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What Happens When Biomedical Engineering Students and Product Design Students Design Medical Devices Together? Evaluating a New Collaborative Course

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Abstract

Engineers and product designers often collaborate in industry to bring products to market, since each profession brings a unique skill set. However, intentional interdisciplinary collaborations are not typical during undergraduate education. This paper describes the initial outcomes of a collaborative course in which 3rd year undergraduate product design students work together with a 4th year biomedical engineering capstone course to design medical devices. The course has been run two times and based on the project outcomes and the student experiences in the first iteration, substantial changes were made for the second iteration of the course.

The biomedical engineering capstone course lasts for an entire school year, but the collaboration with the product design students is only designated for one semester. The first iteration of the interdisciplinary collaboration took place during the spring semester of the capstone course. Because the biomedical engineering capstone involves primarily prototyping in the spring semester, this left very little conceptual design work with which the product design students could be involved, as the design concepts were already finalized. Thus, one major change was to move the collaboration to fall semester so that the product design students could be involved in the initial stages of the design process. Another change was the makeup of the teams. In the first iteration, the product design students acted collectively as a “design consultancy,” with sub teams focused on specific biomedical engineering capstone projects. In the second iteration, the product design students were distributed among all the teams so that each team included four or five biomedical engineering students and one product design student.

We present a comparison of the two iterations by analyzing data drawn from multiple sources. In addition to an analysis of course evaluations, surveys of students, and interviews with students, we present a rubric-based comparative analysis of the project outcomes from the first semester student reports during the first two iterations of the course. Our results indicate that the course was improved in the second iteration, particularly as it pertains to the students’ experiences. However, our results also point to further areas of future improvement.

The results may be used by engineering and design educators to understand the potential benefits of an interdisciplinary capstone course and to understand how to best organize multi-college interdisciplinary capstone design courses.

Introduction

Multidisciplinary approaches are becoming increasingly common in engineering education [1]. The literature on these approaches most frequently describes their occurrence in capstone courses, typically involving students from multiple different engineering disciplines [1]. However, approaches involving students from multiple different colleges across a university, including non-engineering students, are a growing trend [1]. In this paper, we describe a multidisciplinary course involving students from the college of engineering and the college of design at a public university in the United States. In our course, third year product design students worked with fourth year biomedical engineering students during one of the two semesters of the biomedical engineering capstone course.

Due to a unique partnership between departments at our university, the product design and biomedical engineering students have multiple courses in common. These courses currently include courses taught by product design faculty: computer-aided design (SolidWorks, 2 credits), ergonomics (2 credits), user experience design (2 credits), and user interface design (1 credit), and courses co-taught by faculty from both product design and biomedical engineering: human anatomy (3 credits), and entrepreneurship (2 credits, taught by only biomedical engineering faculty in iteration 1). Due to differences in curriculum sequencing, in the first iteration of the collaborative capstone design course, product design students had not yet completed entrepreneurship. In the second iteration, product design students had not yet completed entrepreneurship and were currently taking ergonomics, and biomedical engineering students were currently taking entrepreneurship. So, by the time they took the collaborative capstone design course, the students had completed 8-10 credit hours of common coursework, some delivered by product design faculty and some by biomedical engineering faculty.

The biomedical engineering faculty members who originally advocated for this joint curriculum wanted to provide a human-centered design perspective for their students by integrating design thinking in undergraduate biomedical engineering curriculum. Our university is a comprehensive university which includes a medical school on the main campus. Thus, the product design faculty who originally advocated for the joint curriculum with biomedical engineering had a goal of capitalizing on the increased interest in medtech on campus and leveraging both the clinical and academic areas of campus expertise to conceptualize products. Although the product design and biomedical engineering students have shared coursework where they may work together on specific exercises or assignments, they do not have a focused setting to apply their learnings in a project-based cross-disciplinary manner prior to this collaborative capstone design course. Besides applying the learnings from the other shared courses, this collaborative course also had the goal of mimicking a realistic “real-world” working environment in which engineers and product designers must collaborate to develop design projects.

The structure of this paper is as follows. First, we describe related literature on the topic of multidisciplinary collaborations in engineering design. Then, we describe the structure of the two iterations of our course, and the methodology we used to compare the outcomes of the two iterations. We then present the results, discuss them, and provide our conclusions and plans for future work.

Related Work

Many studies have demonstrated advantages to multidisciplinary design courses [2], [3], [4], [5]. Factors that have been found to correlate with perceived team effectiveness and enjoyment in multidisciplinary projects include clear roles, a match between student interests and skills and their assigned tasks, similar expectations regarding outcomes, clear project management plans, and lower levels of team conflict [6]. Potential disadvantages have also been identified. For example, in a multidisciplinary capstone course, some students perceived the course to be unfair, because students from one discipline had more assigned tasks than students from another discipline [7]. Regardless of whether there was actually a discrepancy in the amount of work assigned to students from other disciplines, students may not understand how much effort is required of others if the work assigned to another student is not a type of work that they have personal experience with.

Various structures of multidisciplinary capstone engineering design courses have been described, but most of them involve a collaboration that lasts for two semesters with everyone participating the whole time. One paper described a similar challenge to what we faced, in that students from one discipline only took the capstone course for a single semester, but students from the other two disciplines took it for two semesters [5]. In this course, computer science students participated in spring semester only, while mechanical engineering technology and electrical engineering participated in both fall and spring [5]. One advantage to this structure was that by the spring semester, the teams could see clearly which projects and tasks required the support of computer science students and allocate resources accordingly [5]. A similar advantage was perceived for the first iteration of our course, where the product design students worked on a subset of capstone projects for which their involvement was deemed most valuable after evaluating the teams' progress during the first semester and the teams' openness to collaboration.

Although many papers describe multidisciplinary engineering courses, the literature describing collaborations which include product design is more limited. There may be additional challenges in courses that include both product design and engineering students, due to fundamental differences between the educational approaches. While both majors teach students about design, product design and biomedical engineering are typically taught quite differently. Product designers typically do not have the math and science training to make relevant calculations or computations to ensure that a design is meeting the requirements, and engineering students typically do not have the artistic training to come up with aesthetically pleasing solutions, nor do they tend to have as much practical experience with user research and iterative prototyping.

Biomedical engineering students may find a particular benefit in working with product design students, since medical device development is generally a multidisciplinary task. In a study of the medical device industry, the primary role that industrial designers were found to play in medical device development was addressing aesthetic design and human factors, though industrial designers also worked on defining needs, creating personas, driving conceptual processes, and branding [8]. From a medical device industry perspective, the value of industrial design is not well understood and is seen to lack specialized skills related to clinical sciences and regulatory processes [8]. Although not all medical device development teams interviewed in the study included industrial designers, they all involved people of multiple disciplines [8]. Thus, working across disciplines is an essential skill for students who plan to go into medical device development. In the medtech industry specifically, design and innovation are increasingly important for companies to remain competitive [9], [10].

Methods

Goals

The overall goal of this multidisciplinary collaborative design course was to serve as a culmination of the shared coursework between biomedical engineering and product design students and facilitate an environment where the two disciplines could come together to design medical technology to a more advanced extent than either could accomplish alone. The design of iteration 1 of our course had a specific goal of engaging product design students to aid in bringing the biomedical engineering students' initial concepts to a market-ready state. Iteration 2 of our course had specific goals of engaging product design students earlier in the process to potentially come up with stronger device concepts, to influence design earlier in the process, and to incorporate the product design students as equal members of interdisciplinary teams versus providing a service to engineering teams.

When designing the first iteration of our course, the faculty members did not refer to any existing examples of multidisciplinary courses involving product design and engineering. However, Prof. Mills, the product design instructor, had prior experience leading a class of product design students to work as a "design consultancy" alongside partners from other disciplines such as global public health, urban planning, and architecture. In designing the second iteration of our course, we looked at a similar example from Carnegie Mellon University (CMU) in Pittsburgh, Pennsylvania, USA. We read a publication about their course [11], and also spoke with Wayne Chung, the product design professor from CMU who co-leads the collaborative course. Both CMU and our course utilized the framework from the book Biodesign: The Process of Innovating Medical Technologies [11], [12].

Participants

Table 1 shows the students who participated in iteration 1 of our collaborative course.

Table 1. Student participants in iteration 1.

Major	Number	Gender	Race	Year in school
Biomedical Engineering	21	57% women, 43% men (est.)	75% white, 5.7% Hispanic/Latine, 5.4% Asian, 3.9% two or more, 3.3% Black or African American, 2.7% unknown, 0.2% American Indian or Alaska Native, 3.6% international (est. from college statistics)	4th year
Product Design	7	29% women, 71% men	86% white, 14% Middle Eastern / North African	3rd year

In iteration 1, the biomedical engineering professor was Dr. Ferriell. This was Dr. Ferriell's first time teaching the biomedical engineering capstone course. A different professor had taught this cohort of students in the fall semester, and Dr. Ferriell inherited the course for the spring semester. The product design professor in iteration 1 was Prof. Mills. Prof. Mills had not taught a collaborative course with engineering students before, but he had taught multiple other courses to this same cohort of product design students and had also taught this cohort of biomedical engineering students in a previous course, so he knew all the students very well. The professors did not have a previously existing relationship and neither of them was involved in the decision to offer this collaborative course. However, Prof. Mills from product design was heavily involved in the earlier decisions about when and how to offer this course.

Table 2 shows the student participants in iteration 2. In both iterations, the biomedical engineering students were more likely to be women and more racially diverse in comparison to the product design students. We note that students were given the option to identify as non-binary or self-describe their gender, but none chose those options.

The biomedical engineering professor in iteration 2 was again Dr. Ferriell. This was Dr. Ferriell's first time teaching the fall semester of the biomedical engineering capstone course, although he had taught the spring semester the year before. The product design professor in iteration 2 was Dr. Bartlett. Dr. Bartlett had not taught a collaborative course with engineering students before, but she had experience working in the medical device industry on both design and engineering. Dr. Bartlett was new to the university and had not taught any of the participating students before. The professors did not have a previously existing relationship, and neither of them was involved in the decision to offer this collaborative course.

Table 2. Student participants in iteration 2.

Major	Number	Gender	Race	Year in school
Biomedical Engineering	37	62% women, 38% men	68% white, 13% Hispanic / Latine, 11% Asian, 5% Black or African American, 3% Middle Eastern / North African	4^{th} year
Product Design	9	55% women, 45% men	100% white	3^{rd} year

Course structure

Table 3 summarizes the differences in course structure between the two iterations, including the logistical differences and the differences in the tasks that the students from each discipline worked on. The differences in tasks were primarily a result of the differences in timing and team formatting. Table 4 summarizes the tasks that the students from each discipline worked on as a result of the differences in course structure between the two iterations.

Comparison Methods

To compare the two iterations of our course, we have opted to use an adaptation of the biomedical engineering department's ABET rubrics to evaluate the reports generated at the end of the first semester. This first semester work would have been completed by biomedical engineering students alone in iteration 1, and by multidisciplinary teams in iteration 2. Others have similarly used ABET outcomes for comparative evaluations. For example, Dickerson utilized ABET student outcome-aligned rubrics to report on discrepancies between industry and academic mentors [13]. Pierakos also looked to ABET outcomes and Bloom's taxonomy in surveying students to find their perceived level of competence for ABET aligned outcomes [14]. Table 5 shows the rubric used in our comparison.

In addition to utilizing the rubric to compare outcomes, we collected some data to represent the students' perspectives. We administered a formal survey to the product design students from iteration 1, and students from both majors from iteration 2. In this paper, we will focus on an analysis of two survey questions which are described in the following section. To analyze the responses, we used thematic analysis. The biomedical engineering students from iteration 1 had already graduated by the time we decided to undertake this analysis, so their survey responses are not included in this paper.

Table 3. Differences in course structure between two iterations

Course Characteristic	**Iteration 1**	**Iteration 2**
Timing of collaborative semester	Spring (second semester of year-long project)	Fall (first semester of year-long project)
Course size	7 product design students, 21 biomedical engineering students	9 product design students, 37 biomedical engineering students
Team format	Product design students worked together in subgroups of 1-2 and helped 4 out of the 7 biomedical engineering teams	One product design student was embedded on each of the 9 teams
Tasks that product design students worked on	Creating CAD models, creating renderings, creating animations, facilitated brainstorming, provided access to prototyping facilities, aided biomedical engineering student teams in prototyping	Helping to identify potential problem areas for the design team to work on, participating in design review presentations, creating digital sketches of multiple concepts, creating digitally sketched storyboard to illustrate use case, creating CAD models, creating 3D renderings of final concept
Tasks that biomedical engineering students worked on	Identifying problem area; design communication; engineering prototype design controls; experimental testing of engineering prototype; end-of-semester presentation; design review presentations and documentation including intellectual property review, regulatory pathway review, and future device proposal	Design communication; problem identification and needs finding; brainstorming solution concepts; articulating design controls; design review presentations and documentation including intellectual property review, regulatory pathway review, risk analyses, and market analyses
In-class meeting times where students from both majors participated	Four facilitated instances throughout the semester beginning the fifth week and ending the twelfth week	Every Monday for 50 minutes and all five presentation days. Class attendance was required for product design students, but attendance was not required for biomedical engineering students, and many biomedical engineering students were not present during the Monday classes

Table 4. Tasks that the students from different disciplines worked on

Tasks	Iteration 1		Iteration 2	
	Biomedical engineering students	**Product design students**	**Biomedical engineering students**	**Product design students**
Identifying potential problem areas	X		X	X
Meeting with clinical collaborator	N/A	N/A	X	X
Narrowing down problem areas to one final	X		X	X
Traceability Matrix	X		X	
Storyboard	X	X	One group only	X
Sketching concepts	N/A	X	One group only	X
Patent review	X		X	
CAD models	X	X	One group only	X
Initial shoe-string prototypes	X		X	X
3D renderings		X		X
Presentations	X		X	X
3D Animations		X		One group only
Patent/prior art review	X		X	
Building final prototype	X	X	X (to be done next semester)	
Performing final validation tests	X		X (to be done next semester)	

Table 5. Rubric adapted from the biomedical engineering department's internal ABET evaluation rubric

	Exemplary, 4	Proficient, 3	Developing, 2	Unsatisfactory, 1
Objectives: Clearly Communicate Design Objectives	**All** design objectives, goals, specifications, constraints, and given information are clearly stated.	**Most** of the design objectives, specifications, constraints, and given information are clearly stated.	**Some** of the design objectives, specifications, constraints, and given information are clearly stated.	Design objectives, specifications, constraints, and given information are **minimal or missing**.
Process: Demonstrate Execution of Design Process	Design process (including formulation, evaluation, and optimization of the design with justification of assumptions) is applied to **more than two** design alternatives. **Comprehensive** metrics for evaluation of the design are provided.	Design process (including formulation, evaluation, and optimization of the design with justification of assumptions) is applied to **two** design alternatives. **Basic** metrics for evaluation of the design are provided.	Design process (including formulation, evaluation, and optimization of the design with justification of assumptions) is applied to **one** design alternative. **Partial** metrics for evaluation of the design are provided.	Design process is **missing one or more element**: formulation, evaluation, optimization of the design, or justification of assumptions. **Does not provide** metrics for evaluation of the design.
Impacts: Identify Impacts of Design	**Fully** articulates and addresses the global, economic, environmental, and societal impacts of the product, process, or design solution. Cites **all** appropriate regulations and standards.	**Mostly** articulates and addresses the impacts of the product, process, or design solution. Cites **most** appropriate regulations and standards.	**Partially** articulates and/or addresses the impacts of the product, process, or design solution. Cites **some** regulations and standards where appropriate.	**Does not** articulate the impacts of the product, process, or design solution. **Missing** citations to appropriate regulations and standards.
Knowledge: Incorporate Knowledge to Support Design Solution	Acquires and applies **all** relevant knowledge (technical literature, regulations, standard practices, global markets, intellectual property) to support design solution.	Acquires and applies **most** relevant knowledge (technical literature, regulations, standard practices, global markets, intellectual property) to support design solution.	Acquires and applies **some** relevant knowledge (technical literature, regulations, standard practices, global markets, intellectual property) to support design solution.	Acquires and applies **minimal** relevant knowledge (technical literature, regulations, standard practices, global markets, intellectual property) to support design solution.
Functionality: Demonstrate Functionality of Design	Final design is feasible and **fully** meets engineering and societal standards and constraints.	Final design is feasible and **mostly** meets engineering and societal standards and constraints.	Final design is feasible and meets **some** engineering and societal standards and constraints.	The final design is broadly infeasible and **does not meet** societal standards and constraints.

Results

Rubric analysis

The average scores for each rubric category are presented in Table 6. The rubric scoring was completed by the biomedical engineering professor, Dr. Ferriell.

Table 6. Rubric averages

Rubric Category	Iteration 1 (N=7) Mean Score	Iteration 2 (N=9) Mean Score
Objectives	3.14	3.33
Process	2.71	2.56
Impact	2.00	2.78
Knowledge	2.43	3.22
Functionality	1.71	2.44

Because rubric scoring is ordinal, rather than continuous, we opted to use the Mann-Whitney U test to compare the final report scores for iterations 1 and 2. Our data passed the four assumptions for the Mann-Whitney U test: the dependent variable is ordinal, the independent variable is two independent groups, no participant is in both groups (independence of observations), and the data from each group has the same shape as verified through histograms. Our results indicated that there was no significant difference between the final report rubric scores of iterations 1 and 2 for any rubric category. The values of the Mann-Whitney U test are shown in Table 7. The largest differences in mean ranks appeared in rubric categories Impact, Knowledge, and Functionality. The only category in which iteration 1 outranked iteration 2 was Process.

Table 7. Results of Mann-Whitney U test

Rubric Category	Iteration 1 (N=7) Mean Rank	Iteration 2 (N=9) Mean Rank	Mann-Whitney U	Exact Significance *p*
Objectives	8.00	8.89	28.000	.758
Process	8.86	8.22	34.000	.837
Impact	6.21	10.28	15.500	.091
Knowledge	6.21	10.28	15.500	.091
Functionality	6.43	10.11	17.000	.103

Student attitudes toward the collaboration

During iteration 1 of the course, one of the biomedical engineering student teams told Dr. Ferriell that they did not want to add any product design students to their teams for the coming semester. The students perceived two things: one, they believed it would be extra work for them to incorporate a new person into their presently functioning team, and two, they were not willing to relinquish responsibility to an untrusted new person. Their perception was that they had formed good group dynamics during the first semester, and they did not want to disrupt it. This request was honored, and this team did not work with the product design students.. A second team of biomedical engineering students was not allowed to work with the product design students because they had missed deliverables up to that point, and it did not seem fair to ask the product design students to work with an underperforming team.

We do not have data on the attitudes of the biomedical engineering students after the collaboration ended. However, the product design students were surveyed. In response to the question, “please share your thoughts on the structure of the collaborative course between the biomedical engineering students and product design students,” many gave quite negative answers. These negative answers centered around three points. One, that the biomedical engineering students had a negative attitude toward them, two, that the product design students felt that they were merely “laborers” helping out with someone else’s project, and three, that they did not feel they were taking away meaningful learning or creating work that would present well in their design portfolios.

In iteration 2, both biomedical engineering and product design students were asked to answer the question “please share your thoughts on the structure of the collaborative course between the biomedical engineering students and product design students.”

The product design students’ answers were more positive than what was seen in iteration 1. Multiple students said positive things about their group members, such as “they were very nice,” “I had a good experience with my group,” and “I got along really well with my teammates.” None of them indicated that they thought the biomedical engineering students looked down on the product design students. Multiple students also felt neutral to positive about the structure of the collaboration, saying that “it went okay” and “the structure was nice for this course.”

The biggest frustration seen in the survey responses was a perceived lack of clarity in the respective roles of the team members. Others expressed that they felt like they bore the majority of the burden for the design portions of the project. The biomedical engineering students also gave generally positive answers, and many said nice things about the product design students, such as, “she was helpful, intuitive, and a great team player,” and, “overall, I thought the collaboration was great and, from my experience, the product design student was very helpful to my team.” Besides the positive interpersonal comments, another positive was that they felt the product design students brought a different perspective to the projects. Another positive was that the biomedical engineering students perceived that the contributions of the product design students led to an overall reduced workload. Some biomedical engineering students expressed frustration regarding the division of work. These comments echoed the similar comments made by product design students. Another positive that the biomedical engineering students identified was the product design students’ increased expertise in design specifically. Others made similar comments stating that the product design students had more experience with SolidWorks and with prototyping, which contributed positively to the overall group outcomes. Multiple biomedical engineers confessed in their answers that they initially did not want to work with the product design students but then changed their mind through the process.

The biomedical engineering students were asked, “if given the choice to keep working with the product design student from your group next semester, would you do it?” In response, 85% of the biomedical engineering students said yes, they would choose to continue working with the product design student if given the option next semester. 12% said no, and 3% were unsure. Of the individuals who said no, all were members of the two groups with the product design students who received the lowest grades in their product design course, suggesting that these two product design students may have been weaker contributors to the collaboration relative to other product design students. Some of the biomedical engineering students who were grouped with these two students also expressed that they felt it was unfair that other groups had gotten better contributions from the product design students, for example, high quality CAD models. The product design students were similarly asked, "if given the choice to keep working with your biomedical engineering group next semester, would you do it?" Of the eight students who responded, four said no, one said yes, and three said it depended on the requirements.

<u>**Discussion**</u>

Overall, the results of our analysis suggest that the course was improved in iteration 2. One point of comparison we made was to compare the final reports from the first semester of iteration 1, which included only biomedical engineering students, and iteration 2, which included both product design and biomedical engineering students. Although none of the categories reached statistical significance, the mean rank scores were higher in iteration 2 for four out of the five rubric categories, especially for the categories of Impacts (identify impacts of design), Knowledge (incorporate knowledge to support design solution), and Functionality (demonstrate functionality of design). Ideally, we would hope that the performance continues to trend upward as we continue to iteratively improve the course.

The students' responses to our survey questions can only provide an incomplete picture of the student experiences across the two iterations since we were not able to include the perspectives of the biomedical engineering students during iteration 1. However, based on the results that we do have, the student experience seems to have been generally positive in iteration 2. The product design student experience, which can be compared more holistically, appears to be improved in iteration 2. Product design students who participated in iteration 1 had almost nothing positive to say about their experience. The product design students who participated in iteration 2 were positive about the interpersonal aspects of the course, but more negative about the structural aspects. One of the repeated complaints from iteration 1 was that the product design students did not feel they were able to produce work that they could include in their design portfolio, which was not a concern voiced during iteration 2. Of course, many of these differences in attitudes could be due to reasons unrelated to the course structure and delivery, such as the personalities of the students.

The biomedical engineering students' attitudes, captured only from iteration 2, were generally very positive, with most of the negative opinions isolated to the two groups who were paired with the weakest performers from the product design class. The results overall suggested that the collaboration was a more positive experience for the biomedical engineering students than the product design students. This is reflected in the responses to the final question about whether they would like to continue to work together on the project in the spring semester. This question was fundamentally different when directed at each group since the engineering students have no choice but the work on the project next semester, whereas the product design students would need to take an additional independent study course to work on the project in the coming semester as it is not part of their curriculum. So, the biomedical engineering students were answering the question of whether they would be better off with their product design student continuing to help them or not, which was overall an 85% yes, and the product design students were answering the question of whether they would continue to work on an optional project or not, which was 50% no.

Fundamentally, since the collaboration is focused on the biomedical engineering students' capstone project but is not a capstone nor a year-long project for the product design students, it makes sense that the product design students and biomedical engineering students feel differently about the collaboration, and that there might be an imbalance in perceived value added. The biomedical engineering students likely came away feeling that they were being helped, while the product design students felt that they were helping someone else. In order for it to feel like an equal partnership on both sides, the collaboration would likely need to change in structure. For example, it could occur as a semester-long separate course outside of the biomedical engineering capstone course or as an optional elective where product design students choose to be involved for the full year. A critical and persistent obstacle to multi-disciplinary collaboration and innovation in this structure are the concerns over isolating individual student engagement and activity for the purposes of ABET accreditation of senior capstone projects. One potential evolution of this type of collaborative, project-based experience could be between non-capstone biomedical engineering and product design students, focusing the goals of the interactions on working collaboratively across disciplines and modeling a complete design process in a single semester, to be expanded on during respective capstone efforts.

Based on the results, there are multiple ways that we plan to improve the collaborative course going forward. One is to improve the process of assigning product design students to groups. The product design professor plans to have a short "audition" project for the product design students during the first few weeks of the semester. The performance on this project would be the basis for how the students would be assigned to groups going forward. Students who do not demonstrate a minimum level of basic product design skills (sketching, CAD modeling, presenting, etc.) would not be paired with a biomedical engineering group and would instead work on a separate independent project. This would be out of fairness to the engineering students and would also be in the best interest of the product design students, as those who do not have a minimum skill level are probably not ready to participate in an interdisciplinary collaboration on a capstone project.

Finally, another theme that arose was the different goals between the students in different majors. The biomedical engineering students appeared focused on team performance and workload, while the product design students were focused on creating work that could be presented well in their design portfolios. While it is possible that these different goals can be met by the same project, this is a challenge that is often not discussed when it comes to multidisciplinary projects.

What we have presented in this paper is not a controlled experiment, but a natural experiment in comparing two iterations of the course. In a controlled experiment, we would change fewer variables between iterations one and two, but in the interest of making the course as positive a student experience as possible, we changed everything that we thought needed to be changed rather than trying to control variables. There were many variables including a different cohort of students from both majors, a different product design professor during the collaboration, different biomedical engineering professor during the non-collaborative semester, etc. As future work, we plan to evaluate the final outcomes of the second semester work from iteration 2 of the course, which is still in progress at the time of writing.

Conclusion

Multidisciplinary collaborations are an important part of educational experiences to prepare students for the type of situations they are likely to encounter in the workplace. In this paper, we have compared two iterations of a multidisciplinary course in which product design students collaborate with biomedical engineering students during one semester of the two-semester biomedical engineering capstone design project. During iteration 2 of the course, we attempted to improve the course by involving the product design students earlier (during fall semester instead of spring) so that they could have more ownership and input into shaping the design concepts. We also had the product design students split up and work as individuals embedded in each biomedical engineering team, instead of working as a "consultancy" as in iteration 1.

The results of our rubric scoring analysis and our student exit surveys suggest that the second iteration of the course led to more positive outcomes in both performance and student experience, but that there is still much room for improvement in the course. Our results also call into question whether an "imbalanced" collaboration such as this one, where a group of students from one discipline work on a single-semester's worth of the year-long capstone project from another discipline, can lead to an equally positive outcome for all students across the board. A common theme in responses was that the product design students felt that they were helping with someone else's project, and the biomedical engineering students felt that they were receiving (or not receiving, in the case of being grouped with a weaker product design student) help. Ultimately, we believe that this multidisciplinary collaborative course was successful, but needs more iterations and tweaks to be further improved. The biggest areas of improvement will be to define responsibilities more clearly and require more design-related deliverables from the engineering students so that the product design students do not end up working on the design tasks alone.

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