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Work in Progress: Multidisciplinary Undergraduate Experiential Learning through Medical Device Innovation

Prof. Christine E King, University of California, Irvine

Dr. Christine King is an Associate Professor of Teaching in the Department of Biomedical Engineering at UC Irvine. She received her BS and MS from Manhattan College in Mechanical Engineering and her PhD in Biomedical Engineering from UC Irvine, where she developed brain-computer interface systems for neurorehabilitation. She was a post-doctorate in the Wireless Health Institute at the University of California, Los Angeles, and a research manager in the Center for SMART Health, where she focused on wireless health monitoring for stroke and pediatric asthma. Her current research is on engineering education and women's health, specializing in pedagogy strategies to promote learning and innovation in design-build-test courses, including senior design, computer programming, and computer-aided-design courses, as well as pre-partum and partum medical devices.

Prof. Hadar Ziv, University of California, Irvine

Hadar Ziv is an Associate Professor of Teaching in the Informatics Department at the Donald School of Information and Computer Science at the University of California, Irvine. His research interests are in software engineering, Agile and SCRUM methodologies, privacy and security, and computer science and software engineering education. He has many years experience in both computer-science education and practical software development. He is an academic and subject-matter-expert in the Software Process, AI and Uncertainty in Software Engineering and CS Education, SCRUM and Agile Software Development. He is the author of "Ziv's Law" which helped shape the definition of SCRUM.

Professor Ziv teaches the Capstone software-project class for Informatics seniors, where students employ many of the same tools and methods to develop real applications for real customers. He was awarded UC Irvine's Excellence in Teaching award in 2003.

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Problem and Context

Capstone or senior-design programs are widely implemented across engineering and computer science disciplines to help students develop technical and professional skills by integrating previous learning of their curriculum to develop new knowledge given a real-world problem that mimics the work of professionals in their discipline [1]. Open-ended projects are typically driven by stakeholders within their respective industries, and utilize design strategies and industry methods specific to their field [1]. However, with the increasing globalization of industry and use of multidisciplinary design processes within industry [2], there is a need to develop senior capstone training programs and projects that incorporate multidisciplinary teams and design processes to perform innovation given real-world problems.

One example of a multidisciplinary field of engineering and computer science is in the field of medical device development. Medical device innovation requires team-based design with multidisciplinary expertise in different fields, including medicine, engineering, computer science, and business [3-5]. However, many undergraduate senior capstone experiences are still siloed, with institutions just starting to offer interdisciplinary courses given that they better reflect real-world scenarios [6,7]; students are typically exposed only to a small portion of a larger project or a small project that is directly related to the field [8-12]. This pilot program has developed an interdisciplinary collaboration across the School of Information Computer Science (ICS) , School of Medicine, and School of Engineering to allow students in multidisciplinary teams to innovate medical devices based on unmet clinical needs.

Background

Engineering and Computer Science disciplines often require senior capstone programs as part of their curriculum for students to introduce students to industry, technical, and workforce ready skills through real-world and open-ended problems [1, 13]. For institutions that are accredited by the Accreditation Board for Engineering and Technology (ABET) accredited, the senior capstone experience is a required final culminating design experience that incorporates appropriate standards and constraints and is based on the knowledge and skills acquired in earlier coursework [14]. Given ABET student outcomes and curriculum requirements, senior capstone programs are typically siloed to projects and mentorship in only the particular major [1]. However, with current globalization of industry, technology requirements spanning across disciplines, and different technologies being combined to improve innovation, particularly medical innovation, multidisciplinary teams and projects in capstone projects are becoming more common, particularly in the fields of ICS and Biomedical Engineering (BME).

In BME disciplines, students are exposed to the BioDesign process [19] that focuses more on how clinical needs are identified, evaluated, innovated upon, and implemented both through FDA regulatory processes as well as business strategies. At the University of California Irvine (UCI), BME students are introduced to this process first in their freshman year through on-paper unmet need design and evaluation, and more complex considerations of medical device design are scaffolded throughout the curriculum using group projects (e.g. a 3D printed prototype design of a medical device sophomore year), assignments (e.g. on-paper quantitative systems analyses assignments on unmet needs and designs in electrophysiology junior year). For students in the School of ICS, Agile [15,16] and SCRUM [17,18] design processes are utilized and introduced at key points in their 4-year curriculum. They are first covered in their lower-division introduction to software processes courses as lectures and active discussions, then students follow at least a light or “loose” (see below) variation of Agile in their upper-division project courses. Specifically, students are taught the four values of Agile via example assignments (e.g. Pair Programming and Test-Driven Development (TDD), Sprints and iterative-development, self-organizing teams, CI/CD and DevOps) in the upper division projects prior to their Capstone projects, where they implement these frameworks as well as become familiar with SCRUM roles, as defined in the Methods section below. Integration of these design processes throughout the BME and ICS curricula allow students to become familiar with methods that are typically utilized in their early careers. Although the design processes taught throughout have differences in focus in regards to their application, both highlight an understanding of the design lifecycle process that are common across all disciplines [20].

Purpose

To be able to provide undergraduate students with multidisciplinary team-based design, the Schools of Engineering, Medicine, and ICS developed innovative projects given unmet clinical needs from industry as well as healthcare professionals, under the guidance of engineering, medicine, and computer science faculty at UCI. Using Kolb’s experiential learning model [21], collaborative capstone projects were developed to include multidisciplinary design requirements, but allowed for different learning styles reflected in BME and ICS disciplines by having students engage in their respective design processes through learning and cognitive process development within their separate capstone courses. To this end, BME students first developed teams under an unmet clinical need presented by industry and physician mentors, and formulated a project plan to integrate a MD student near-peer mentor and ICS student team in fall quarter prior to ICS student engagement. The BME and ICS teams then performed their capstone projects under their respective courses, but worked together to define the scope of the project, identify the requirements and constraints of the required hardware and software, propose solutions, create the product to satisfy the requirements, and test the product given FDA regulations and standards in winter and spring quarters. In addition, the teams also explored market analyses and commercialization through performing customer interviews, business model canvas development, and competing in undergraduate business competitions. Given the differences across design processes (e.g. Agile Design [15,16] versus BioDesign Processes [19]), the study assessed the ability of student teams to be able to collaborate and perform teamwork across capstone programs, develop project-related outputs, and potential commercializable solutions to unmet clinical needs. In particular, the following research questions (RQ) were posed to assess the feasibility of the interdisciplinary cross-collaboration:

RQ 1) What logistical strategies support versus require improvement to perform cross-collaborative capstone projects across different schools given differences associated with design processes and course structures?

RQ 2) To what extent do interdisciplinary collaborative capstone projects meet engineering ABET student outcomes requirements?

RQ 3) To what extent do these projects meet information computer science capstone student learning outcomes requirements, such as use of the Agile or SCRUM design processes?

RQ 4) What benefits and challenges exist in multi-course capstone projects in regards to mentorship, administration, teamwork and collaboration?

Methods

Overview of Interdisciplinary Capstone Projects

The interdisciplinary capstone projects were first piloted in the 2024-2025 academic year for two projects across the BME and ICS capstone courses. The collaborative effort was limited to two projects, one driven by an industry-related unmet need and the other by a pre-commercialization and physician driven need, to first assess the feasibility of students across different disciplines and in different course structures to complete a collaborative project. A brief summary of each of these two projects are described below.

Project 1 - NasoCoustics: Cleft lip and palate is the most common major congenital anomaly affecting the head and neck region. Every child born with a cleft palate requires surgery and long-term speech therapy. Despite surgical closure of the cleft and restoration of native palatal anatomy, persistent speech differences in this population remain high. Such differences are typified by nasal air emission and hypernasality, two problems difficult to diagnose, treat, and monitor. Nasometry is the analysis of nasal air escape through the nose and is measured with a nasometer. Standard nasometers are large, expensive, and uncomfortable for patients, making them less than ideal for routine clinical use. The goal of the project was to develop a portable nasometer that integrates with a phone-based speech application. The ICS team helped lead the speech application development, while the BME team developed the nasometer hardware.

Project 2 - Smart In-Home Health Monitoring System with Predictive Analytics: In collaboration with a large industry partner that develops wireless and digital twin technologies, this project sought to develop a comprehensive in-home health monitoring system that uses a combination of wearable devices and ambient sensors to track ageing individuals' health and daily activities. The system employed predictive analytics and machine learning to detect signs of health deterioration and behavioral changes from physiological sensors. The ICS capstone team led the development of the real-time, personalized health recommendations and alerts system, while the BME team developed the wearable device that monitored patient vital signs.

ICS and BME Capstone Course Structures

One administrative challenge to overcome prior to proposing the above projects as a multidisciplinary course project was to assess how to implement these projects across two varying capstone course structures. For the BME capstone course, students are required to perform the course over a full academic year (9 months) in which they follow the BioDesign process [19]: 1) identify the clinical unmet need (fall), 2) invent a solution and physical prototype given design criteria after understanding the gaps in clinical standards of care (winter), and 3) implement the solution through testing given the FDA regulatory pathway as well as appropriate commercialization strategy (spring). Conversely, the ICS capstone course is structured as a two-quarter (6 months) course [22] in which students follow the Agile design process [15,16]: 1) discover and ideate by understanding the user needs and identifying key objectives, 2) determine user requirements and prioritize tasks based on user needs (winter), 3) create interfaces and designs that can be tested quickly through short design "sprints" (winter, spring), and 4) launching the produce incrementally to gather user feedback and improve iterations (spring). Throughout the ICS capstone course, students also perform SCRUM role development [23] such as as Product Own and SCRUM Master, conduct Sprint Backlog and Spring Reports, and develop SCRUM ceremonies such as Release Planning, Sprint Planning, Sprint Retrospective, and the Daily Stand Up. Given that both courses run on separate timelines, only concurrently in winter and spring, development of teams, project scopes and definitions, and proposed deliverables had to be adjusted to fit each of these different design processes.

Preliminary Assessment of Feasibility and Acceptability

Under an IRB-exempt observational study (UCI IRB-Exempt protocol #6971), student surveys and interviews with instructors and students are being performed for a mixed-method analysis [24] given quantitative survey findings and qualitative response from the interviews and survey questions (Appendix A). Given that there were only two projects performed during the pilot year and thus student responses are limited, statistical analyses are still ongoing and will be repeated in the 2025-2026 academic year once more students have participated in the collaborative capstone design experiences. For the quantitative analysis, a Wilcoxon-Signed Rank Test is being used to assess the 5-point Likert responses and compare whether they were different from a neutral response. Qualitative analysis utilizes an in-vivo coding method [25] to develop the constructs based on students' actual words from their responses to assess their perceptions on the feasibility of the interdisciplinary capstone projects for BioDesign, Agile, and SCRUM design, the administrative feasibility of the interdisciplinary project approach, and their ability to perform teamwork and collaboration in the projects.

Progress and Early Results

Preliminary Assessment of RQ1: Two of the four instructors of each of the capstone courses were interviewed in regards to RQ1 with the question *"What logistical hurdles and strategies worked well versus not throughout these cross-collaborative projects?"* Two of the four instructors of each of the capstone courses were interviewed in regards to RQ1 with the question "What logistical hurdles and strategies worked well versus not throughout these cross-collaborative projects?" Preliminary qualitative findings from the instructor interviews found that the logistical strategy of developing a design plan with the BME students in the fall for the ICS students to then implement in winter was beneficial in developing clear design constraints and deliverables for the additional ICS team members. Keeping assignments separate also allowed introduction and assessment of the different design processes used across disciplines, such as regulatory framework considerations in the BioDesign process and sprint backlogs in the SCRUM process. Conversely, one hurdle that was noted by the instructors was the awareness and support of the mentors given the timing when ICS student involvement was expected, and the limited scope given the 6 month duration of the software deliverables of the projects. Furthermore, given the large number of students that were integrated into the two projects, instructors found it difficult to best monitor student workload across team members given the large number of projects being managed across the instructors for each respective capstone course.

Preliminary Assessment of RQ2: Eleven BME, two MD, and 11 ICS students participated in the collaborative capstone projects. Of the student participants, 10 completed the survey and interviews (6 ICS students, 4 BME students). Quantitative findings from the survey (Appendix B) found that students were overall satisfied with the experience and that the multidisciplinary capstone project was feasible, and importantly, added value to their degree program. Preliminary qualitative data demonstrated that students found the ability to work a variety of students, mentors and professionals, particularly rewarding:

> *"Being able to work with so many different teams and people was an amazing experience. I really loved working with my team and seeing how our different skill sets came together to push the project forward."*

> *"The most rewarding aspect of this capstone design was getting to work with a variety of students, mentors, and various professionals. This exposed me to so many different avenues of work that I may hope to pursue. It provided me insight and some experience that I feel assured will aid me in my future endeavors."*

In regards to the BME students' perceptions on the multidisciplinary experience improving ABET engineering student learning outcomes [14], BME students reported that the collaborative experience greatly or substantially enhanced their ability to meet the student learning outcomes of the capstone program (Figure 1). Respondents also reported that it greatly enhanced their ability to use the BioDesign process [19] to solve real-world problems in healthcare. In particular, students noted that the projects enhanced their ability to apply design principles to produce solutions, communicate effectively with a wide range of audiences, function effectively on a team, and develop appropriate experimentation to draw conclusions.

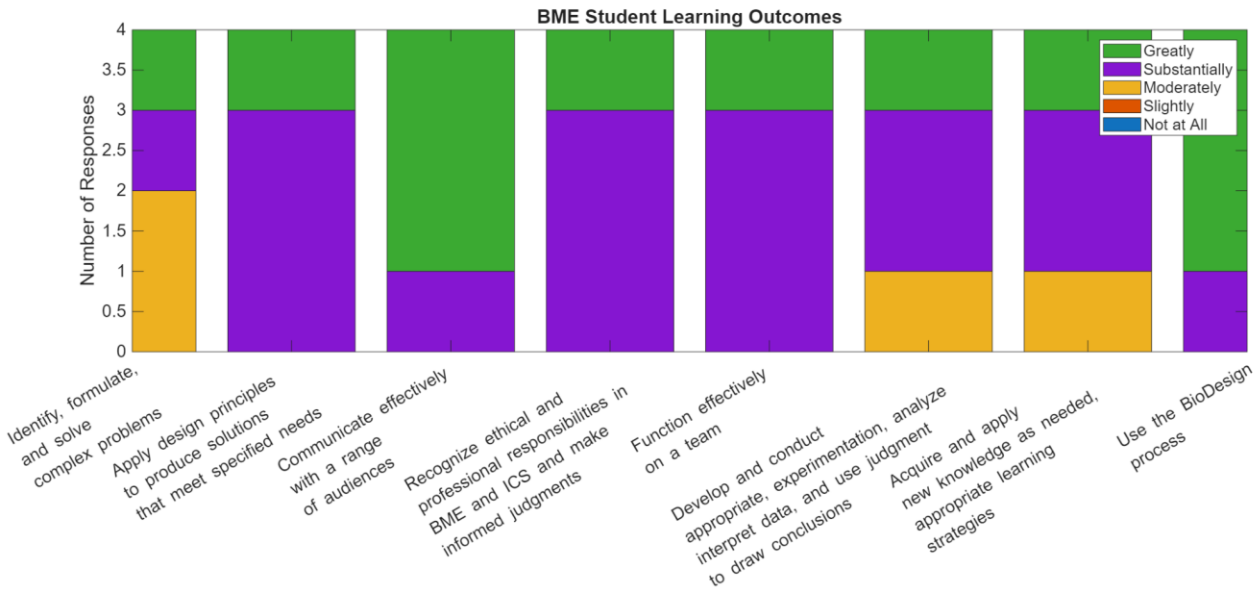

Figure 1: BME student perceptions of the collaborative capstone project experience enhancing their ability to achieve student learning outcomes and use of the BioDesign process [19].

Preliminary Assessment of RQ 3: Preliminary assessment of RQ 3 through student surveys and interviews found that the majority of the ICS students reported that they did not utilize the Agile or SCRUM processes a great deal during their capstone experience (Appendix B). However, qualitative responses found that they did utilize the processes, only loosely:

> "*We followed it very loosely and kept our scope small and manageable.*"

> *"We utilized a few techniques that were introduced to us by our teaching staff such as the SCRUM poker. We made use of user stories a lot, especially in the beginning, and had an existing and generally active sprint backlog and weekly meetings that somewhat acted as our sprint planning/review. We had a very "flexible" approach to it, not too rigidly sticking to the process itself but using parts and structures that benefitted us and made sure we were getting done what we needed to get done."*

There are several factors or reasons why ICS students would typically follow Agile and SCRUM only partially or "loosely". Some of the key influencing factors include (a) most students are just learning about the Agile/SCRUM methods, and applying them to real projects for the first time – and therefore cannot be expected to have advanced proficiency and familiarity with them, and (b) for most students, the capstone course is only one of several courses and other activities they engage in during the academic year – and thus are only partially-available or "partially-engaged" in the process unlike software developers who are fully engaged as their primary occupation.

A popular way to explain or define SCRUM (for example, in the Guides in [18]) is along several dimensions of practice where SCRUM improves upon or adds novel and new ideas to software development. In each of the primary dimensions of SCRUM, students inevitably follow a looser or "discounted" version of SCRUM. For example:

(a) Tools: Students learn and gain practical experience with Agile issue-tracking and project management tools such as JIRA or Trello or Notion or Asana – but not to the same level of detail, rigor and completeness as would professional developers.
(b) Ceremonies: Students learn and make use of primary SCRUM ceremonies such as Daily SCRUM stand-ups, Product Demos, and especially Retrospectives. However, given the partial part-time nature of their work, they may reduce the frequency of daily standups to, for example, once a week, or twice a week, or similar.
(c) Artifacts and Deliverables: Students learn about the range of SCRUM artifacts, such as sprint backlogs, product backlogs, and product increments. In their Capstone course, they typically are required to deliver only a subset of such artifacts.

Preliminary Assessment of RQ 4: When asked about the benefits and challenges associated with the mentorship and teamwork throughout the project, students reported that the mentorship for a multidisciplinary project problem challenged them to think critically and creatively, and fostered an environment conductive to learning and growth (Appendix B). However, some found that the mentorship was not as clear in terms of guidance and expectations (Figure 2). Unclear guidance in capstone projects has been described in other capstone design studies [26, 27], particularly those that have industry representative mentors [28], as students find the open-endedness of real-world problems particularly challenging to frame into structured tasks and solutions. The findings from the survey were similar to prior research findings [28], as the qualitative and quantitative survey results found that the students who had the industry-led mentor also had lower perceived mentorship guidance, availability and feedback. Lastly, all student respondents to the survey reported that the collaborative teams were very effective in collaborating and completing tasks despite the large group size, differences in disciplines, and differing coursework schedules. They highlighted that they were able to distribute workload based on individual strengths:

"The workload was distributed depending on the expertise and interest of each team member, for which there were no issues."

"The workload was distributed pretty fairly between our team members. Each person had a niche they would occupy and take the work for. The developers had ways to split up their tasks and the designers worked together on most action items to ensure everyone had something they could contribute with each sprint and everyone could reach out for help and collaborate on something. I would say that especially during the Bluetooth connection challenge, our developers had more on their plate than the designers ever did. We tried to make up for that with taking on the user testing and updating our designs as changes came up."

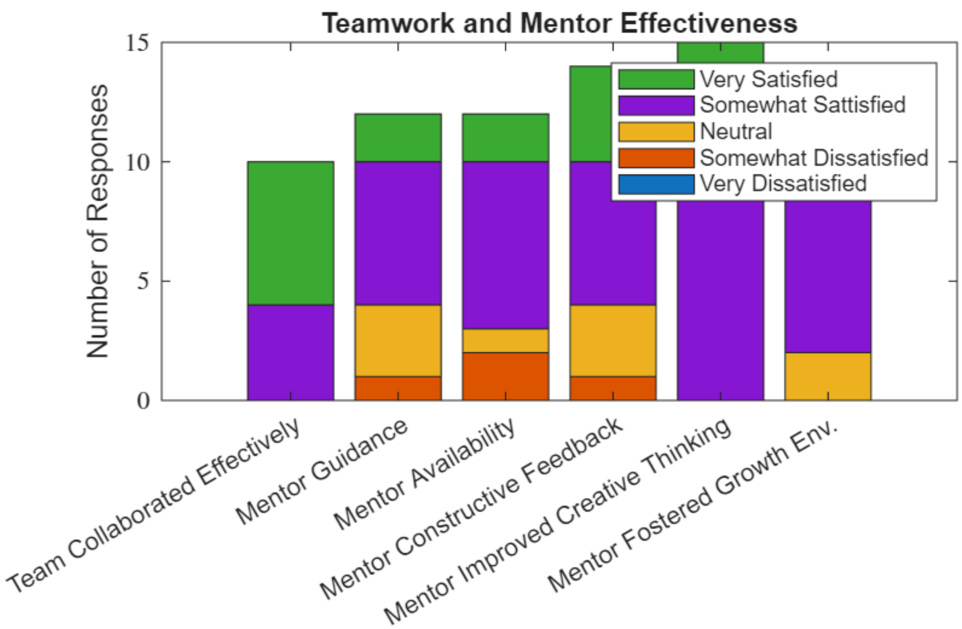

Figure 2: Quantitative student responses to the effectiveness of teamwork collaboration and mentorship across ICS and BME students.

Qualitative findings from the interviews and surveys highlighted that the students observed several administrative challenges and provided recommendations for improvement. For example, students found that the timing of the capstone courses, one starting in the fall while the other in the winter, to be challenging in regards to team formation and goal definition. They also mentioned issues associated with mentor guidance given their limited knowledge in all fields necessary for solving the unmet clinical needs. Students suggested future cross-instructor check-in meetings outside of the mentor and class to improve communication and technical skills guidance, as well as provide more clear directions and instructions for students throughout their project progress. Lastly, BME students highlighted the need for a prerequisite course on unmet clinical needs evaluation and problem definition, as this is a very involved process in healthcare innovation. This is currently being implemented as an improvement through an asynchronous online prerequisite course [29], and given the growing number of interdisciplinary capstone projects in future course offerings, as described below, may help provide a more sustainable curriculum design for multidisciplinary capstone design programs.

Limitations and Next Steps

Given the limited number of students and projects of the preliminary multidisciplinary capstone collaboration, future work will include more projects that incorporate MD, ICS, and BME student teams with mentorship from both industry and faculty. Specifically, in the 2025-2026 academic year, four projects (one with an industry representative mentor, three with faculty mentors) are utilizing the collaborative framework across schools and will participate in the survey and interviews at the end of the academic year. In addition, further interviews will be conducted among the instructors, teaching assistants, industry and faculty mentors to provide insights into the logistical strategies to perform the projects and whether student learning outcomes improved using a cross-collaborative strategy. The mixed-methods and statistical analyses will then be performed given significant student responses to assess RQ 2, 3, and 4 above. Furthermore, in future course offerings, the instructors of the ICS and BME capstone programs plan to increase the number of collaborative projects with consideration of mentor and project needs, administrative limitations and challenges, and student teamwork capabilities.

The preliminary findings and student survey responses have also led to suggestions for improving the administration of the collaborative capstone projects. For example, BME students highlighted that the problem definition and evaluation of the unmet clinical need should be introduced and analyzed prior to the capstone course, as this is a very involved process in medical innovation [19]. Through requiring the identification and evaluation of the unmet clinical need to create a problem definition with clear gaps, design requirements, and goals in the year prior to the capstone experience as an asynchronous online course [29], faculty and industry mentors, as well as instructors, may be able to improve guidance, framing structured interdisciplinary tasks among projects, and goal definition. Sentiment analysis and assessment of self-regulated learning [30] will also be performed and monitored in future offerings to help improve teamwork and provide actionable guidance from instructors. In addition to sentiment analysis, we will conduct a more thorough analysis, including performing natural language processing on sprint deliverables such as written sprint reports, design and requirements documents, homework assignments, and GitHub repositories to better assess design processes, as well as tracking intellectual property (IP) to assess whether the collaborations led to commercialization. Currently, one of the two projects has led to a provisional patent filing, and is being considered for commercialization with the mentors, team, and university. The current collaborative projects, as well as future projects, will be tracked in regards to IP filing and commercialization to assess whether multidisciplinary capstone projects can improve medical innovation and entrepreneurship.

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Appendix A: Survey Questionnaire

1. What is your age?
2. How would you describe your gender identity?
    a. Man
    b. Woman
    c. Non-Binary/Third Gender
    d. Transgender
    e. Gender Variant/Non-Conforming
    f. Prefer Not to Say
3. How would you describe yourself (check all that apply)?
    a. American Indian or Alaska Native
    b. Asian
    c. Black
    d. African-American
    e. Hispanic or Latina/o
    f. Middle Eastern or North African
    g. Native Hawaiian or Other Pacific Islander
    h. White
    i. Prefer Not to Say
4. Which School are you from?
    a. Engineering
    b. Information Computer Science
    c. Medicine
5. Which project did you participate in?
    a. NasoCoustics - Nasometer Project
    b. Senior Sense Solutions - Dassault Elderly Care Project
6. Overall, how satisfied are you with your capstone design experience?
7. To what extent do you feel the capstone design experience was a valuable component of your degree program?
8. What was the most challenging aspect of your capstone design experience?
9. If you could change one thing about the capstone design experience, what would it be and why?

For BME Students Only:

1. To what extent do you feel the capstone design experience enhanced your ability in the following areas? (1 = Not at All, 2 = Slightly, 3 = Moderately, 4 = Substantially, 5 = Greatly)
    a. Identify, formulate, and solve complex engineering problems
    b. Apply design principles to produce solutions that meet specified needs

    c. Communicate effectively with a wide range of audiences
    d. Recognize ethical and professional responsibilities in engineering situations and make informed judgements
    e. Function effectively on a team
    f. Develop and conduct appropriate experimentation, analyze and interpret data, and use judgment to draw conclusions
    g. Acquire and apply new knowledge as needed, using appropriate learning strategies
2. To what extent did you use the BioDesign process (Identify and Unmet Clinical Need, Invent/Innovate a Solution, and Implement a Business and FDA Strategy)?

For ICS Students Only:

1. To what extent did you follow the Agile design process? (1 = Not at All, 2 = Slightly, 3 = Moderately, 4 = Substantially, 5 = Greatly)
2. How did you use the Agile and SCRUM design processes?

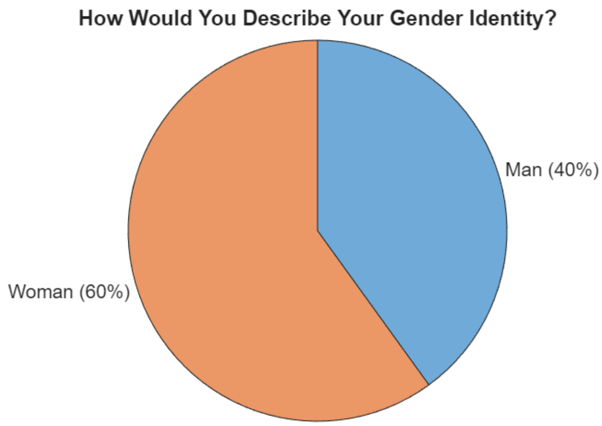
For All Students:

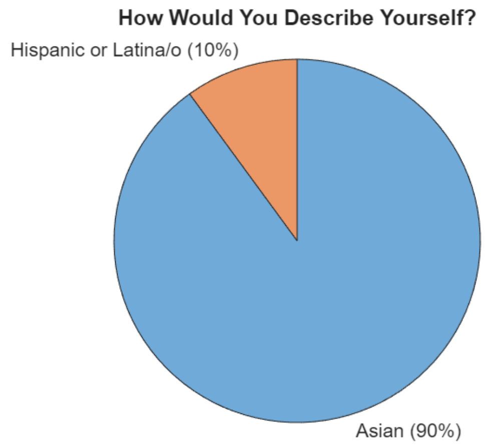
1. How effective was your team in collaborating and completing tasks? (1 = Very Ineffective, 5 = Very Effective)
2. What challenges did your team face, and how did you overcome them?
3. How was the workload distributed among your team members? Were there any issues with this distribution?
4. To what extent do you agree with the following statements regarding your faculty advisor(s)? (1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly Agree)
    a. My advisors provided clear guidance and expectations
    b. My advisors were readily available for consultation
    c. My advisors provided constructive feedback
    d. My advisors challenged me to think critically and creatively
    e. My advisors fostered an environment conducive to learning and growth
5. What aspects of the capstone program's structure or administration could be improved? Do you have any general recommendations for future iterations of the capstone design experience?

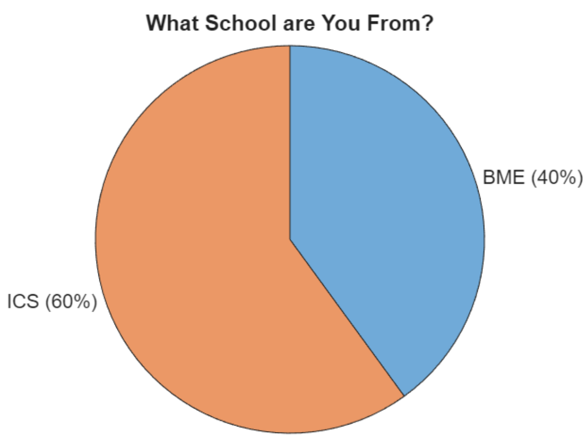
Appendix B: Preliminary Quantitative Results from Survey

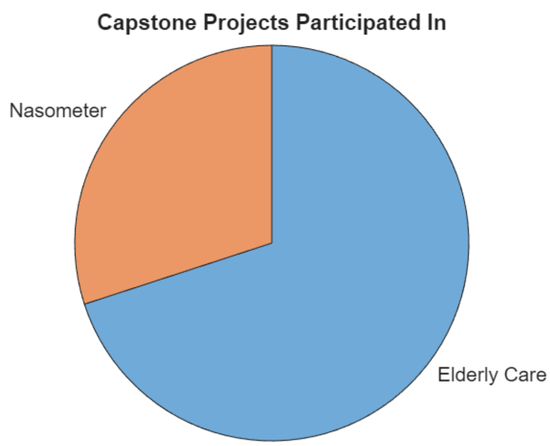
Demographic Results:

Age: 22 ± 0.67

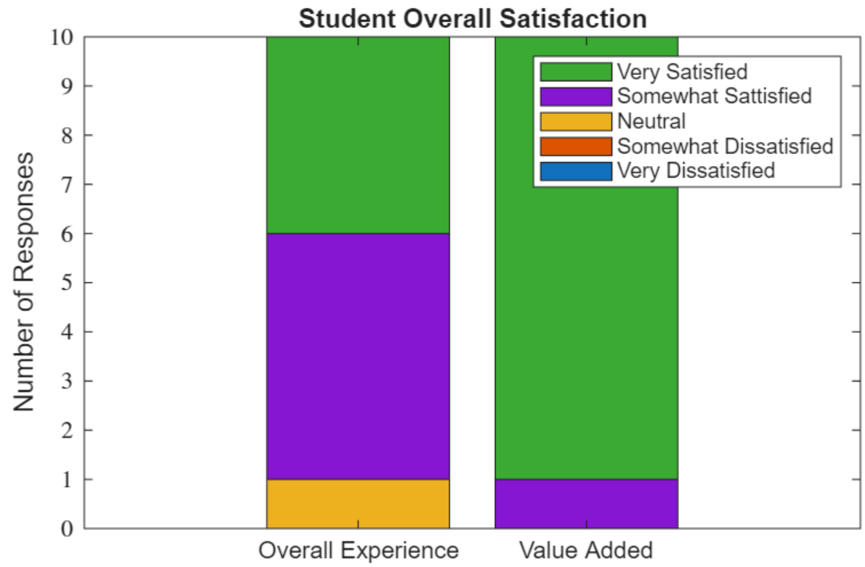




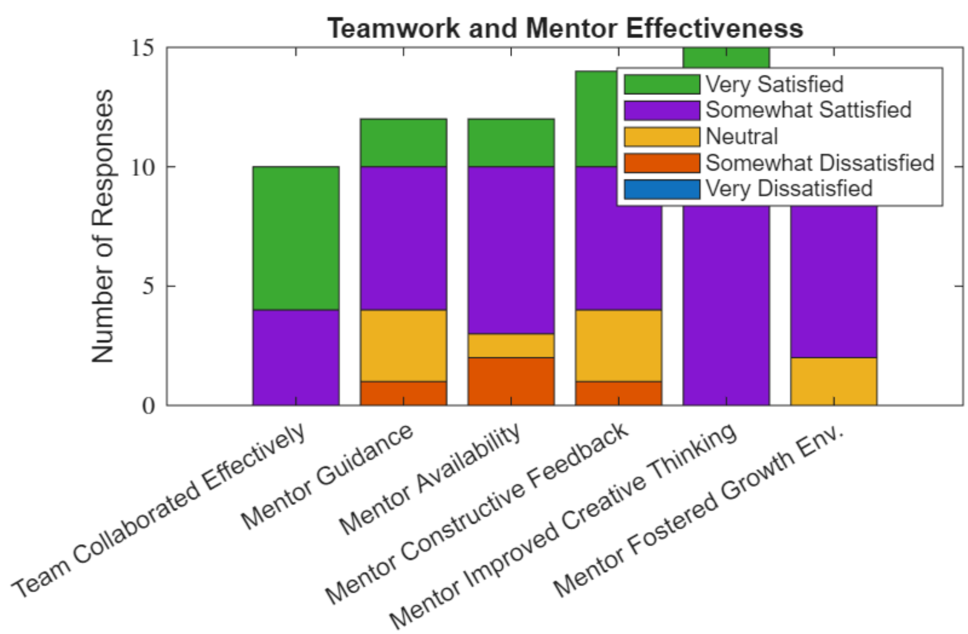




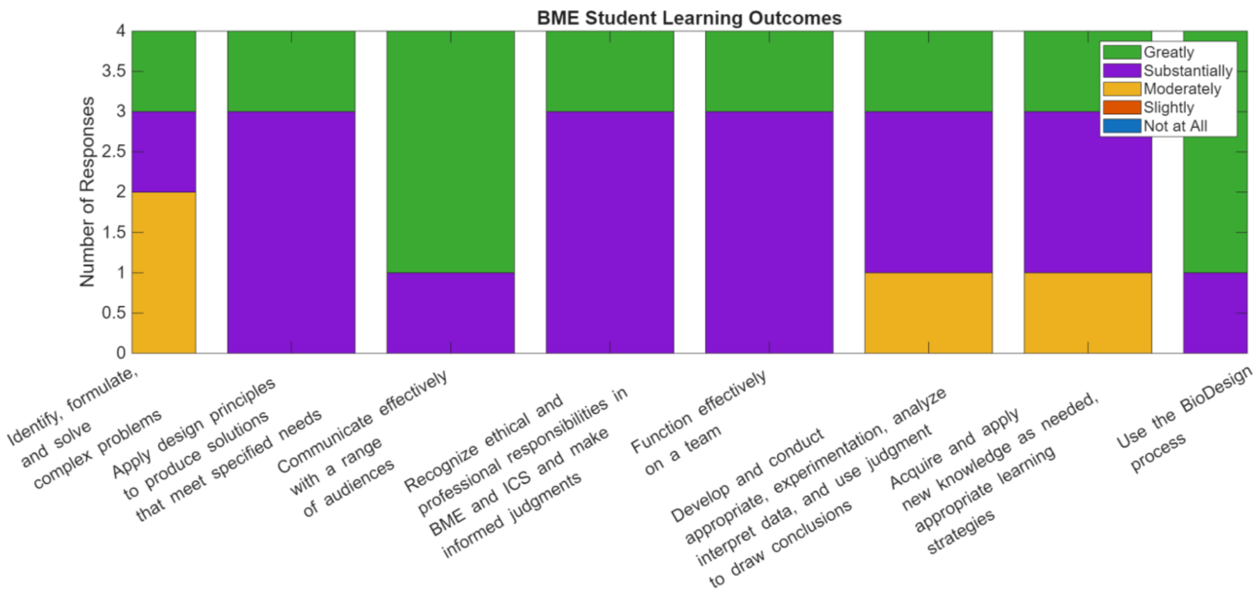
Responses to Overall Experience Questions: "How Satisfied are you with your capstone design experience?" and "To what extent do you feel the capstone design experience was a valuable component of your degree program?"



Responses to Teamwork and Advisor Questions: "How effective was your team in collaborating and completing tasks?", To what extent do you agree with the following statements regarding your faculty advisor(s)?: 1) My advisors provided clear guidance and expectations; 2) My advisors were readily available for consultation; 3) My advisors provided constructive feedback; 4) My advisors challenged me to think critically and creatively; 5) My advisors fostered an environment conducive to learning and growth.,"



Responses to Questions for BME ABET and Students Learning Outcomes: "To what extent do you feel the capstone design experience enhanced your ability in the following areas?: 1) identify, formulate, and solve complex problems; 2) apply design principles to produce solutions that meet specified needs; 3) communicate effectively with a range of audiences; 4) recognize ethical and professional responsibilities in engineering and information computer science situations and make informed judgments; 5) function effectively on a team; 6) develop and conduct appropriate experimentation, analyze and interpret data, and use judgment to draw conclusions; 7) acquire and apply new knowledge as needed, using appropriate learning strategies." "To what extent did you use the BioDesign process (Identify an Unmet Clinical Need, Invent/Innovate a Solution, and Implement a Business and FDA Strategy)?":



Responses to Question for ICS Student Learning Outcomes: "To what extent did you follow the Agile design process?"