. multidisciplinary teams, and with vs. without lecture content. Some programs have interpreted this requirement uniquely where students satisfy this ABET requirement through community engagement [2]. Despite the many differences in approach, capstone courses generally aim to provide students with a culminating engineering design experience to show off technical competence, incorporate engineering standards, and practice soft skills necessary for an engineering career.

In 1995, Todd et al. completed an extensive survey of engineering capstone courses in North America [3]. The results of their work showed that capstone courses are quite varied between degree programs in a variety of ways. Two key areas for improvement were noted: first, a need to better teach students how to work in teams and second, a call to action that more programs should strive to provide a capstone experience that involves industry involvement [3]. In a more recent survey of engineering capstone programs from 2004, McKenzie et al. showed that many more capstone programs opted to place students in collaborative teams (90%) of varying sizes [4]. In addition, they state that an increasing number of programs were incorporating multidisciplinary teams despite the significant logistical challenges [4]. In an even more recent study conducted in 2015, Howe et al. report that only 6% of capstone programs span more than one discipline, and that multidisciplinary teams included 5 students most commonly (with 3 or 4 students per team for single-discipline teams) [5]. In addition, internal funding was shown to be the most common funding source for capstone projects with 58% of capstone programs reporting at least a single project being industry sponsored [5]. Taken together, these reports generally show a shift towards 2-semester, industry sponsored, team projects over the last 4 decades. Despite this shift, these surveys show that considerable variety remains in how capstone design is approached. As educators adapt to changing industry demands and technological capabilities, there is still a need to increase the number of projects funded through industry sponsorship and to increase multidisciplinary emphasis.

Transitioning a capstone program to include primarily industry-funded, multidisciplinary projects can be challenging for many reasons. Design education is often relegated to the end of an undergraduate program, which does not allow students to learn from their mistakes because they are given tight deadlines and linear deliverables. In response, Fazelpour et al. argue for a holistic approach to design education throughout an undergraduate curriculum [6]. Students with design experiences throughout their undergraduate program will learn to work in teams earlier, better preparing them for peer collaboration and meaningful engagement with industry sponsors. That said, those who have implemented multidisciplinary capstone programs warn of potential issues. Behdinan et al. note the potential for exacerbation of student performance issues such as "imbalance in contributions by team members" or a "lack of effective communication" to name a few [7]. Forsyth and Hesson report that industry sponsors of a multidisciplinary team felt that communication issues were the biggest hurdle, which mainly occurred when instructors changed during the second semester of their capstone sequence due to scheduling complications [8].

There may also be concerns about appropriate personnel to facilitate a multidisciplinary capstone program. Generally, a university may only have one or two faculty members (if any) with expertise in design theory that might be able to teach multidisciplinary lecture content on design at scale. There are also models where the industry sponsor and the faculty instructor are not the only sources of mentorship for capstone teams. For example, some programs might recruit industry volunteers, faculty, postdocs, or graduate students to serve as an additional mentor to a few capstone teams. At large universities with hundreds of students in capstone, the instructor may not have the bandwidth to provide individualized mentorship to each capstone team. Encouragingly, Arpini et al. showed no differences in students' longitudinal psychological safety on teams with a volunteer mentor from industry vs. an assigned mentor from academia in a model where additional mentors are recruited [9]. Leveraging faculty and industry volunteers may help alleviate some of the personnel concerns associated with a multidisciplinary capstone program. As a final point, there may be concerns about what to teach in general given that different disciplines might use significantly different vernacular when talking about design. The authors of this paper suggest that a design thinking approach [10], [11] may offer a domain-neutral perspective on the design process appropriate for a multidisciplinary capstone design experience.

This paper first describes the development, history, and current approach for a multidisciplinary capstone program at a younger university. The current program is characterized to give context. Next, faculty involved in the capstone program provide details about senior-level culminating courses in their discipline, how our multidisciplinary capstone program has added value to their students' education, and what challenges are left to be solved. Finally, lessons learned and future improvements are discussed.

2 DEVELOPING A MULTIDISCIPLINARY CAPSTONE PROGRAM

As a new university, the Capstone Design program started in 2016-2017 as two junior-year courses, Design 1 and Design 2, which exposed students to a two-semester, industry-related, project-based learning opportunity. These courses focused on practical problem-solving in mostly monodisciplinary teams and did not include the formal design methods the program now emphasizes.

During 2017-2018, the university was preparing for ABET accreditation. Design 1 and Design 2 were moved to the senior year and became the Capstone Design program. The goal was to allow students to focus on building technical skills and apply those skills to larger, team-based projects in their final year. A Capstone Design Coordinator role was also created to align expectations and improve collaboration across departments. Although enrollment was low during the first cycle (many students had already taken the course in the junior-year format), this change was critical.

By 2018-2019, the program introduced a more unified curriculum that focused on design principles and problem-solving strategies. This was the first full cycle of a multidisciplinary capstone experience for students. The Spring Capstone Showcase was added, giving students a platform to present their projects and connect with industry sponsors. The following year, the program brought in sponsors from more companies, including aerospace, healthcare, and technology. However, the COVID-19 pandemic hit in 2019-2020, requiring students to work remotely, focusing on simulations and analyses. Despite the challenges, the program continued to emphasize practical, real-world skills. These critical challenges laid the foundation for a stronger program moving into the 2021-2022 academic year (designated here as "Year 1") to build our current capstone design program.

2.1 Year 1: Return to In-Person Instruction (2021-2022)

During the 2021-2022 academic year, the program fully returned to in-person instruction. The course met three days a week: one day for lecture on design principles and two days for mentorship of student teams and project work. The return to campus post-pandemic allowed the multidisciplinary teams to collaborate more effectively, focus on physical prototyping if necessary, and complete deliverables for their project. The capstone program remained a two-semester course, with an accelerated version for December graduates. Students were assigned projects based on comprehensive surveys evaluating their aptitudes, experiences, and interests.

The return to in-person instruction came with many challenges. First, an in-person student presence on campus was difficult to reestablish for the entire university after the COVID-19 pandemic. This issue manifested in the capstone program when student teams showed reluctance for regular in-person team meetings. In general, capstone groups were only present together in the classroom during project presentations. Second, the program lacked a large, dedicated workspace for capstone students. It may have been unclear where students were supposed to meet each other in person even if they were willing to. The university had not moved into the new large academic building (partly due to complications from the COVID-19 pandemic) where a dedicated space could be allocated for these students. Finally, as the program became more multidisciplinary, instructors from different departments brought different formats or templates for reports and deliverables causing communication issues as teams prepared documents and presentations.

There were also unique challenges while searching for industry partners during this time. Many professionals were still working from home and had restrictions post-pandemic. This made finding industry sponsors particularly difficult. In addition, it sometimes made it difficult for students to meet or communicate with sponsors. Despite these challenges, the return to in-person instruction and a multidisciplinary capstone program was successful and set the stage for improvements in subsequent academic years.

2.2 Year 2: Advancement of Capstone Resources (2022-2023)

The opening of the Capstone Design Laboratory in 2022-2023 provided students with advanced tools and resources for prototyping and construction of their final projects, leading to improved quality. The students were afforded more meeting/collaborative spaces with the opening of our new academic building. This also improved the scalability of the capstone program as the enrollment and number of capstone projects increased. The students were provided with more standardized report and presentation formatting and expectations in response to the varied formats given in the previous academic year. Ultimately, this year's objectives and deliverables were comparable with those from the 2018-2019 academic year for the first time since the pandemic.

While presentations were still handled as they were the previous year (with students not necessarily presenting to the faculty that they received lecture from), students would spend one or two lectures before a major presentation in the classroom where the presentation would be given. This greatly improved presentation quality and reduced communication issues between course sections. Of course, some issues with maintaining an in-person presence were still felt post-pandemic. It proved challenging to encourage students to use the newly available spaces and resources available to them where a culture of using those spaces had not been established. These resources included the aforementioned Capstone Design Laboratory, an updated 3D Print Lab, a new CNC machine for our machine shop, and a dedicated staff fabricator to oversee the machine shop operations.

Some companies still offered hybrid or at-home work formats or were generally not ready to venture into academic sponsorship given a recent return to relative normalcy. As before, this made finding new industry sponsors challenging and led to communication issues for the capstone teams even for the industry sponsors that we did find. As a final point, the faculty noticed that the students significantly struggled with public speaking. This was partly attributed to the lack of in-person education and student socialization opportunities. The capstone program made note to address this issue in the following academic year.

2.3 Year 3: Introduction of Panel Presentations (2023-2024)

In 2023-2024, the course schedule was revised to provide students with working knowledge of the design process earlier in their first capstone semester, which would also allow more time for project work throughout the two-semester sequence. The lecture content was front-loaded into the first six weeks of the fall semester, outlining the entirety of the design process. The students were given mini projects during this time to exercise the principles that they were being taught in the lectures. At the end of the sixth week, the students were assigned their capstone projects and sponsors, and the remaining time was dedicated to individualized mentorship on a team basis.

The program also added two critical elements to advance students' presentation skills. First, Dale Carnegie's communication training was presented in three lectures with miniature public speaking assignments in front of their peers, which were recorded so they could later complete a reflection activity [12]. Second, while the students were still required to complete a midterm and final presentation in-class each semester, they were also required to present to a panel of faculty the week following their in-class presentations. The faculty panel was comprised of three or four faculty members from varying disciplines. The faculty panelists changed throughout the semester; therefore, the students were required to present to, and receive feedback from, multiple different faculty members throughout the year. This requires students to practice explaining their project to professionals from varied backgrounds who know little about the project and may know little about the specific technical areas involved but are still able to digest project information and prepare feedback. Additionally, the curriculum was further standardized to make expectations clearer for all teams, regardless of discipline.

The students enrolled in the capstone program have an instructor of record, a faculty mentor (who advises the entire multidisciplinary team as if they were in their own classroom), and they present to a rotating panel of faculty twice each semester. The measured and deliberate changes implemented in capstone have improved student communication within multidisciplinary teams, established a university-wide set of student expectations for the course, improved student presentation skills, and overall have resulted in higher quality project outcomes for the course as reported by instructors of the course, faculty panelists, and anecdotal student feedback at the end of the semester. There was also a notable increase in the frequency that the available on-campus resources were being used by the capstone team.

2.4 Year 4: A Design Thinking Approach (2024-2025)

Adjusting content to be more inclusive of various perspectives on the design process from different disciplines, the lecture content was redesigned with an emphasis on design thinking. Many design theory textbooks arguably take an engineering perspective that is often best aligned with mechanical engineering [13], [14], [15]. This is very likely due in part to design theory's roots stemming from the industrial revolution as tools, methods, and machinery were rapidly developed. Many pioneers of the field of design theory also happened to be from mechanical engineering traditions, which has set the stage for a lot of the academic work on the design process since. That said, many perspectives outside of engineering have entered the arena including perspectives from business analytics [16], video game design [17], architecture [18], and healthcare systems [19] to name a few.

Given that our capstone program includes students from every degree program at the university, we decided to draw inspiration from The Design Thinking Toolbox [11] and The Design Thinking Playbook [10]. These texts offer numerous design theory methods that are not domain specific with case studies from a wide range of fields. The Design Thinking Toolbox offers many concise and actionable methods that come with templates, which were adapted for our capstone course. These books emphasize a cyclical approach to the design process including the following phases: Understand, Observe, Define Point of View, Ideate, Prototype, Test, Reflect. As an example as to how this approach reaches students from different programs, a lecture on design embodiment first introduces product architecture, modularity in design, configuration design, parametric design, and computer-aided design. During lecture, examples were shown from various fields such as computer-aided design in a mechanical engineering context, modularity in personal computers for a computer engineering context, and a university webpage mock-up in a computer science context. A design thinking approach, which is inherently domain neutral, allowed examples and case studies from a variety of contexts to be relevant to all students.

Additional content was sourced from Engineering Design by Dieter and Schmidt [13] and Product Design by Otto and Wood [14] when necessary to fill in content gaps. These texts were critical when developing content more specifically tailored for STEM students. For example, traditional methods for design of experiments (DOE) and different prototyping considerations were sourced from these texts. When compared to previous semesters of our capstone program, the newly implemented design thinking approach to lecture content kept all our students engaged throughout the first semester regardless of degree program. In previous semesters, instructors would hear complaints that the content was only relevant to certain students or was catered for the mechanical engineering students. These complaints have reduced after implementing the new content with plans to continue improving the curriculum in the future.

3 CHARACTERIZING THE CURRENT PROGRAM

Most capstone programs enroll students in a two-semester fall-to-spring course sequence that prepares them for their STEM careers by focusing on real-world problems provided by industry sponsors. Over 90% of capstone projects come from industry partners, with approximately 60% being multidisciplinary. For students seeking a December graduation, there is a special section of the course informally known as "Concurrent Capstone." This 6-credit hour option allows students to enroll in both Capstone 1 and Capstone 2 simultaneously. Generally, fewer than 10% of capstone students meet the criteria to enroll in Concurrent Capstone; however, it is designed to accommodate those who are ahead or behind in their academic progress for various reasons, ensuring they have an opportunity to graduate in an appropriate frame of time. As shown in Figure 1, 30 of our capstone teams are multidisciplinary and 15 are unidisciplinary.

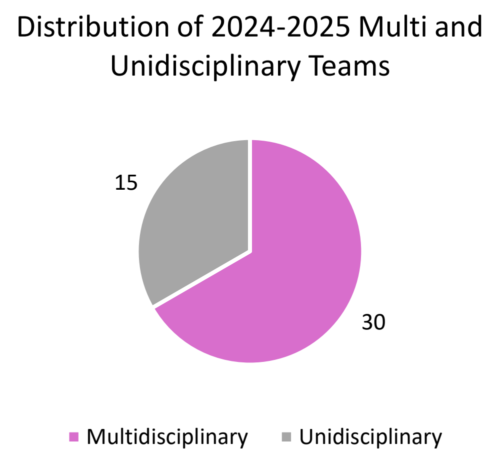

Figure 1: *The distribution of multidisciplinary teams vs. unidisciplinary teams during the 2024-2025 academic year.*

It is important to note that the 15 unidisciplinary teams are exclusively comprised of computer science students. This is necessary for two reasons. First, computer science constitutes by far the largest disciplinary group of students in capstone at 138 students. Second, a portion of industry sponsored projects are highly focused on computer science topics and are best served by computer science students. These projects include application development, artificial intelligence (AI) integration, or development of virtual reality (VR) training environments. These unidisciplinary teams typically attend lectures with instructors from the computer science department when the students are reassigned to different classrooms after receiving their capstone projects. All other teams are comprised of students from various majors depending on the demands of the project. The distribution of students by discipline in our 2024-2025 capstone program is shown in Figure 2.

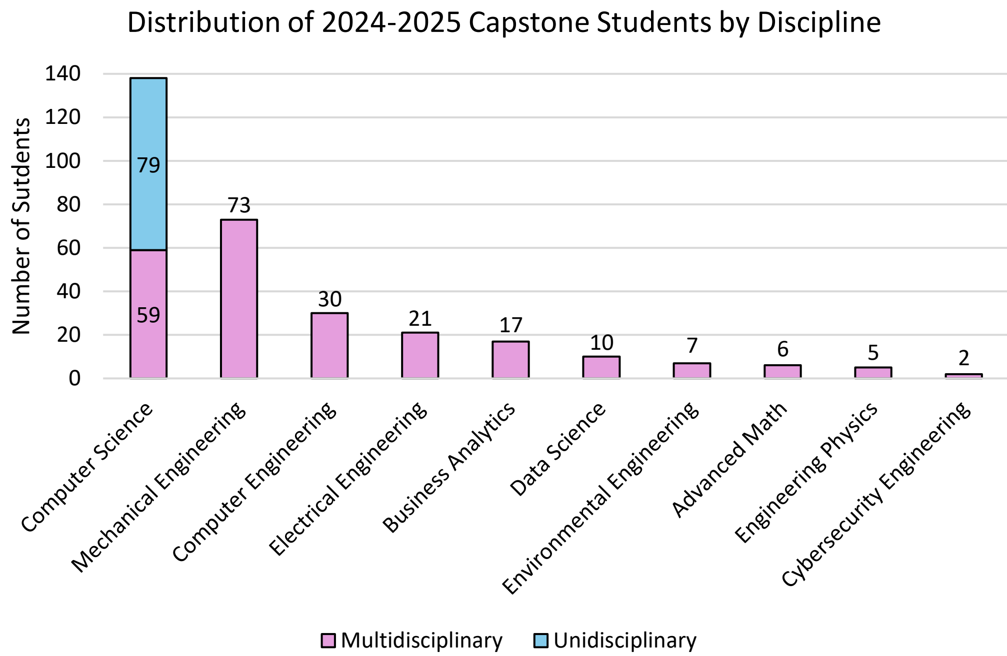

Figure 2*: The distribution of students from each degree program at Florida Poly during the 2024-2025 academic year.*

As shown, computer science has the most students in the program with mechanical engineering having the second most. This distribution is not necessarily reflective of current enrollments in these programs since the teams only consist of students in their final year.

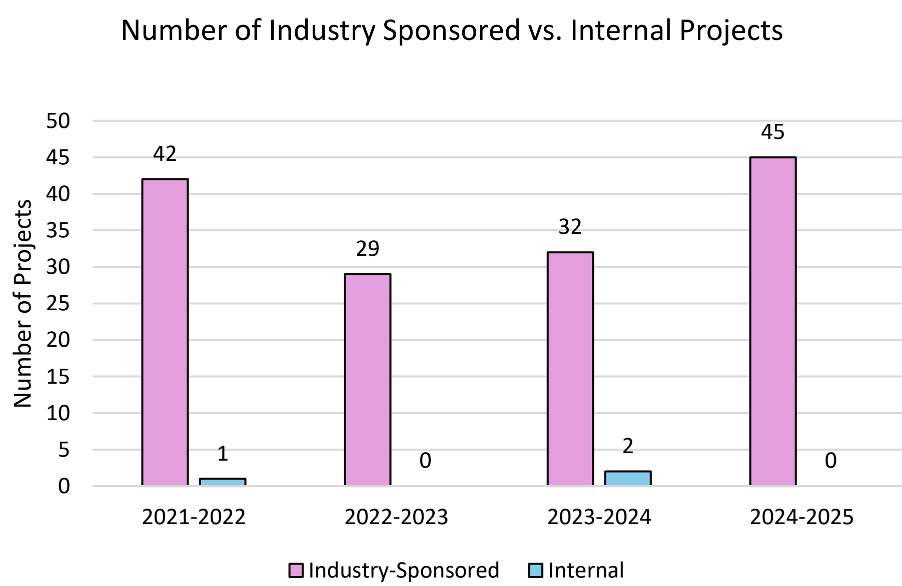

Figure 3*: The number of industry sponsored projects vs. the number of internal projects for the past four academic cycles.*

Figure 3 shows the total number of industry sponsored and internally developed capstone projects per year for the past four academic cycles. The dip in the number of projects in 2022-

2023 was due to increasing team sizes to support the scalability of the program as enrollment at our university continues to increase and difficulty finding sponsors after the pandemic. On average, there have been seven students per team since the 2022-2023 academic year. Our goal is to continue providing a multidisciplinary capstone experience where 100% of the projects are industry sponsored without increasing the average size of a capstone team.

4 PERSPECTIVES FROM DIFFERENT DISCIPLINES

The authors of this paper are the current 2024-2025 instructors for the capstone program at Florida Polytechnic University. The instructors are from four different departments: Mechanical Engineering, Data Science and Business Analytics, Computer Science, and the Electrical, Computer, and Cybersecurity department. The following sections function as a series of micro case studies, written by the different instructors in different voices to characterize how the multidisciplinary capstone program uniquely serves students from different disciplines at Florida Polytechnic University. These testimonies also explore what discipline specific challenges are left to address.

4.1 Mechanical Engineering

Capstone design courses are common within the field of mechanical engineering, serving as the bridge between academia and industry [20]. Capstone is also a required culminating experience by accreditation agencies such as ABET [20], [21]. The capstone format for mechanical engineering degrees differs between universities, ranging from one to three semesters, assigning single-disciplinary teams versus multidisciplinary teams, and leveraging differing extents of industry sponsorship. While the format of these courses varies widely across universities, the scopes of projects remain relatively consistent. Mechanical engineering is a broad field of study, but capstone projects tend to be discipline-specific, catering to a subset of mechanical engineering, e.g., mechanics, fluid mechanics, thermodynamics. In place of industry sponsorship, some programs rely on internal research projects or student competition teams (such as Baja SAE racing, Formula racing, rocketry clubs etc.).

Florida Poly's capstone program seeks to maximize the number of multidisciplinary and industry-sponsored projects, which has proven to offer a unique opportunity for the students. As expected, the multidisciplinary nature of the capstone program ensures that students are not siloed within their own degree program. Multidisciplinary projects allow students to experience challenges outside of the confines of mechanical engineering. The students are required to collaborate across majors, with many differing ideas and vernaculars, similar to the experiences they will have post-graduation. The students must learn the nuances of common phrases for majors other than their own and understand that a single word may have different meanings in different fields. This, combined with the requirement to present to multidisciplinary faculty panels, equips students to communicate effectively with diverse audiences. Additionally, research has shown that one of the desired learning outcomes from capstone is how to effectively work on a project team [1], [22]. Multidisciplinary team structures require dissimilar students to work on the same project/problem. Inherently, this can increase the likelihood of challenges within the team, but also increase the learning potential for teamwork and leadership.

The objective of capstone design is to closely replicate industry standards and practices, which can be effectively achieved through industry-sponsored projects, while offering an opportunity for students to engage in a culminating design experience. That being said, there are still challenges. For example, students often report a lack of communication from industry sponsors, causing frustration and confusion. This is compounded by communication issues among team members, especially between those from different majors. Our capstone program could be improved by more directly addressing these issues before they happen through intentional course content and activities that help equip the students for cross-discipline communication and collaboration. It is also worth mentioning that a mechanical engineering degree is inherently broad in technical content. This breadth shines on multidisciplinary projects, but not without strife. The increased complexity of a multidisciplinary project often leaves students unsure exactly how to make initial progress. Moreover, the broad technical content of a mechanical engineering degree can sometimes leave students struggling to determine how to apply their specific expertise to the early stages of multidisciplinary projects.

4.2 Data Science and Business Analytics

Business programs often rely on a strategic management course, which in turn often relies at least in part on the case study method, to provide a culminating experience [23]. An advantage of this approach is that it can broadly integrate insights from across the curriculum and apply them to a wide array of real-world situations. Florida Polytechnic's Business Analytics program retains strategic management in the final semester of the senior year and incorporates case studies in it and many parts of the curriculum. The Data Science program (DS) includes a course called Contemporary Issues and Case Studies in Data Science, which plays a somewhat similar role in integrating broad insights from the curriculum and applying them to contemporary issues and events. This course is typically taken in the 3^{rd} year and is not intended as a final culminating experience.

The classroom/case study approach, however, is lacking in two major respects that are addressed by Florida Polytechnic's capstone experience. First, most of our business students go on to work with individuals with varied backgrounds over their careers, e.g. engineers and software developers. Preparing students for this reality requires practice communicating with people with diverse backgrounds, whether to distill and refine project requirements, negotiate agreements on how to approach a problem with clients or teammates, or to convey results. Second, while the prepackaged and focused nature of the case study approach allows a wide variety of applications to be considered, it does not prepare students for the deep challenge of identifying requirements, developing potential solutions, and testing those solutions in highly ill-defined settings.

In our experience, there are several sources of student frustration with our capstone sequence. One is the ill-defined nature of the projects which makes expectations for success ambiguous. Another is the difficulty of establishing a shared understanding with teammates from other disciplines with different vocabulary and different frameworks for conceptualizing problems. A third relates to unclear communication or a lack of support from industry sponsors. These difficulties interact with and exacerbate one another. None of these complications arise in relatively sterile single discipline classroom settings, including in strategic management courses serving as culminating experiences for business programs.

Yet, providing students the opportunity to engage with these realistic workplace challenges, to learn to deal with them productively despite the frustration involved, and to do so before they encounter them in the higher stakes environment of the workplace, is one of the major advantages of Florida Poly's approach to capstone. The real challenge is for faculty mentors to prepare students for this frustration and mentor them throughout the design process, even when the projects themselves may not be in the instructor's primary discipline. Great efforts are made to prepare students for these frustrations, coach them through the parallels between their capstone experiences and the STEM workforce, and support them by providing resources that expand their undergraduate education beyond their home discipline.

4.3 Computer Science

Computer science programs typically leverage senior projects or a senior thesis either in small groups or individually. It is most common for these projects to be focused on software development. Some programs do offer a capstone experience, but they often center around computer science principles specifically as a summative experience for their undergraduate degree. Many programs emphasize topics such as gathering user requirements, testing approaches, software solutions, and long-term software maintenance in courses delivered during the 3rd or 4th year of their degree program. While approaches to a summative design experience in computer science reinforce technical skills, they do not mirror the complexity and collaborative nature of real-world computer science projects in industry.

Florida Poly's multidisciplinary capstone program has added a lot of value to our computer science students. In their careers, computer science graduates will often work to provide software support to sub-teams on a design project. These sub-teams are often focused on different subsystems of the design project and are composed of many professionals from different disciplines. Our capstone program mimics this experience for our students. Further, hardware selections made by capstone team members from different degree programs constrains the design space and increases solution complexity for our computer science students. Computer science faculty who have taught capstone at Florida Poly have also shared the value it brings for them. The faculty gain exposure to domain-specific problems that are outside of their direct expertise. They often learn interesting new things from the non-computer science students throughout the two-semester sequence.

Despite the strength of our program, a few challenges remain from the perspective of computer science. It has been noticed that computer science students often struggle to convey computer science concepts to non-computer science audiences. This is particularly prevalent during our panel sessions, where panelists are made up of faculty members from many different departments. Providing students with more strategies to communicate their efforts may be worth exploring in future iterations of our program. In addition, large capstone teams often subdivide themselves into smaller groups while working on their projects (often aligning by discipline). This can cause tension as different sub-groups work on the project from various perspectives, each advocating for their own vision of the solution. This leads to communication issues. In the future, the faculty plan to continue improving the course content by identifying vernacular with discipline-specific meaning and exposing students to the various ways different disciplines leverage technical language.

4.4 Electrical and Computer Engineering

For the electrical and computer (ECE) engineering programs (as separate ABET accredited programs), project-based learning is one of the most effective techniques widely adopted in North America and worldwide. These disciplines rely heavily on deep mathematical theories. Without real-life project involvement, it is very difficult for a student to fully grasp all the intricate details. While design education is important for ABET accreditation, it importantly serves to prepare students for entry-level careers in ECE disciplines that require evidence of prior design experiences. In ECE programs, it is common for at least 20% of courses to include a project component. These projects are limited to the course content, with about 8 weeks for completion, and involve smaller project teams (typically 2-5 students). This is true in Florida Poly's ECE program as well. While many ECE capstone programs seek industry sponsors for these projects, it can be a challenge for many departments to find enough industry-sponsored projects specific to ECE disciplines to serve all the students. This gap is often filled with faculty-led research projects, student proposed projects, student organization contributions, or external competitions. However, these kinds of projects might not prepare students for their careers as well as industry sponsored projects.

Florida Poly's multidisciplinary capstone project addresses some of the common concerns shared by many ECE departments. For example, ECE students can contribute to cross-disciplinary industry sponsored projects where the same volume of industry sponsored projects would not be possible if focused on a single discipline. In addition, these projects are much larger in scope, allow for direct industry interaction/mentorship, and give our students an opportunity to learn how their ECE skills can contribute to projects that are not strictly within their own domain. There is a big difference between designing an audio amplifier circuit design versus the design of a mm-wave radar sensor to measure the concentration of microplastics in water (an actual project our students worked on in the past). If the sensor is expected to be mounted on a UAV, then the problem becomes 100% real and open-ended. Issues like economic feasibility, robustness, maintainability, environmental impact and other considerations, which are likely to be less relevant for ECE specific course projects, are of great importance in a multidisciplinary capstone project. Overall, our ECE students' capstone course experience is very comparable to a 1st-year industry experience working on a design team.

There are several challenges left to be addressed. In typical ECE programs, communication and documentation skills are usually considered of secondary importance compared to coding or circuit design skills. A good percentage of ECE students start Florida Poly's Capstone Design course without full appreciation of these important details. We have observed several students with excellent technical skills not being productive enough on their team because of lacking communication skills or lacking appreciation for these skills. In addition, Florida Poly's ECE students pick a concentration during their 3rd and 4th years of study. In these concentrations, they focus on a relatively narrow area of study. For an industry sponsored, multidisciplinary, open-ended project, an ideal ECE team must have several such highly specialized students (ideally from different concentrations). Finding a well-rounded ECE capstone project team leader has proven challenging since this role requires a broad understanding of topics rather than a deep, narrow understanding. Capstone mentors play a critical role in mitigating this issue, but it has always proven to be a major challenge in the past couple of years. To address these issues, it may be necessary to make curriculum adjustments that prepare our ECE students for the communication skills necessary for a successful capstone project. In addition, it may be necessary to examine how concentration areas interact with capstone success, and where we can incorporate experiences that expose our students to more broad selections of ECE topics.

5 LESSONS LEARNED & RECOMMENDATIONS

Based on the mini case studies from the different departments, a few points of consensus are evident. First, a multidisciplinary capstone program helps prepare our students for their careers after graduation across the various disciplines. Professionals in STEM careers will most often work on projects that are not unidisciplinary. Our capstone program confronts our students with the unique challenges of communicating with others of differing expertise all while managing the expectations of internal and external stakeholders. That being said, communication was also universally noted as a key challenge we face. Different disciplines use different vernacular. This can lead to communication issues between team members as they search for and develop solutions for their project. This also includes communication issues with industry sponsors or to faculty panelists during presentations. While the introduction of the Dale Carnegie communication training has helped mitigate an aspect of this issue, there is still more work to do. It is also worth noting that the case studies highlight that typical undergraduate curricula do not necessarily do a great job teaching students how to apply their technical skills in unfamiliar circumstances. Interestingly, all the faculty that contributed to the mini case studies noted that our multidisciplinary capstone program offers value for them as well. They are often exposed to projects and contexts that are outside of their field, forcing them to improvise and learn new things from the project itself. Most importantly, the faculty are learning new and interesting things from their students' involvement in these projects.

As a newer university, it can be challenging to secure industry sponsorships for a few reasons. Many companies already have industry sponsors, especially larger, well-known companies. We recommend looking locally for sponsors from smaller companies that might be excited to work with their local university. However, working with a virgin industry partner presents its own challenges. Notably, faculty/staff liaisons must coach industry mentors on how to work with students, how to align their mentorship with course deliverables, and how to manage expectations for project outcomes. As we know, not all capstone projects result in innovative success. Further, it is critical to avoid a situation where students become free labor for industry sponsors. After all, capstone design as an educational experience for our students is the priority.

It isn't hard to imagine that some might be resistant to trying a multidisciplinary capstone approach where finding appropriate projects could be challenging. However, in our experience, the majority of projects are inherently multidisciplinary by nature or are exclusively based in computer science. Some of the computer science projects are indeed multidisciplinary, but they typically are multidisciplinary within subgenres of computer science. For example, they may incorporate elements of data visualization, data science, business analytics, or cybersecurity, but do not include other multidisciplinary engineering topics (e.g., thermal-fluids or circuit design). Capstone faculty can work with industry sponsors to expand the scope of the project when necessary. We would encourage anyone interested in trying to implement multidisciplinary projects to take a look at their past unidisciplinary projects and wonder how they could be transformed to include students from other majors, or whether they were actually multidisciplinary at the outset before faculty pruned the scope of the project for their students.

Of course, the logistics of this are challenging. Overhead costs, the availability of space, garnering faculty engagement, and choreographing faculty panels four times over two semesters present significant logistical challenges. While tackling these challenges is difficult, it is worth it. Our students are exposed to projects with greater complexity, learn how to communicate to those with differing expertise, gain presentation skills, and are overall better prepared for careers in STEM fields. Further, faculty become more involved in the capstone process offering their unique perspectives and experiences to our students' education. At many universities, the majority of faculty may never interface with their capstone program, which is supposed to be a culminating design experience. Awareness of their capstone program operations can inform how and what they teach in lower-level courses that better contextualizes how technical content fits into a bigger picture, creating a more vertically integrated educational experience for students. As a recommendation, we recommend looking at successful university coop programs to appreciate how resources can support something like a multidisciplinary capstone program at scale including the availability of funding, staff, faculty, space, and industry partnerships.

As a final recommendation, don't do this alone. One university department can't make this happen. You need champions across your various degree programs working together to make strides towards a multidisciplinary capstone program. Those involved will come from different disciplines with different experiences and differing expectations for a capstone design experience. It is also critical that this cooperation is in conjunction with administrative support in all its forms. Course registration, student learning outcomes, allocated credit hours, etc. can affect accreditation criteria and could take a lot of time to get right through multiple levels of approval. It may be beneficial to start small and grow towards whatever vision your faculty may have for the program. As a place to start, consider incorporating a few Engineering Projects in Community Service (EPICS) projects into your capstone program to get a feel for how this style of capstone might work in for your university [24]. EPICS was founded at Purdue University in 1995 and offers real-world experiences for engineering students through non-profit community projects. EPICS has been adopted by many other universities since.

6 MOVING FORWARD & CONCLUSIONS

In the short term, Florida Poly is seeking a community partnership with Catapult, a privately funded, non-profit incubator for startups and entrepreneurs. They have access to fabrication processes that the university does not. This partnership will also connect Catapult's clients to academic experts in various fields that can support and counsel startup companies as they venture into innovative new spaces. In addition, Catapult may be able to help connect our students to business owners looking to accelerate their ideas with sponsorship for undergraduate capstone projects. These connections have the potential to lead to internship and career opportunities for our graduates. Next academic year, the program is also going to make efforts to secure sponsors earlier in the summer so that students can be assigned to projects earlier in the fall semester. In addition, the program might recruit graduate students to pilot a model where capstone teams have an opportunity for more individualized mentorship beyond the teams' sponsors and instructor. Research has shown that industry volunteers may also be viable for this role [9]. As the program grows, there is interest in diversifying our sponsors; in some cases, a sponsor will occasionally fund 5+ projects. While the program deeply appreciates the support from these sponsors, it would be beneficial to expand our list of industry partners, leading to variety in project availability, which may better serve our multidisciplinary format. Finally, the university is in a reaccreditation cycle. This year, the faculty are closely examining student outcome alignment within the program, and adjustments to this alignment might shape the inclusion of additional lecture content, especially during the first semester of capstone.

In the coming years, Florida Poly plans to rapidly expand. By 2030, the university is expecting to increase enrollment to 3000 students across all our programs, which is over a 50% increase in student body. This will come with significant challenges for our multidisciplinary capstone program. To meet demand, we will need to plan for additional project spaces for our capstone students, dedicated faculty to help run the program, more supporting staff (e.g., administrators to help with purchasing, faculty to seek sponsorships, and instructors to teach content), and additional industry partners to name a few. These challenges will be significant, but the value for our students, faculty, community, and staff makes the effort worth it.

It is important to point out that this paper is in no way criticizing universities with significantly larger enrollments, and we recognize the challenges of doing a multidisciplinary capstone program with thousands of students in programs that have established senior design procedures. Our program currently faces challenges with imbalanced student populations between our various degree programs, space issues, and finding faculty to shift some of their focus towards supporting this program even with our comparatively smaller student body. All these issues will be more complex as we grow if we want to keep as many projects multidisciplinary as possible. This paper is intended to primarily serve as a case study for those wanting to incorporate multidisciplinary elements into their programs or for younger universities crafting a capstone design sequence of their own. We hope that the recommendations, findings, and lessons learned are useful. We also hope that this paper serves as a reference point showing how a multidisciplinary approach to a culminating capstone experience can work and the value it adds to our students' educational experience.

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