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Faculty-Driven vs. Student-Driven Design Projects for Mechatronics Engineering Capstone

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The senior capstone design experience plays a crucial role in undergraduate engineering education, offering students a valuable opportunity to bridge the gap between theory and real-world practice. Typically spanning a year, this team-based challenge allows students to apply their knowledge to a comprehensive engineering design project. In traditional disciplines like mechanical or electrical engineering, students often engage in industry-sponsored projects that are carefully scoped to provide both a rewarding educational experience and tangible value to industry partners. However, for interdisciplinary fields such as mechatronics engineering, finding industry projects that fully capture the essence of a mechatronics capstone project can be more difficult due to the variety of elements required but need for a narrow enough scope for undergraduates. This paper presents a two-course senior capstone design sequence at Middle Tennessee State University, specifically tailored for undergraduate mechatronics engineering students. It outlines two distinct approaches employed at Middle Tennessee State University to enhance the capstone experience for mechatronics engineering majors. The first approach, used from 2015-2019, features faculty-driven design projects, where professors independently define the problem statement, scope, and design criteria, and assign team members, with no input from students. The second approach, implemented from 2019-2024, emphasizes student-driven projects, where students form teams themselves and collaborate closely with faculty to co-create the design challenge, identify the problem, and establish appropriate design constraints. The strengths and weaknesses of both approaches are compared, and sample projects are provided, along with general student feedback and faculty observations, as well as survey data from the most recent 2024 class. The authors aim to share insights, resources, and lessons learned at Middle Tennessee State University that may benefit faculty at other institutions tasked with developing capstone course sequences for mechatronics engineering majors. Additionally, the approaches discussed in this paper can be adapted for traditional mechanical or electrical engineering programs, particularly for students with a strong interest in mechatronics, robotics, and interdisciplinary applications.

I. Introduction

Mechatronics engineering capstone is essential to the undergraduate mechatronics engineering experience. A mechatronics engineering capstone is a culminating design project experience that demonstrates the skills that students have acquired throughout their undergraduate degree program. It serves as a way for students to apply principles from mechanical, electrical, and computer engineering, alongside control system and user interface design, to solve real-world problems. These projects often involve the design, analysis, simulation, optimization, and prototyping of automated systems or devices, showcasing students' ability to innovate in areas such as robotics or fixed automation. By tackling these challenges, the capstone experience prepares students to address industry demands for mechatronics solutions, bridging theoretical knowledge with hands-on application.

Mechatronics is a rapidly growing field, yet there are surprisingly few undergraduate programs dedicated specifically to mechatronics engineering. For example, the Bachelor of Science in Mechatronics Engineering at Middle Tennessee State University is the only program of its kind in the state. Since few undergraduate mechatronics engineering programs exist, there is limited guidance in the academic literature on how to effectively structure and implement a comprehensive, two-semester-long capstone project experience tailored to undergraduate mechatronics engineering students. While discipline-specific capstones in mechanical, electrical, or computer engineering are well-understood, the complexity of integrating these fields in a cohesive mechatronics engineering capstone remains relatively unexplored in terms of implementing the capstone sequence at scale. The bulk of work in the literature is focused primarily on describing a mechatronics sequence within an undergraduate mechanical or electrical engineering program. In 2006, Muller et al. [1,2] described a mechatronics course within the Penn State Electromechanical Engineering Technology program. This work provides an excellent case study on a wind energy mechatronics senior design project. In 1999, Murray and Garbini [3] presented a mechatronics sequence within the Mechanical Engineering Department at the University of Washington. This work discusses a mechatronics sequence followed by a ten-week mechatronics capstone design course which included 24 students working on six different mechatronics projects. Similarly, in 2014, Jovanovic et al. [4] implemented a mechatronics design methodology in the Mechanical Engineering Technology program at Old Dominion University. In this program, multiple mechatronics courses were added to the curriculum, and the senior design projects placed a greater emphasis on mechatronics. In 2017, Rai et al. [5] described the mechatronics engineering pedagogy used within the Mechanical Engineering program at the University of California Los Angeles. In this work, Rai et al. took an approach in which all students received identical project tasks and design requirements. In 2019, Currie and Craig [6] outlined a mechatronics senior design course within the Mechanical Engineering Department at Hofstra University. This work explores a capstone experience in which each team of students design a planar mechanism and follows a comprehensive mechatronics engineering design methodology. While each of these examples outlines a mechatronics engineering design process, none of them are implemented in the context of an undergraduate mechatronics engineering major. One example of a mechatronics engineering capstone within a mechatronics major in the literature was presented by Marshall and Ham [7] in 2017 for the Kennesaw State University Mechatronics Engineering program. However, this work summarizes an isolated industry project and not a comprehensive two semester senior design course sequence. Thus, there is a lack of literature around undergraduate mechatronics senior design for mechatronics engineering majors. This gap in the literature poses a challenge for educators aiming to design meaningful experiences that align with industry demands and prepare students for the multifaceted nature of mechatronics careers.

Creating an undergraduate mechatronics capstone experience poses challenges when compared to implementing a disciplinary capstone experience. Primarily, balancing the scope and complexity of industry-sponsored projects with undergraduate capabilities is a significant challenge in mechatronics capstone design. Industry projects often focus on highly specialized needs, which may lack the integration of mechanical, electrical, software, and control components required for mechatronics or are too complex for undergraduates to complete within their resources and timeframe. Conversely, academic projects are well-suited for learning objectives but may lack the real-world constraints and relevance of industrial applications. To address this, mechatronics engineering capstone programs must carefully select or adapt projects to ensure they integrate these components cohesively while remaining achievable. Further, mechatronics capstone projects are often more challenging to scope properly for industrial partners than other forms of interdisciplinary projects. For example, interdisciplinary mechanical and industrial engineering projects are common and can be easily accommodated by industry. In contrast, mechatronics engineering has a much narrower scope of project types that capture the essence of a mechatronics engineering capstone project.

This work describes the two-semester undergraduate mechatronics capstone experience developed and implemented at Middle Tennessee State University, with the goal of providing an example of how to implement a mechatronics capstone experience at scale. Additionally, the purpose of this paper is to compare faculty-driven and student-driven mechatronics capstone projects across several dimensions: student satisfaction, project quality, skills development, and the respective pros and cons of each approach. *Faculty-driven* projects are defined as student projects where professors independently define the problem statement, scope, and design criteria, and assign team members, with no input from students. *Student-driven* projects are projects where students form teams themselves and collaborate closely with faculty to co-create the design challenge, identify the problem, and establish appropriate design constraints. The comparison of both types of projects aims to identify how each model supports the achievement of ABET student outcomes (SO's), including the development of technical and professional skills, as well as how they influence students' overall capstone experience.

The hypothesis of this paper is that both faculty-driven and student-driven mechatronics capstone projects can effectively instill the essential ABET student outcomes and professional skills in students, even without direct industry sponsorship. These projects provide a robust platform for students to engage with mechatronics engineering challenges, integrating mechanical, electrical, software, and control components. By navigating the complete engineering design process —conceptualization, design, analysis, optimization, prototyping, and testing—students develop critical competencies such as problem-solving, teamwork, communication, and ethical decision-making. Furthermore, students demonstrate a strong investment in learning these skills, driven by their recognition of the importance of hands-on experience and practical knowledge for success in the workplace. This motivation ensures that mechatronics engineering capstone projects, regardless of their source, serve as a vital link between academic preparation and industry expectations.

The remainder of this paper is outlined as follows. Section II describes the methods and approach used for both faculty-driven and student-driven projects. Section III presents the qualitative and quantitative results comparing both types of projects. Section IV provides a discussion of the results, and Section V provides concluding remarks and ideas for future improvements.

II. Methods

This section provides an overview of the methods used for both faculty-driven and student-driven mechatronics capstone projects. The capstone experience at Middle Tennessee State University is a two-course sequence taken during a student's senior year. Students take a three-credit senior design course in the Fall semester followed by a three-credit senior design course in the Spring semester. The first mechatronics engineering capstone cohort was in 2015, and from 2015-2019 the program primarily used the faculty-driven model. From 2019-2024, and continuing in the present, the program has primarily implemented the student-driven model. During the first three years of the faculty-driven model, this course was taught by a single instructor, who was joined in the 2018-19 school year by a second instructor co-teaching. The second instructor then taught the course alone beginning with the 2019-2020 school year, transitioning to the student-driven model. In contrast to traditional engineering programs, where faculty often share senior design project advising responsibility, instructors of this course are solely responsible for all aspects of the course, without assistance from additional engineering faculty in the department.

a. 2015-2019: faculty-driven

Due to the mechatronics engineering program at Middle Tennessee State University being a relatively new program at the time, the 2015-2016 academic year was the first year the capstone sequence was developed and implemented at Middle Tennessee State University. The initial cohort had 16 students and expanded to 60 students by 2019. From 2015-2019, the program used the faculty-driven model for the capstone sequence. The faculty-driven model is one where professors independently define the problem statement, scope, and design criteria, and assign team members, with no input from students.

Each project is designed by the instructor to ensure that every project meets the necessary ABET requirements for a mechatronics undergraduate degree. The projects must be designed such that the project can be completed during the two-course sequence and within a reasonable budget. Typically, $1000 is provided for the budget, and students are not permitted to seek any additional donated funding. An example project for a faculty-driven project is the "WhiteBoardBot" used in the first year of implementing this model. For this project, students were tasked with designing a robot that could automatically write and erase text on a whiteboard based on user inputs. This project was selected because it meets the requirements for a mechatronics engineering project. It requires a combination of mechanical, electrical, computer engineering, and control system design to solve a real-world challenge. Students must design and select appropriate mechanical components, sensors, and actuators. The system also needed to contain a user-friendly graphical user interface. Safey and professionalism were highly emphasized as well.

The faculty-driven approach is meant to mimic as many aspects of industry as possible without having an industry sponsor. For example, the course instructor acts as the "customer" that provides the problem statement to the engineers. Students are not allowed to select their team, as this is often not possible in industry. Student teams were required to have both a project manager and technical lead to emulate industry team dynamics. The design criteria are often somewhat vague and require questioning between the students and the "customer" for clarity. Students needed to setup specific meetings with the "customer" and could not simply ask the instructor to clarify the requirements at any given moment. Additionally, the customer requirements often would change somewhat significantly halfway through the Fall semester. This forced students to adapt their designs and deal with simulated industry challenges such as "change orders" and negotiating "wants" versus "needs". Thus, in this model, the instructor needs to carefully play the role of both instructor and "customer" simultaneously, ensuring students receive the best training possible to prepare them for an ever changing and challenging industry projects. After the first semester, "upper management" (i.e., another faculty member) would visit the class to learn about project progress and ask the students difficult questions. Industry standard processes such as project management, version control, and extensive documentation were emphasized. Additionally, students were required to engage with industry standards and regulations when developing their solutions. This shows how the faculty-driven approach can be used to create a challenging and real-world mechatronics engineering capstone project without directly involving an industry sponsor.

b. 2019-2024: student-driven

The current method used for capstone projects, adopted in 2019 at the request of students and due to program growth, is student-driven. One challenge of the faculty-driven model is that it works well with a relatively small number of students (< 20 or so) but becomes challenging with a large number of students. With approximately 15 or more new projects needed each year, a student-driven approach makes managing the capstone sequence practical for a single instructor. Prior to the start of the semester, the instructor sends out a call for proposals. Students are encouraged to form teams and submit project proposals following certain guidelines and a template (see Appendix A). All projects must be novel and useful at least in a proof-of-concept sense, and comprise invention of a portable, electromechanical system with a user interface. Both team and individual submissions are allowed, in case a student has an idea for a project but has not found teammates (this will be discussed subsequently). The instructor then reviews the proposals, accepts or rejects as appropriate, and works with the students of accepted projects to refine the design constraints and determine an achievable project scope as well as stretch goals. In this manner, the students are actively involved and invested in the project definition, while the instructor ensures that each project includes all the components necessary for an ABET-accredited Mechatronics capstone project while maintaining a reasonable scope for undergraduate students to achieve.

Because proposal submission is encouraged but not required, some proposals were rejected, and some students may have submitted accepted proposals but not found enough teammates. Therefore, the first day of class is devoted to project signups. The instructor compiles all the finalized proposals into a single PDF, which the students review in class and then sign up for whichever project they wish to join. Students are encouraged to specify their first, second, and last choice projects for ease of assignment, as well as any classmates they do or do not wish to work with. The instructor then optimizes teams to ensure each has 3-5 members as appropriate for the difficulty of the project and that as many students as possible are working on a project with teammates they enjoy. Typically, 85-90% of students receive their first choice of project and teammates.

c. Course process

The capstone course follows a two-semester lecture-lab format. Each course is three credit hours and five contact hours per week, meeting twice a week for 2.5 hours each time. The first semester focuses on design, mathematical modelling, simulation and subsystem prototyping, while the second semester focuses on system integration, fabrication, testing, and optimization. The whole course is structured to meet all seven ABET student outcomes in multiple formats over the two semesters. A guide for implementing this method of engineering capstone instruction is available in [8], an open educational resource. Course milestones are shown in Table II.1:

Table II.1: Capstone Sequence Milestones

Milestone 1	Detailed design	Semester 1 midterm
Milestone 2	Prototyped subsystems	Semester 1 final
Milestone 3	Integrated subsystems	Semester 2 midterm
Milestone 4	Optimized system	Semester 2 final

Capstone I, the first semester, consists of a guided design cycle, spanning brainstorming, design, calculations, prototyping, testing, and revision. Additional topics such as sensors, controls, budgeting, project management, project pitching, market analysis, and ecosystem mapping, are also covered. A flowchart depicting phases of the design process with related class activities is shown in Figure II.1. One or more class periods are devoted to each topic, with a few additional class periods designated for prototyping work days, as well as a midterm and final presentation. Students are expected to have their full design drafted by the midterm, and their finalized design as well as individually prototyped subsystems completed by the final.

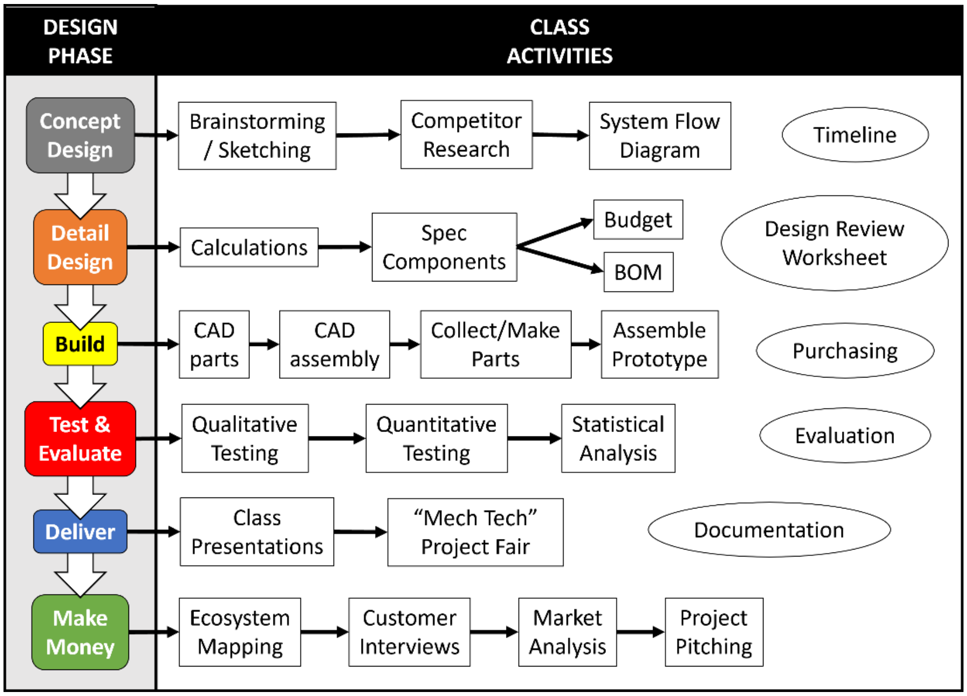

Figure II.1. Capstone Course Diagram

Capstone II, the second semester, is primarily lab-focused, with most class periods devoted to project work and technical consultation with the course instructor. By this point, the design is typically complete, and the students are focused on integrating their subsystems into a fully functional system, testing, and optimizing their final product. Students are expected to have their full system integrated and functioning by the midterm, with the second half of the semester devoted to testing and revision, in order to present a refined and reliable system at the final.

Grading for the course is based on a combination of documentation, presentations, demonstrations, and individual participation, as well as a peer evaluation factor. Approximately 40% of the course grade comes from individual participation, in the form of in-class activities and biweekly progress checks (written or oral). The other 60% is the team grade component, roughly half of which is allotted to documentation (final project report, user manual, assembly guide, etc.) and the other half allotted to presentations and demonstrations. In the interest of ensuring individual accountability in a team environment, the "team" portion of each student's grade is scaled based on peer evaluations. The peer evaluations also provide an opportunity for the instructor to compare his or her observations of a student's performance against the observations of the student and his or her team, so that problem areas can be more precisely addressed.

d. Data collection

In order to compare and contrast the two different approaches of faculty-driven versus student-driven projects, and gauge the effectiveness of each on student performance and satisfaction as well as meeting ABET requirements, the authors developed surveys modeled after the one by [6], (see Appendix B). Students enrolled in the capstone courses in 2024 were asked to identify which ABET outcomes the course met sufficiently, as well as rate their perceived competency level with each, and identify hardware and software skills they believed to be important to succeed as an engineer. These survey results were collected and analyzed, along with course grades, final report grades, and peer evaluations for 2024 and previous years for comparison. Qualitative instructor observations and anecdotal evidence from both approaches was also included to round out the analysis. This study was approved by the Middle Tennessee State University IRB under study #IRB-FY2024-247.

III. Results

1) Faculty-driven

The faculty-driven model was implemented from 2015 to 2019. During this period, student survey results were unavailable. Therefore, this discussion relies on instructor observations and anecdotal evidence. According to these observations, the faculty-driven model was highly successful in achieving ABET student outcomes. An example of a student capstone project from this time is shown in Figure III.1 [9]. In this project, students were tasked with designing a robot capable of playing the popular game Yahtzee against a human opponent. As depicted, the project fulfills all the requirements for a mechatronics engineering project, encompassing mechanical, electrical, pneumatic, and computer vision components. The robot begins by rolling the dice using a mechanical system. It then identifies the numbers on the dice through computer vision. Based on these readings, the robot determines which dice to keep and which to re-roll. Using precision control, the robot picks up the selected dice with a pneumatic system and places them in a Yahtzee cup to roll again. Throughout the process the system tracks the overall score and updates its decision-making. The design integrates various sensors and actuators and includes multiple safety features to ensure safe operation. Additionally, the robot is operated through a graphical user interface. This project demonstrates the integration of key mechatronics principles and showcases the effectiveness of the faculty-driven model in fostering comprehensive engineering skills.

While the Yahtzee robot was not industry sponsored, students that completed the project demonstrated many skills that are necessary for designing fixed automation for industrial applications. To ensure the project meets ABET student outcomes, the project required extensive documentation. Documents required included an engineering design document (main project report), technical specifications document, project management spreadsheet, sprint planning spreadsheets, test procedures, source code, electrical schematics, customer acceptance document, a user manual, and final project poster and presentation. This comprehensive documentation allowed for evaluation of many of the ABET student outcomes. Extensive mathematical modeling, simulation, and optimization were highly emphasized.

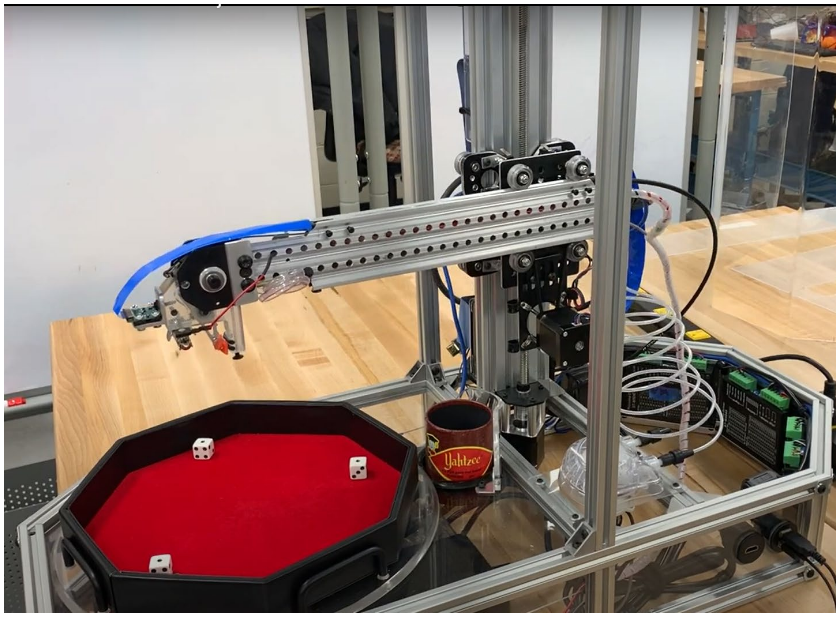

Figure III.1. Example Faculty-Driven capstone project [9]

Instructor course evaluations for the capstone courses during this time were generally favorable with overall scores typically ranging from 4.6/5.0 to 4.9/5.0 across a variety of different questions related to course effectiveness and quality. Students were generally highly satisfied with the courses. The projects were often shown in local and state media [10-12]. The overall grade distributions are not available, but generally students performed well with almost all students passing the capstone courses. The capstone projects were used as a major tool for the initial ABET accreditation of the program. The program was accredited with the highest marks – no deficiencies, weaknesses, or concerns. This anecdotal evidence, including passing ABET accreditation, shows that faculty-driven approaches for mechatronics engineering capstone projects can lead to a successful outcome.

2) Student-driven

The student-driven model was implemented from 2019-2024 and was also highly successful, evidenced by observations, media attention, student course evaluations, and survey results. An example project from this time frame is shown in Figure III.2. This is a remote-controlled inspection submersible, inspired by the catastrophic implosion of the *Titan* sub in 2023 and a desire to prevent future calamities. This prototype consists of a watertight hull, hydraulic ballast tanks, thrusters, camera, and is tethered to a control buoy (not pictured), which sends and receives remote control signals from a user-operated gaming controller and relays those signals through an Ethernet cable to the sub. Including all the required subsystems of mechanical, electrical, software, and user interface control, the sub proved to be reliable and watertight up to a depth of at least 3 m. This project and other similar ones were spotlighted in a video from Middle Tennessee State University's media department [13].

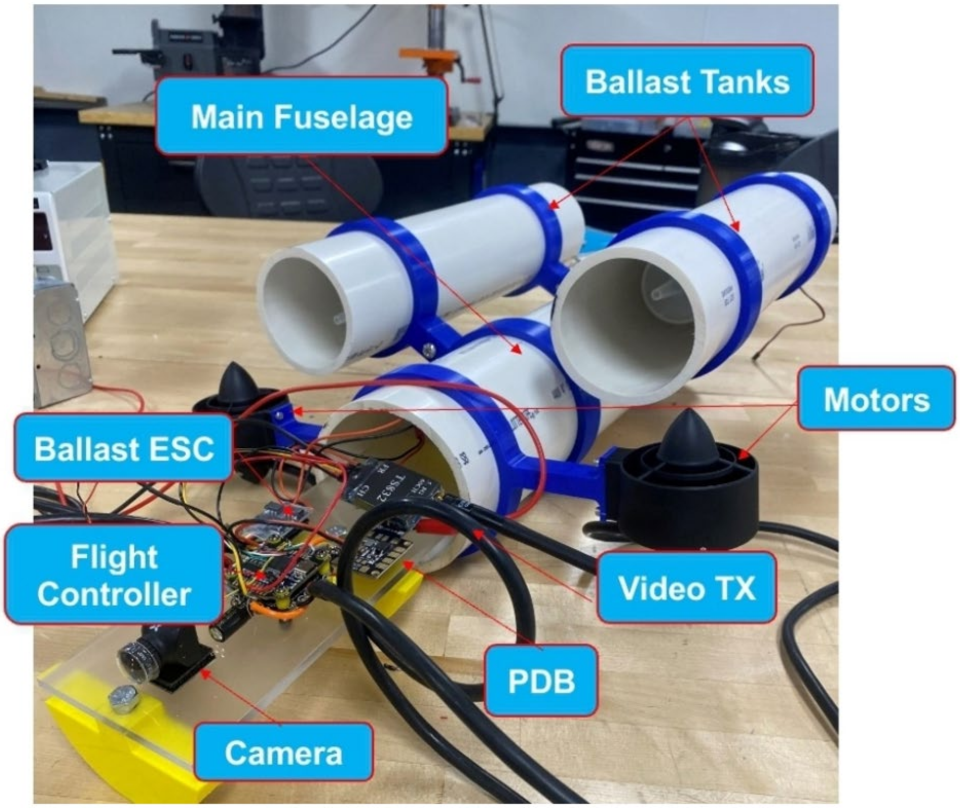

Figure III.2. "*Odysseus"* Remote-Controlled Inspection Submersible. Photo taken from student report; names omitted for privacy.

The inventions of this and other student-driven projects demonstrated the design, prototyping, and documentation process similarly to the faculty-driven process used in previous years. Every year, the projects are showcased in a departmentally-sponsored technology expo, open to the public, where the students present and are judged by engineers from local industries. Judges' ratings of the student projects typically fall within the range of 18-20 out of a possible 20 points. These projects are often spotlighted by local media [14-19]. Student course evaluations of the instructor (encompassing a variety of questions) typically fell within the range of 4.4/5.0 - 5.0/5.0 during this time frame. In 2023, the program also passed its first audit post-accreditation, where the reviewers spoke favorably of the capstone course.

Results from the 2024 student survey (n = 45) are shown in the figures below. The first survey measured the sufficiency of the course in meeting ABET student outcomes (SO's) as well as additional desirable effects for students. Figure III.3 lists each ABET student outcome from [20] (sometimes split into separate items to measure different aspects) and indicates the percentage of students who agree that the course meets each item sufficiently. Figure III.4 lists additional desired effects of the course that are not specifically ABET-related, and indicates the percentage of students who agree with each statement.

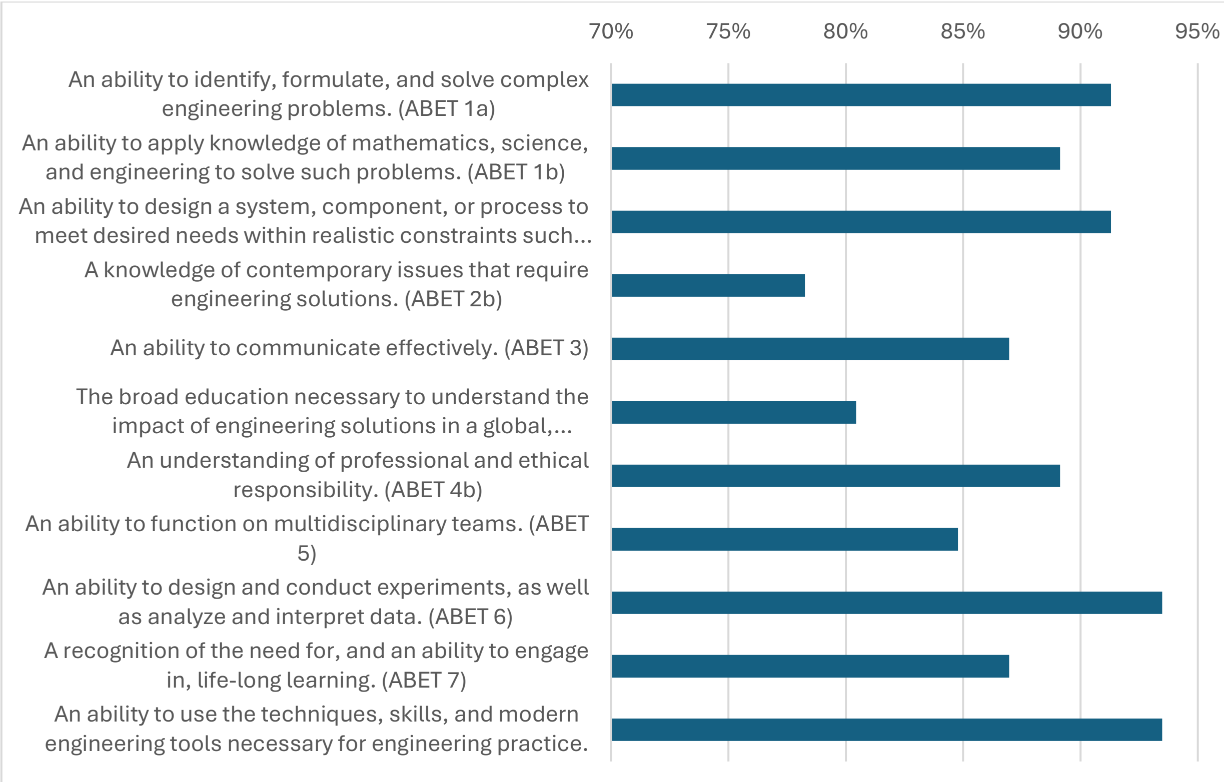

Fig. III.3. Capstone Course Meeting ABET Student Outcomes. The vertical axis indicates the ABET student outcomes, while the horizontal axis shows the percentage of students who believe the course meets the requirements sufficiently.

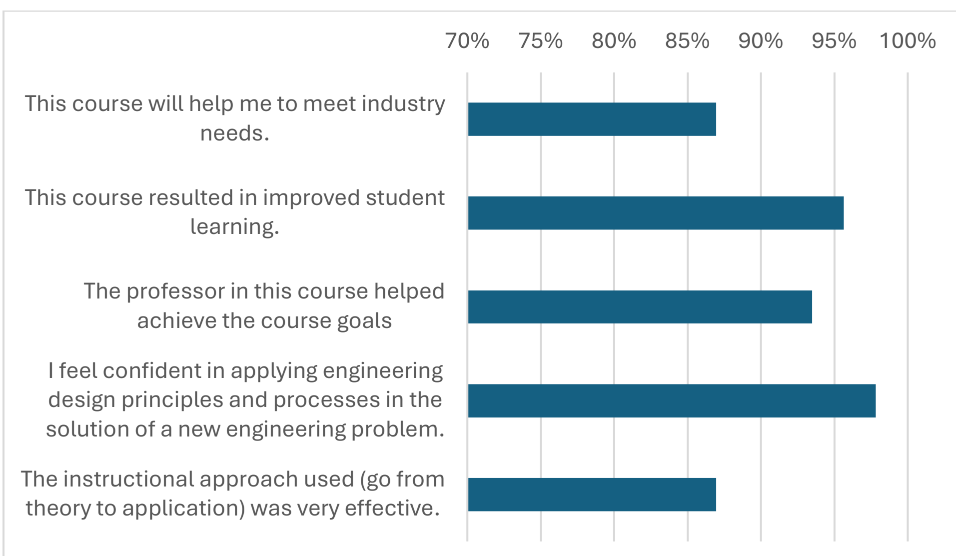

Fig. III.4. Capstone Course Effectiveness. The vertical axis indicates desired impacts of the course on students, and the horizontal axis indicates the percentage of students who agree with each statement.

The second survey measured students' perception of their own skills related to each ABET student outcome. The students rated themselves on a scale of 0-10, where 0 indicates no competence and 10 indicates complete competence. Average ratings are shown in Table III.1 below as mean $\pm$ standard deviation. All mean ratings fell between 7.6 and 8.6, with a maximum standard deviation of 2.0.

Table III.1. Student Self-Evaluation of Skills

Skills Corresponding to ABET Student Outcomes	**Rating**
Using STEM principles to solve problems (SO1)	8.2 $\pm$ 1.5
Designing a system or product to meet constraints (SO2)	8.2 $\pm$ 1.5
Written communication (e.g. reports & email) (SO3)	8.1 $\pm$ 2.0
Oral communication (e.g. presentations & internal with team) (SO3)	7.6 $\pm$ 1.9
Visual communication (e.g. diagrams, videos, graphs) (SO3)	7.7 $\pm$ 1.7
Making ethical professional engineering decisions (SO4)	8.6 $\pm$ 1.7
Teamwork (e.g. leading, planning, contributing) (SO5)	8.5 $\pm$ 1.7
Planning & conducting testing & analysis (SO6)	8.0 $\pm$ 1.5
Learning & applying new information independently (SO7)	8.6 $\pm$ 1.4

Average grades for overall course performance, final project reports, and peer evaluations for students in Capstone 1 and Capstone 2 are shown in Table III.2 for graduating classes from 2020-2024. Each class enrolled 30-40 students. In the "Sem." column, a prefix *F* indicates a fall semester, while *S* indicates a spring semester. There is a marked increase in course and report grades from Capstone 1 to Capstone 2 for nearly every class, while peer evaluation averages are in the upper 90's regardless of the semester.

Table III.2. Average Capstone Scores for Student-Driven Projects

	Capstone 1				**Capstone 2**			
Year Grad	**Sem.**	**Avg. Course Grade**	**Avg. Report Grade**	**Avg. Peer Eval**	**Sem.**	**Avg. Course Grade**	**Avg. Report Grade**	**Avg. Peer Eval**
2020	F19	88.8	79.6	n/a	S20	94.5	84.7	95.7
2021	F20	88.0	80.2	97.5	S21	90.6	88.0	97.0
2022	F21	88.0	79.0	99.5	S22	90.1	81.3	98.5
2023	F22	84.9	82.3	97.3	S23	86.8	81.2	97.5
2024	F23	89.4	83.4	98.1	S24	89.1	89.8	98.5
Average	Fall	87.8	80.9	98.1	Spring	90.2	85.0	97.4

Per the instructors' observations, students can be successful in the capstone course regardless of the origin of the project idea. While many students are highly motivated to join forces with their friends and scope a project in which they are heavily invested, not all students are motivated to submit proposals and are happy to choose from ideas provided or join an existing team. Working with friends typically results in positive outcomes, and the instructors have observed that nearly all teams have been welcoming to new members who were not originally part of the friend group or proposal. However, after sorting students into teams on project signup day, there typically remains 10-15% of the class who do not receive their first choice of project and/or teammates. These "leftover" students either signed up for less popular projects (so needed to be reassigned in order to create a full team), were excluded by other students, or simply did not know many others in the class. The teams formed by grouping these "leftover" students together tend to struggle a bit more than the others to work together and produce a quality prototype and documentation. In many cases, but not all, these students tend to earn lower grades and struggle with project management.

IV. Discussion

1) Faculty-driven and Student-driven Strengths and Weaknesses

Based on observations and ABET review results, the faculty-driven model can be used in the capstone course to meet the desired ABET outcomes. Compared to the student-driven model, the faculty-driven model has various strengths and weaknesses. One important strength of the faculty-driven approach compared to the student-driven approach is that it is easier for the instructor to mimic industry best practices. Faculty can easily leverage their industry experience to design great projects that align with industry standards. However, this approach also leads to significantly more effort on the part of the instructor, and it becomes difficult to implement at a large scale (e.g., 40+ students). A risk with implementing this approach is that faculty must carefully design an appropriate project for mechatronics engineering majors. A poorly designed project will result in a subpar experience for students. Furthermore, students often resist this approach at the start of the semester, expressing dissatisfaction with their lack of input in choosing their teams and/or projects. Instructors must be prepared to address this pushback and motivate students to engage fully. Encouragingly, it is common for students to overcome their initial resistance and develop strong buy-in by the end of the first semester, ultimately recognizing the value of the structured approach.

In contrast, the student-driven model offers its own set of advantages that focus on student engagement and scalability. A primary strength of this approach is the heightened sense of involvement and ownership it fosters among students. When students have the opportunity to choose their teams and projects, they are often more motivated to invest effort and creativity, leading to higher-quality work. Additionally, this model reduces the burden on instructors, as they are not solely responsible for generating project ideas. By allowing students to propose and develop their own projects, the student-driven model becomes more scalable, making it feasible to manage larger cohorts with minimal additional faculty workload. However, the student-driven model also has limitations. Students may lack the expertise or experience needed to propose projects that align with industry standards or meet ABET outcomes. This could result in projects that are less rigorous or less relevant to real-world engineering challenges. Instructors must still play an active role in guiding students, ensuring that project ideas are feasible, appropriately challenging, and aligned with the program's learning objectives. Additionally, without a structured framework provided by the instructor, there is a risk of uneven quality across projects, which could compromise the program's overall effectiveness in meeting educational outcomes.

2) Student-driven Survey Results and Observations

Based on the survey results, most students (78-93%) believe that the capstone course meets the ABET student outcomes. The lowest scored areas (78% and 80%, respectively,) were the aspects of SO2 and SO4 that deal with "knowledge of contemporary issues" (2b) requiring engineering solutions and the impact of those solutions in a "global, economic, environmental, and societal context" (4a). [20] This may be due to the fact that while the course does require students to consider the potential impacts of their own project in a real-world context (hence the rating of 92% on the "design a system, component, or process to meet desired needs within realistic constraints…" for SO2a), they are not required to broaden their speculations to include other projects. The highest scored areas (92-93%) were SO's 1a (STEM problem solving), 2a (just discussed), and 6 (testing and analysis). All these items are heavily emphasized in the capstone process using the engineering trident of "design, build, test," so it is reassuring that the students recognize this in the survey and clear based on course grades and project quality that students can apply these principles to their projects. The guide to an ABET-focused engineering capstone course [8] based on this approach was developed to ensure that all required student outcomes were met regardless of the instructor teaching the course.

The additional non-ABET-related aspects of the course assessed in the survey, addressing practical applications and instructional techniques, were all well received. On the practical side, 93% of students agreed that the course covered "techniques, skills, and modern engineering tools necessary for engineering practice," 87% said that the course would help them to "meet industry needs," and 98% were confident in their abilities to apply engineering principles and practices to solve new problems. Regarding the instructional approach, 87-96% of students agreed that the theory-to-application approach was effective and improved student learning, and that the professor helped the students achieve success.

The second survey evaluated the students' perception not of the course but of their own skills related to ABET SO's. It is important to note that while a goal of the capstone course is indeed to develop these skills, students should have been practicing them throughout their academic career, so the survey indicates the perceived abilities of students graduating from the program. Average student self-evaluation scores fell between 7.6 and 8.6 out of 10 for all items, with standard deviations between 1.4-2.0. These results are quite reasonable. Very high averages (> 9.0) would be unrealistic, indicating that students had an inflated perception of their abilities, while low averages (< 6.0) would indicate a problem with the program. At least 60% of students rated themselves highly (≥ 8.0) on all skills except oral and visual communication. Per the instructor's observation, this is a realistic impression – many young engineers struggle giving PowerPoint or poster presentations in front of an audience, with difficulties ranging from the soft skills of volume control, eye contact, and punctuality, to the more technical aspects of showing data and information in an efficient and visually appealing manner. More students rated themselves highly on other skills related to the SO's such as (1) problem solving, (2) design, (3) written communication, (4) ethics, (5) teamwork, (6) testing and analysis, and (7) learning & application.

The grades students earn in the course reflect their understanding of the course priorities and corroborate their perceived skill levels. Typical grades for the capstone course are in the A-B range (average 88-90%), with few students scoring C or below, revealing that most students have mastered the design process and produced a reliable prototype with sufficient documentation. It is rare but possible for students to fail, and in the case where a student does fail Capstone I, the instructor has noticed a marked improvement in performance when retaking the course. In four out of the five years of student-driven projects, average student grades increased in Capstone 2 over Capstone 1 by two or more percentage points, and there was also a major increase in final report grades (2-8% in all years but one). This may be an effect of students needing less time in Capstone 2 to find their stride as a team since they head into the semester with a game plan and prior workflow experience. Per the instructor's observation, the teams of "leftover" students tend to struggle more a bit more than the others to work together efficiently and effectively. In many cases, these students tend to earn lower grades and struggle with project management, although their performance typically improves from Capstone 1 to Capstone 2 as they learn to mesh as a team and hold themselves and each other accountable. Documentation quality is an area many teams need to improve, as indicated by the final report averages falling around 80% in Capstone 1 and 85% in Capstone 2. Many students are so focused on making their prototype work that they forget to tackle documentation until a deadline approaches, resulting in rushed submissions. This has been mitigated by mandating intermediate deadlines prior to final report submission, but there is still room to improve.

Peer evaluations were positive in almost all cases for student-driven projects, with average ratings in the upper 90's regardless of semester. Teammates who chose each other almost always give each other A's, although this is not always the case, and the "leftover" teams tend to turn in more critical reviews but also reflect on ways to improve in their self-evaluation.

3) Speculations

As evidenced by student performance and satisfaction within the course, as well as visible adherence to ABET guidelines, it is clear that both faculty-driven and student-driven projects can be successful approaches for a capstone course. Faculty can either scope the project for the students or empower them to choose their own adventure. The benefit to faculty involvement is a well-defined and achievable project scope, as well as incorporation of mechanical, electrical, programming, and user interface elements (all required for a Mechatronics Engineering capstone project). While many engineering programs in broader fields such as Mechanical or Electrical Engineering implement industry-sponsored capstone projects, this is rare for Mechatronics Engineering due to the narrower scope and increased level of complexity that accompanies the range of required project elements. However, automation or robotics industries could be ideal partners for these undergraduate capstone projects, where students could perform robotics integration. Automating a task on an assembly line or part of a process using a standard industrial robot or cobot could simplify the design task, allowing students to focus on end-effector and jig design (mechanical), PLC ("programmable logic controller") wiring (electrical), and robot programming and IO ("input-output") communications (programming and user interface) elements without the daunting task of designing an entire automation cell from the ground up. In this way, Mechatronics Engineering students could gain experience on a real-world engineering project similarly to their peers in other majors.

V. Conclusion

Both faculty-driven and student-driven capstone projects can provide a comprehensive and engaging Mechatronics Engineering design experience and succeed in meeting ABET student outcomes. Grade and course evaluation data from the past several years as well as examples of capstone projects support the effectiveness of both approaches, corroborated by instructor observations and positive third-party attention. Student survey data from the most recent class reveals high student opinions of the course regarding ABET compliance and instructional approach, as well as positive evaluations of graduating seniors in their personal proficiency with various engineering skills in relation to the ABET Engineering student outcomes. While industry-sponsored projects are a rarity in the Mechatronics Engineering field due to the tradeoff between complexity and scope requirements, a robotics integration or small-scale automation project within the robotics and automation industry could be an ideal initial pilot for industry partnership.

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VII. Appendix A: Project Proposal Template

Project Title:

Product Overview:

One paragraph about the background and goal of the project, plus an applicable image.

Design Constraints and Specifications:

A. The machine/system must (list task 1)

B. The machine/system must (list task 2)

C. The machine/system must (list task 3)

D. The machine/system must …. (Add more as necessary)

E. The system must include a user interface with (list features)

F. The final structure should be display-worthy.

G. The system should be self-contained (electronics and wires neatly enclosed, no tethers).

H. The robot must weight < X kg and be transportable by a single team member.

I. The robot must be contained within a X m x Y m x Z m volume and fit through a standard doorway.

J. Safety should be a primary consideration. This includes an emergency stop and error alerts.

K. The maximum budget is $800 per team.

Stretch Goals:

A. Stretch goal 1

B. Stretch goal 2

C. Stretch goal 3

Include any applicable url references

VIII. Appendix B: Senior Design Survey

Part A

The purpose of the senior design capstone course is to develop in the student the attributes of a professional engineer in the application of their undergraduate engineering, mathematics, and science knowledge, combined with independent research, to the solution of a real-world engineering challenge using the model-based, integrated design approach, (virtual design to functional prototype), that is the hallmark of 21st-century engineering practice. Did this course accomplish the goal for you?

_____ Yes _____ No

Part B

1. This course has provided me with: (check all that apply).

_____ an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (SO1)
_____ an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. (SO2)
_____ an ability to communicate effectively with a range of audiences. (SO3)
_____ an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts. (SO4)
_____ an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives. (SO5)
_____ an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions. (SO6)
_____ an ability to acquire and apply new knowledge as needed, using appropriate learning strategies. (SO7)

Does this course do a sufficient job in meeting the ABET engineering student outcomes?

_____ Yes _____ No

2. Check all that apply to this course.

_____ This course will help me to meet industry needs.

_____ This course resulted in improved student learning.

_____ The professor in this course helped achieve the course goals (see top of page).

_____ I feel confident in applying engineering design principles and processes in the solution of a new engineering problem.

_____ The approach used, i.e., to teach subject matter and then use that knowledge in the current design process (go from theory to application), was very effective.

Part C

Rate your abilities related to each student outcome on a scale of 0-10, where 0 is lowest and 10 is highest.

- Using STEM principles to solve problems (SO1) __________
- Designing a system or product to meet constraints (SO2) __________
- Written communication (e.g. reports & email) (SO3) __________
- Oral communication (e.g. presentations & internal with team) (SO3) __________
- Visual communication (e.g. diagrams, videos, graphs) (SO3) __________
- Making ethical professional engineering decisions (SO4) __________
- Teamwork (e.g. leading, planning, contributing) (SO5) __________
- Planning & conducting testing & analysis (SO6) __________
- Learning & applying new information independently (SO7) __________

Part D

1. Which soft skills are important to succeed in a career as a practicing engineer?

_____ Communication

_____ Teamwork

_____ Project management

_____ Time management

_____ Problem solving

_____ Organization

_____ Leadership

2. Which courses and the theoretical knowledge they provide are important to succeed in a career as a practicing engineer?

_____ Statics / dynamics and physics

_____ Strength of materials and machine design

_____ Robotics

_____ Electronics and circuits

_____ Control systems

_____ Fluid mechanics

_____ Thermodynamics

_____ Heat transfer

_____ Programming

3. Which of the following software skills and knowledge are important to succeed in a career as a practicing engineer?

_____ CAD (SolidWorks, AutoCAD, Inventor, etc.)

_____ MATLAB / Simulink

_____ LabVIEW

_____ Arduino

_____ Raspberry Pi

_____ PLCs

_____ Other (specify): ___________________________

4. Which of the following hardware skills and knowledge are important to succeed in a career as a practicing engineer?

_____ Power tool use (drills, saws, dremel, etc.)

_____ Machine tool use (mill, bandsaw, drill press, etc.)

_____ 3D Printing

_____ Laser cutting

_____ Other (specify): ___________________________