# Re-designing Design: A Technology-enhanced Graduate-level Biomedical Design Course

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## A. Introduction

Biomedical engineering (BME) is an evolving discipline that involves collaboration among engineers, physicians, scientists and entrepreneurs, in academia and industry to provide interdisciplinary solutions to biomedical problems. During biomedical design, a range of strategies can be used to identify a problem and to generate and evaluate solutions. At Columbia University, we have an established program for teaching biomedical design to undergraduates which culminates in our capstone 'Senior Design' course. However, no specified design experience exists for terminal degree BME Master's students. Design courses are traditionally taught utilizing a textbook, lectures, and a team design project, with often limited time for interactions between and among teams and instructors in the classroom. We also recognized that the background and educational and professional goals of undergraduates and graduate students are unique. Therefore, we saw a valuable opportunity to not only extend BME design education to our Master's students but also to redefine and enhance the approach to teaching BME design. Our primary objective was to develop an immersive Master's-level course in biomedical engineering design, utilizing a blended learning pedagogical approach.

To begin, the advantages of teaching in blended learning environments will be discussed and placed in the context of the growing demand for improved teaching and use of technology in higher education. The history and context for this work will then be provided by discussing undergraduate and Master's level engineering education broadly and more specifically unique to design and within our Department. Next, a new course, designed to meet the unique needs of Master's students and utilizing a new approach to teaching design based on blended learning pedagogy, will be introduced. Evaluation of the course and approach from the student perspective will then be presented. The article concludes with reflections on the course including lessons learned and challenges faced.

### i. Teaching in Blended Learning Environments

"Neither the purpose, the methods, nor the population for whom education is intended today, bear any resemblance to those on which formal education is historically based"[1]

Over the past decade it has become widely accepted that the context, technology, and students of today are different from those of past generations and those differences must be accounted for in current teaching practices.[2] The learning environment has traditionally been dominated by a lecture format, with students passively listening to the course instructor. This format has been criticized as an ineffective way to learn and many strategies have been suggested to improve this, including that of blended learning. Blended learning[a] is defined as "the organic integration of thoughtfully selected and complementary face-to-face and online approaches and technologies".[3] By integrating these complementary approaches in the classroom, it provides students with the opportunity for increased interactions with course materials, instructors, and peers, creating

[a] The term "flipped classroom" is a form of blended learning where the student is exposed to new concepts outside of class and class time is spent applying these concepts. For the purpose of this article, we will utilize the terminology of blended learning and flipped classroom interchangeably.

communities of inquiry that support engagement and collaboration.[4] A community of inquiry, involving personal reflection and shared discourse, allows for the "fusion of critical and creative cognitive processes known as higher-order thinking".[5] Blended learning may be an appropriate teaching strategy for current and future generations of students.

### ii. Addressing the Unique Needs of Master's Students

Undergraduate and graduate students not only differ in their length of program but also in "age, maturity, self-discipline, and work experiences".[6] Based on personal observations and post-graduation statistics, it is also clear that the educational and professional goals of undergraduate and graduate students are distinct, particularly in biomedical engineering.

At the undergraduate level, biomedical engineering prepares graduating students for three main areas: professional employment (i.e., medical device industry, engineering, and consulting), graduate studies (in biomedical engineering or related fields), or attendance at professional school (i.e., medical or dental school). A survey conducted by the Academic Council of the American Institute of Medical and Biological Engineering determined that 36% of engineering graduates went to industry, 36% went to graduate school in engineering or related fields, 21% went to medical school, and the remaining were unknown at the time of graduation.[7,8] This distribution is typical of many BME undergraduate programs, including the one at our institution.

At the Master's level, students come from diverse training, including research and industry, and backgrounds including sciences, mathematics, and several fields of engineering. Many are seeking to redefine their career direction, and most Master's students are seeking employment in industry after graduation. An informal survey conducted as an introduction to this course revealed that 11 out of 12 students' goals were to work in industry or at a start-up company upon graduation.

As a result of these differences, instructors must consider different instructional styles depending on their audience. Traditionally, the primary difference between undergraduate and graduate curricula is "the extent and complexity of course readings, the depths of discussions, and difficulty of assignments."[9] Researchers have also proposed that peer interactions are more likely to affect the performance of graduate students than undergraduates.[6] Creating an environment that involves graduate students in the learning process is also extremely helpful in meeting student expectations and convincing them that the class will be useful for them in the short and long term.[10,11] It is likely that graduate students, in particular, would thrive in a blended learning environment.

### iii. History and Context

*Undergraduate.* At our institution, undergraduate students are provided a continuum of design experiences. Starting in their freshman year, the students participate in a program called the Art of Engineering. The course is designed to help students transition from a science-oriented high school way of thinking to an engineering point of view. In particular, students that participate in the BME section in this course are introduced to and charged with utilizing the engineering design process to solve open-ended problems. Following this course, opportunities for exploring design can be found both within BME laboratory courses and in the parallel lecture courses. The culmination of the laboratory sequence and the design experiences introduced throughout earlier courses is the required senior “capstone” design course, which includes a significant design project that ties together the core program, encourages creativity, explores practical aspects of engineering practice, and provides additional experience with communication skills in an engineering context.

“Capstone” senior design is common to all engineering programs in the United States and is a requirement according to the Accreditation Board for Engineering and Technology (ABET). At our institution, this course is traditionally taught utilizing a textbook, lectures, and a team design project. The goal of this two-semester class is to design a novel biomedical device/system/product that satisfies a set of pre-defined criteria. Students have the opportunity to select their own design projects and groups. They also work closely with clinical and engineering faculty advisors. In the 1st semester, students learn and practice the design process, as well as learn about commercial aspects of product development including entrepreneurship, intellectual property, FDA regulations, modes of reimbursement, and business plan development. The students also perform early feasibility (proof of concept) tests and complete the initial stages of prototyping. In the 2nd semester, students develop functional prototypes and quantify the performance of their prototypes with respect to specifications. In each term, students are expected to share their progress both in informal meetings with instructors and in formal presentations. Concepts are taught via traditional lectures in the classroom and implemented via hands-on working sessions and design project meetings both inside (sometimes) and outside the classroom (more often). Currently, 39 students are enrolled in the course, which is broken down into 9 teams (4-5 members), each with independent projects.

*Master’s Program.* While BME undergraduates receive broad, structured training in many aspects of biomedical engineering over the course of 4 years of study, BME Master’s students come from diverse training and backgrounds, including non-engineering disciplines, and many are international (~50% according to admissions data from 2015); thus, they may or may not have had a capstone design experience, significant training in engineering design, or well-refined technical skills. Therefore, we wish to provide a rich design experience for Master’s students that will fill in knowledge gaps and meet their unique educational and professional goals during their accelerated (~1 year) degree program.

## B. Our Unique Approach

A one-semester graduate-level course in BME design was developed that incorporated a blended learning approach with core video lectures outside the classroom and collaborative in-class learning experiences. The course enrolled 12 students (4 teams) in the Spring of 2015. For development and delivery of this new course, funding and in-kind support, including collaboration with an educational technologist from the Center for Teaching and Learning

(CTL)[b], was provided by a faculty grant from the Columbia University Office of the Provost on Hybrid Learning Course Redesign and Delivery.

### i. Defining Course Goals

The overall goal of the course was to provide Master's students with a real-world design experience. The specific educational goals were similar to Senior Design, with greater emphasis on development of teamwork skills and understanding the business opportunity, and were as follows:

1. Design a novel biomedical device.
2. Demonstrate knowledge of all aspects of product design, from problem definition through solution/idea generation to prototyping, verifications and validation via development of a design history file (DHF), outlining each aspect of the design process, explaining design decisions, and prototype planning and evaluation.
3. Demonstrate knowledge of regulatory and intellectual property issues that accompany the design of a novel biomedical device
4. Demonstrate knowledge of business opportunity via development of an executive summary describing the technology, main benefits, and value proposition to attract potential investors
5. Develop communication skills via formal presentations, written reports, and group meetings
6. Develop teamwork skills via collaborative learning and team-based design experiences

### ii. Course Content & Structure

To address our course goals, a blended learning approach was used with "thoughtfully selected and complementary face-to-face and online approaches and technologies" (Garrison & Vaughan, 2008) discussed below.

*Use of Technology.* Three main technologies were utilized in order to enhance interactions, organization, and creativity. This included video technology, project management technology, and a brainstorming and concept mapping tool. First, video technology (Camtasia, TechSmith, Okemos, Michigan, USA) was utilized to record short (~5 minutes) lectures and assess student's initial understanding. Second, project management technology (Basecamp, Chicago, IL, USA) was utilized to act as a central place for project team information including discussions, information dissemination, scheduling, task-assigning, and questions. Sharing of documents and regular feedback was also achieved utilizing the Basecamp tool. Third, a brainstorming and concept mapping tool (LucidChart, Lucid Software, Salt Lake City, Utah, USA) was utilized during the concept generation and brainstorming phase of the design process. During this phase, student teams were expected to brainstorm ~50 potential solutions per team and screen these solutions in a systematic way. LucidChart was utilized to organize and narrow potential solutions.

[b] Formerly the Center for New Media Teaching and Learning (CCNMTL)

*Course Structure.* A summary of the course structure and what occurred before, during, and after class can be seen in Table 1. Students watched the videos prior to class and were quizzed during the viewing as a formative assessment. Questions were based on the main takeaways from the video and included multiple choice and free response. The beginning of class was spent expanding on concepts in the videos, exploring examples, and addressing concerns. The majority of in-class time was utilized for active learning exercises, allowing for enhanced interactions with course materials, instructors, faculty, other students, and/or outside visiting industrial and entrepreneurial experts. Specifically, students participated in group exercises, including storyboarding and case studies, to implement concepts presented in the video lectures. Course instructors and assistants provided support to student project teams by providing recommendations and guidance during regular in-class coaching sessions. Visiting experts from industry, start-up companies, and expert faculty were able to share their own experiences in engineering design and provide guidance to individual projects. Hands-on workshops in electronics and CAD software were performed to enhance student's prototyping skills and/or address deficiencies among students without an engineering background. Lastly, significant time was made available for hands-on prototyping and proof of concept testing in the laboratory.

| Topic (s) | BEFORE | DURING | AFTER |
|---|---|---|---|
| Needs Finding | Videos | Active Learning | Team Project: Update DHF, Prototyping |
| Problem Definition and Need Statement | | | |
| Design Thinking, Deep Dive | Video | Active Learning | |
| Disease State Analysis | Videos | Active Learning | |
| Treatment Analysis | | | |
| Stakeholder Analysis | Videos | Visiting Expert, Active Learning | |
| Market Analysis | | | |
| Design Review Meeting #1 | Progress Report | Coaching Session | |
| Design Inputs & Specifications | Video | Active Learning | |
| Brainstorming & Ideation | Video | Active Learning | |
| Concept Screening | Video | Active Learning | |
| Prototyping | Videos | Active Learning | |
| Proof of Concept | | | |
| Design Review Meeting #2 | Progress Report | Coaching Session | |
| Intro to Facilities & Equipment | | Workshop | |
| Intro to Electronics | | Workshop | |
| Design Review Meeting #3 | Progress Report | Coaching Session | |
| Intro to CAD | | Workshop | |
| Design in Industry | | Visiting Expert | |
| Proof of Concept Testing #1 | | Lab Session | |
| Regulatory | Video, Reading | Case Study | |
| Proof of Concept Testing #2 | | Lab Session | |
| IP & Technology Commercialization | | Visiting Experts | |
| Design Review Meeting #4 | Progress Report | Coaching Session | |
| BME Entrepreneurship | | Expert Panel | |
| Reimbursement | Videos | Active Learning | |
| Business Planning & Models | | | |
| Prototype Refinement #1 | | Lab Session | |
| Prototype Refinement #2 | | Lab Session | |
| Design Review Meeting #5 | Progress Report | Coaching Session | |

**Table 1**. Course topics and content before, during, and after class.

*Feedback for Students.* To ensure continued progress, regular feedback was provided to teams through comments provided on their DHF (shared electronically via Basecamp) and through in-class coaching sessions, consisting of formal design review meetings with the instructor and individual teams and in-formal discussions with the instructor and visiting experts during group exercises and breakout sessions. Additionally, each group exercise concluded with a final deliverable for each team to be shared with the group. This sharing provided opportunities for collaboration, engagement, and feedback across teams and fostered a peer learning environment and community of inquiry. Lastly, students and instructors provided written feedback and scoring to each team via an established rubric during midterm and final presentations.

*Comparison between Undergraduate Senior Design and Graduate Design.* For reference, a summary of differences between undergraduate Senior Design and the new Graduate Design course can be found in Table 2.

| | **Senior Design** | **Graduate Design** |
|---|---|---|
| **Level of Students** | 4th year undergraduates | Master's |
| **Required/Elective Course** | Required | Elective |
| **# Enrolled** | 39 | 12 |
| **Student Background** | Engineering (biomedical) | Engineering (biomedical, chemical, electrical), Physical Sciences (physics, chemistry), Biotechnology, Medicine |
| **Length (semesters)** | 2 | 1 |
| **Supplementary Textbook** | Zenios, Makower, Yock (2010). Biodesign | Zenios, Makower, Yock (2010). Biodesign |
| **Lecture** | In-class | Video |
| **Duration of Program** | 4 years | 1-1.5 years |

**Table 2**. Senior Design and Graduate Design at Columbia University, Department of BME.

### iii. Course Evaluation

Evaluation of course dynamics and effectiveness was achieved through the development and use of Critical Incident Questionnaires (adapted from Brookfield 1995)[12] given twice in the semester (1/3 and 2/3 of the way through), a pre- and post-course survey, and course evaluations at the midpoint and end of the semester.

*Critical Incident Questionnaire.* Questions for the CIQ were designed to prompt students to describe their experiences in regards to the structure of the course: the online-delivered material, guest speakers, group work, and role of the instructor and TA. Students were asked to reflect on the following prompts/questions twice in the semester:

1. Think about your interaction with the material. Does the material (video and quiz) being delivered prior to class support your learning? If so, how? If not, why?
2. Think about the opportunity to interact with guest speakers. Have these been beneficial to your learning? Why or why not?
3. Think about the interactions you're having with your group. Has this contributed to your learning process?
4. Think about your interactions with the instructor and teaching assistant (TA). Is our class time together aiding in your learning process? Why or why not?
5. General comments - Please give our team any other feedback that you think would make the class better.

*Pre-course/Post-course Survey.* To evaluate initial and final reactions to course structure (use of technology, flipped classroom) and whether or not course objectives were met, a pre- and post-survey was conducted (Appendix A).

*Midterm & Final Evaluation.* The Midterm and Final evaluation were administered via the Columbia University CourseWorks system. The students were asked to rate the course as ((Poor, Fair, Good, Very Good, Excellent) according to the following criteria:

1. Amount Learned
2. Appropriateness of Workload
3. Fairness of Grading Process
4. Overall Quality
5. Additional Comments

## C. <u>Results</u>

### i. Critical Incident Questionnaire

Overall, students felt that the flipped classroom model of watching videos to learn about the topic prior to class was highly beneficial and made classroom time more effective. In addition, students enjoyed interacting with visiting experts, who provided critical feedback to their projects in addition to advice on career opportunities in the field. The students particularly valued the opportunity to network with these individuals. The team's interaction with each other and with other groups during class time was also found to enhance student learning. Lastly, the students felt like regular guidance from the instructor and TA allowed the teams to stay on track and continue their progress throughout the semester. Representative comments grouped by theme can be found below.

Regarding use of video prior to class:

> "Yes, it definitely does support the learning. I've always wished I were the kind of person to read before class but I am not. Watching videos and actively answering the questions is a great way to prepare me for class."

> "Yes, videos and subsequent evaluation with quizzes prior to class helps to solidify concepts that we later reinforce in the following class activity. Topics are then seen and thought of several times allowing for better retention of the information."

> "The quizzes helps to highlight what the professor finds most important and the big take-away ideas from each section of the video."

> "The video quiz lets me know the key point in the slide, and will also help me to concentrate on the content in the video and slide."

Regarding interactions with guest speakers:

> "Yes! Meeting professionals from relevant industries is helpful for learning practical tips as well as networking."

> "Great way to network and meet new people outside of the class"

> "These have been beneficial because each speaker has a different perspective and specialty in the entire biodesign process so it helps to be able to get at the purpose of this class from different angles."

> "Definitely yes! The guest speakers helped to bring in a real world perspective on the topics learned in lecture."

Regarding interactions with group:

> "I think the interactions I am having with my group are a major component of the learning process for this course."

> "Absolutely. Working with my group has taught me how to effectively communicate to others, while expanding our capacity for ideation and work."

> "Yes, everyone has their own specific skill set and what they are good at so group work is crucial to coming together and creating a device from the best of our combined abilities."

Additional comments regarding interactions with other students in the class:

> "I liked when we had a structured time to receive feedback from other groups in the class."

> "Feedback from students and help from business advisors was the most valuable aspect"

Regarding interactions with instructor and TA:

> "Both the instructor and TA are good resources for keeping the group focused and on track. They can help facilitate discussions and the flow of ideas. They also both give good feedback on written assignments."

> "The time in class is aiding the learning process. The instructor and TA are both like slightly removed extensions of our group members. Definitely helpful to bounce ideas off them the same as we do each other and it's good to have them steering us in the right direction"

> "Both the instructor and TA are good at facilitating discussions that help develop our projects."

> "Yes, interactions with the instructor has been crucial in steering us in the right direction. Sometimes general lectures and activities are hard to apply to our specific project and interactions with instructors help to narrow it down."

### ii. Pre-course & Post-course Survey

Results from the pre- and post-course survey are shown below. 6 out of 12 and 8 out of 12 students responded to the pre- and post-course survey, respectively, and therefore results will be presented as a percentage.

*Use of technology & flipped classroom*. After the course, students became more comfortable with technological tools to organize and disseminate information and were more comfortable collaborating online than at the beginning of the course (Figure 1A, 1B). The students also felt strongly that the use of technology and collaboration enhanced their learning in the course (Figure 1C, 1D). The students also agreed that watching videos prior to class was an effective method of preparation (Figure 2A) and an effective complement to, or replacement for, the traditional readings that are usually assigned for classes (Figure 2B).

Figure 1A. (Survey Question #1)

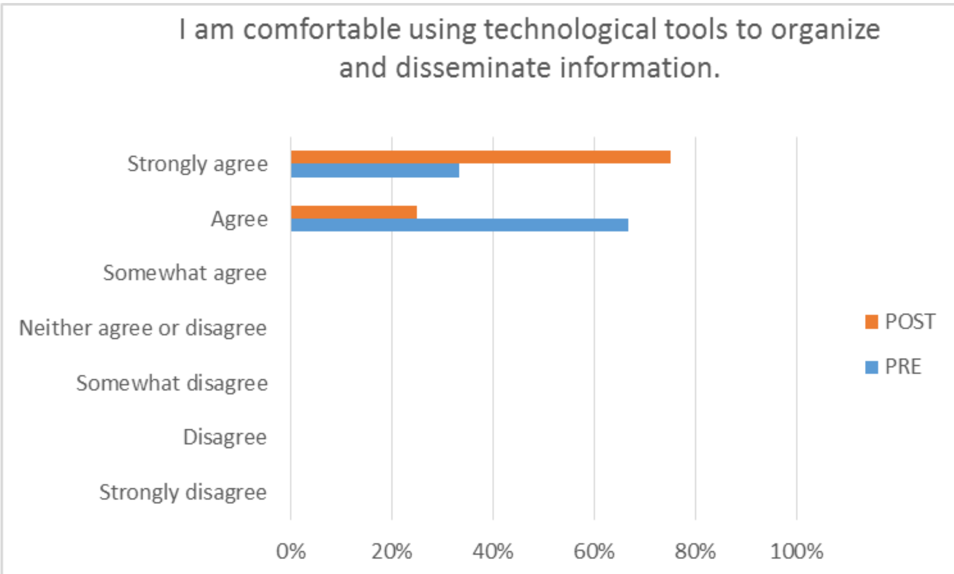



Figure 1B. (Survey Question #2)

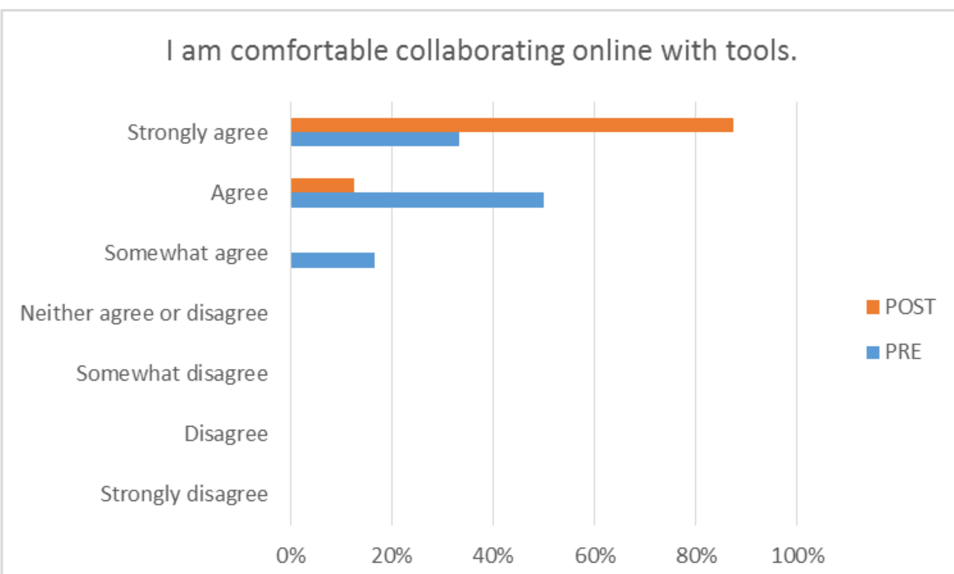


Figure 1C. (Survey Question #16)

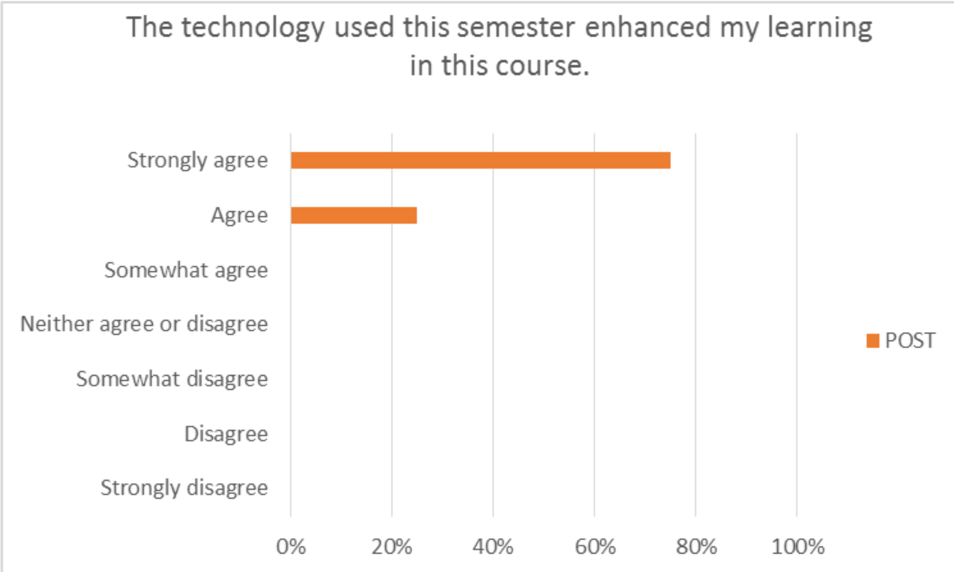



Figure 1D. (Survey Question #17)

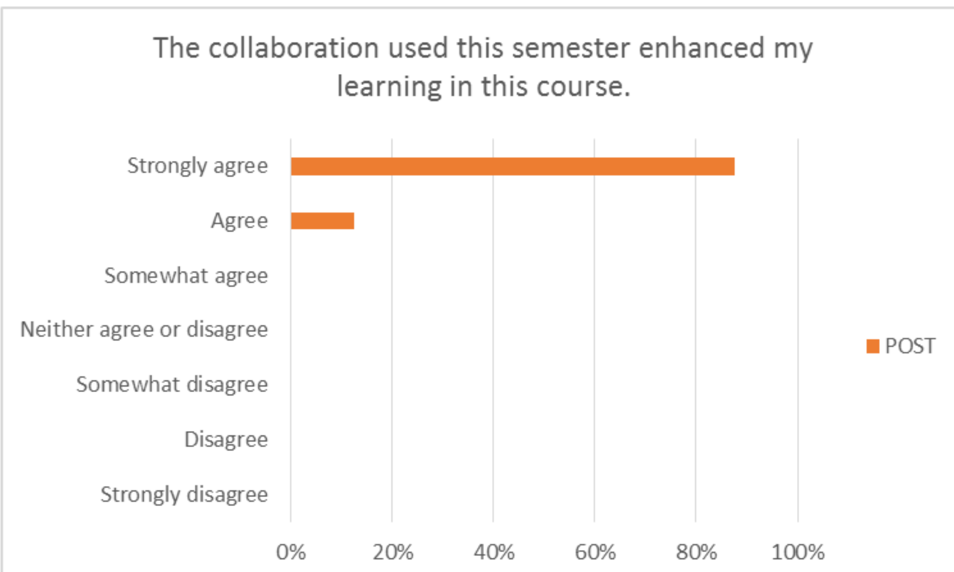


Figure 2A. (Survey Question #3)

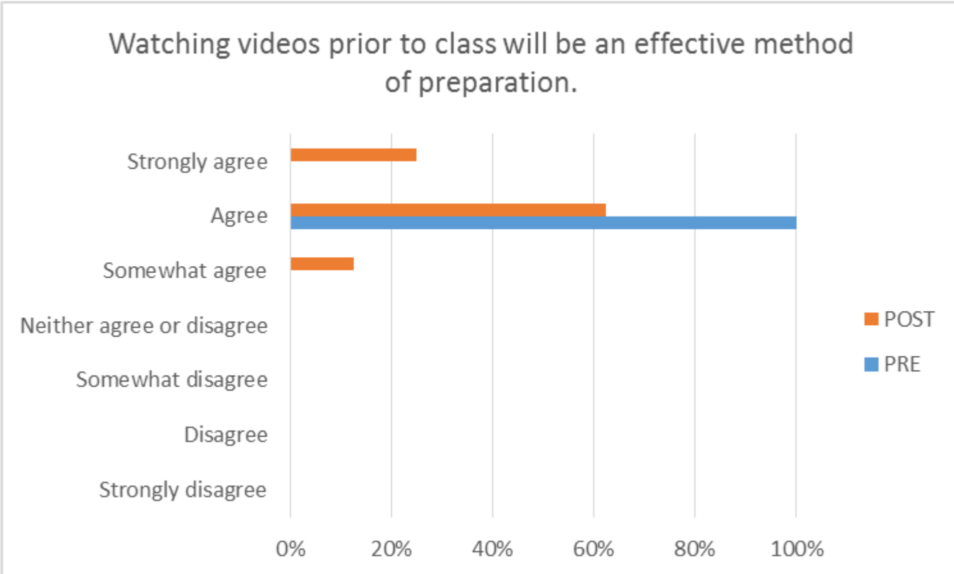
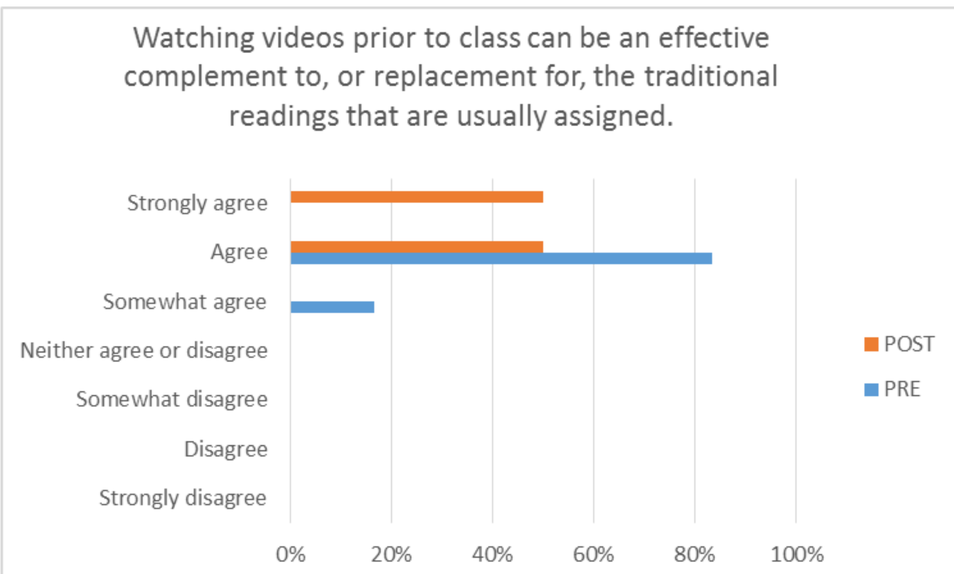



Figure 2B. (Survey Question #4)




*Were course objectives met?* At the end of the course, students agreed that they were more knowledgeable about the biomedical design process (course objective #2) (Figure 3A), regulatory and intellectual property issues (course objective #3) (Figure 3B, 3C), and how to evaluate the business opportunity for a medical device (course objective #4) (Figure 3C). In addition, students agreed that they were more comfortable giving a presentation to an audience and communicating their scientific knowledge effectively (course objective #5) (Figure 4A, 4B, 4C) and were able to work in a team environment effectively, were comfortable resolving team conflict, and were comfortable learning from their peers and teaching their peers (Objective #6) (Figure 5A, 5B, 5C, 5D) at the end of the course compared to the beginning of the course.

Figure 3A. (Survey Question #5)

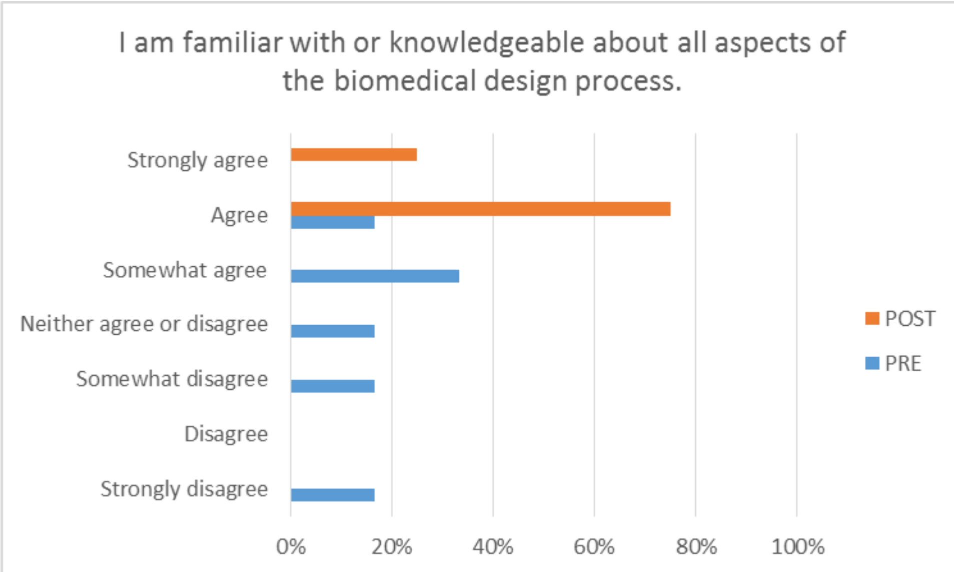



Figure 3B. (Survey Question #6)

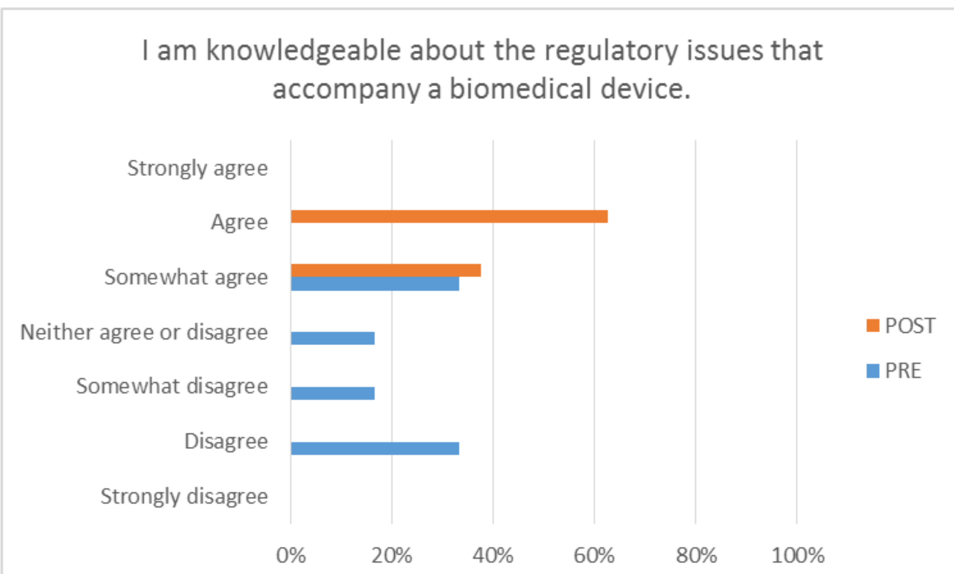


Figure 3C. (Survey Question #7)

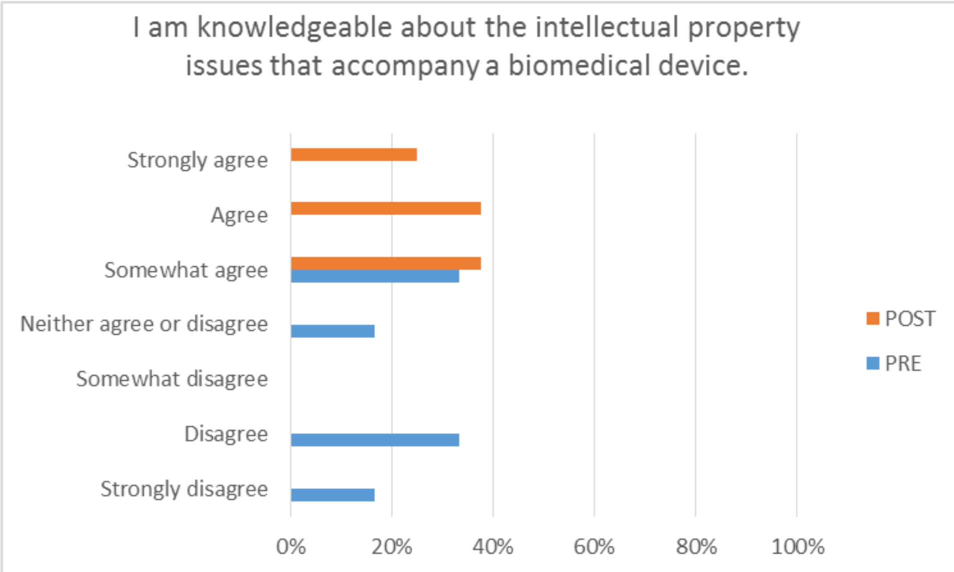



Figure 3D. (Survey Question #8)

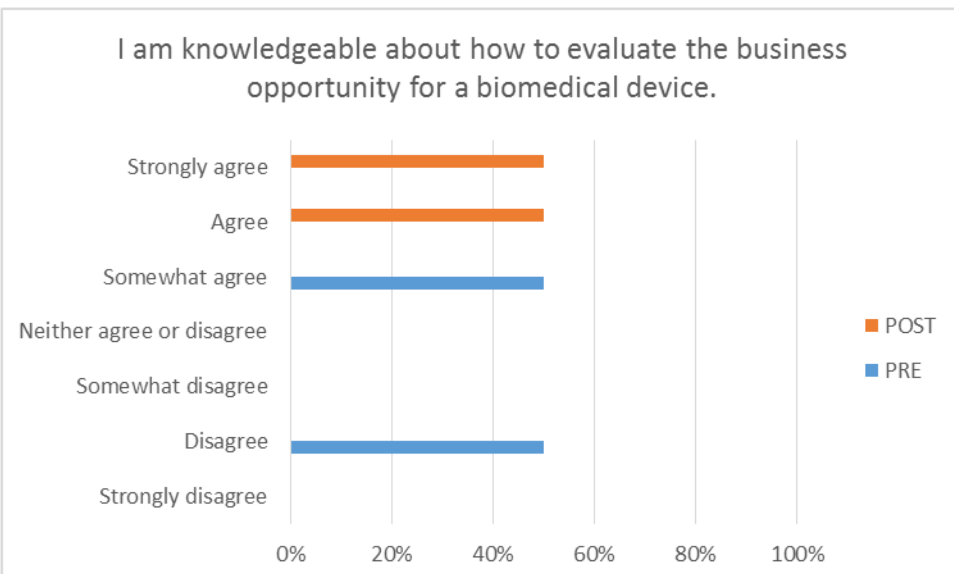


Figure 4A. (Survey Question #9)

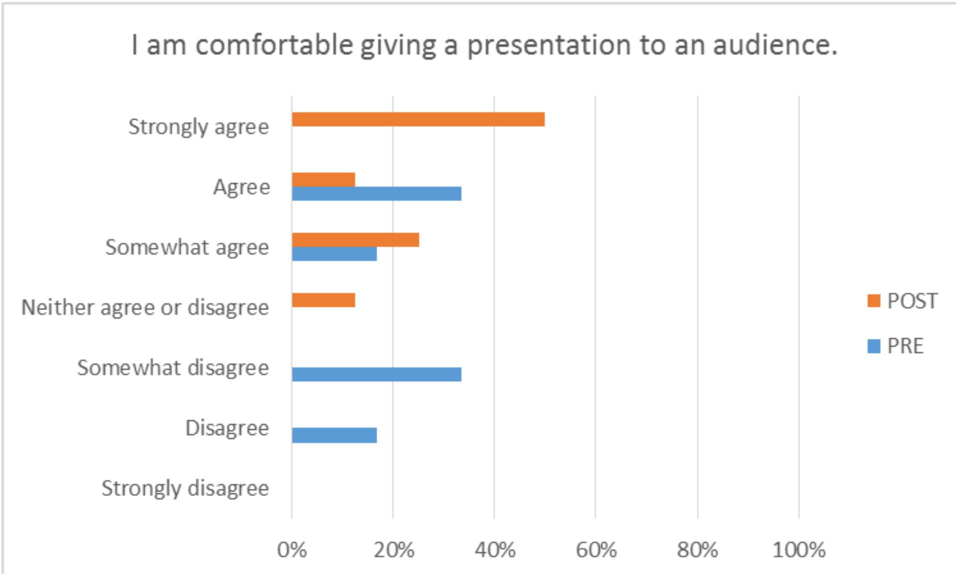



Figure 4B. (Survey Question #10)

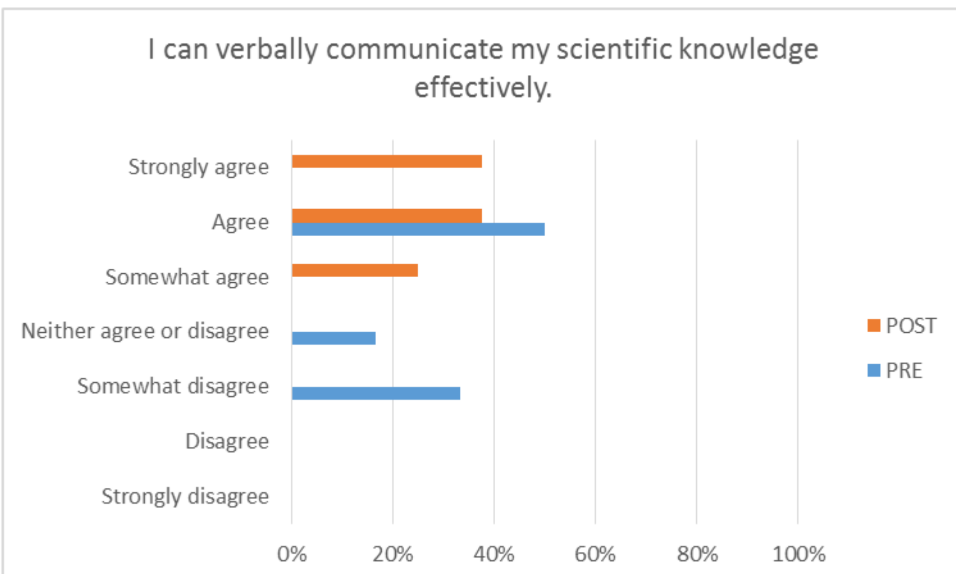


Figure 4C. (Survey Question #11)

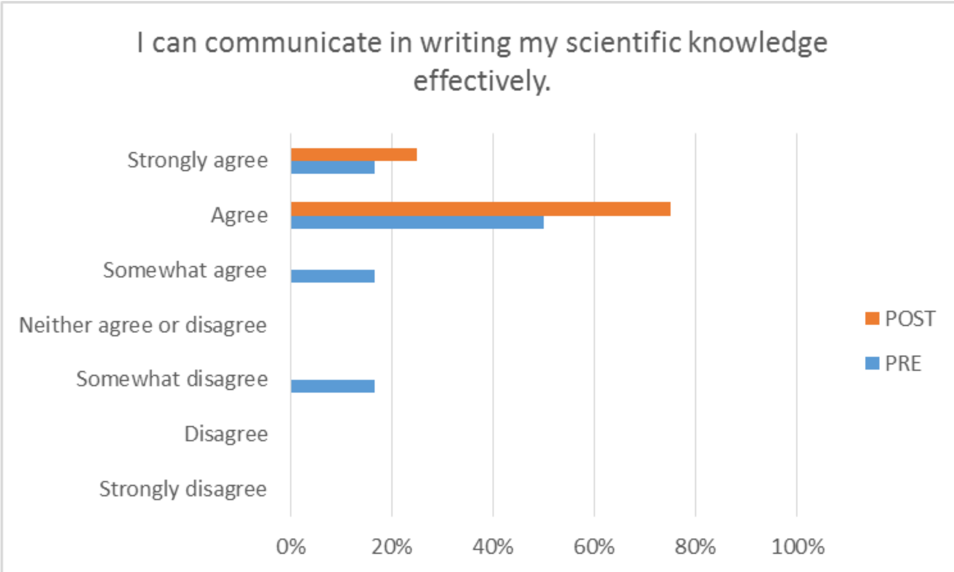



Figure 5A. (Survey Question #12)

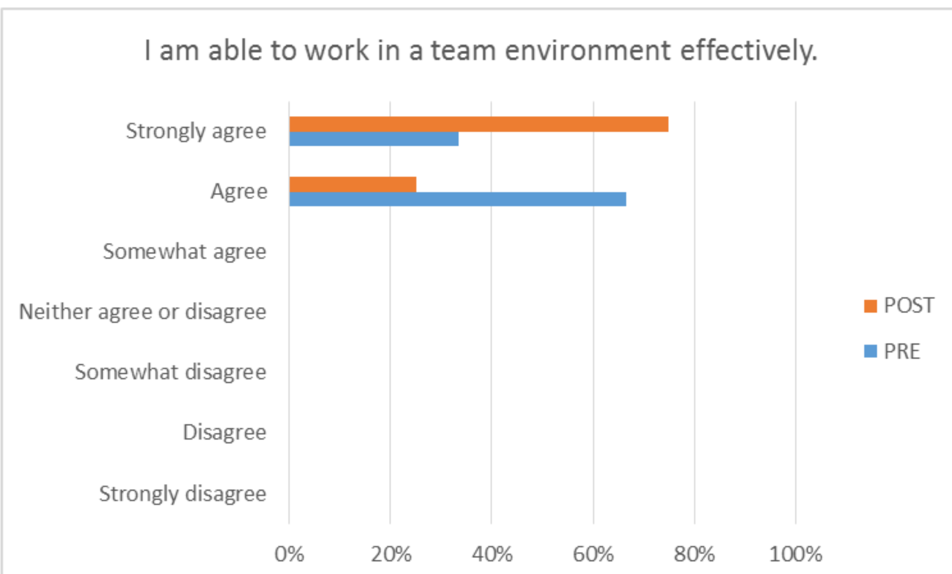


Figure 5B. (Survey Question #13)

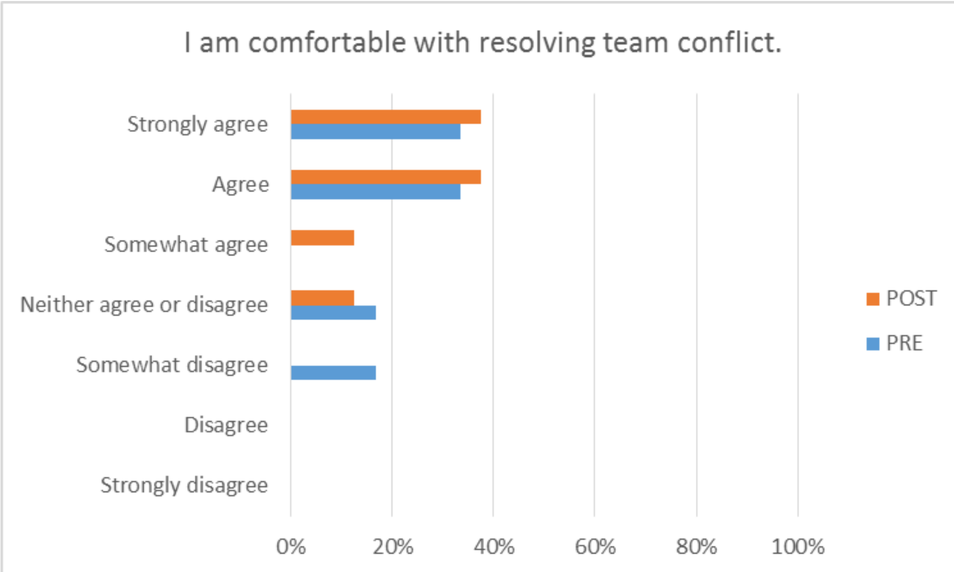



Figure 5C. (Survey Question #14)

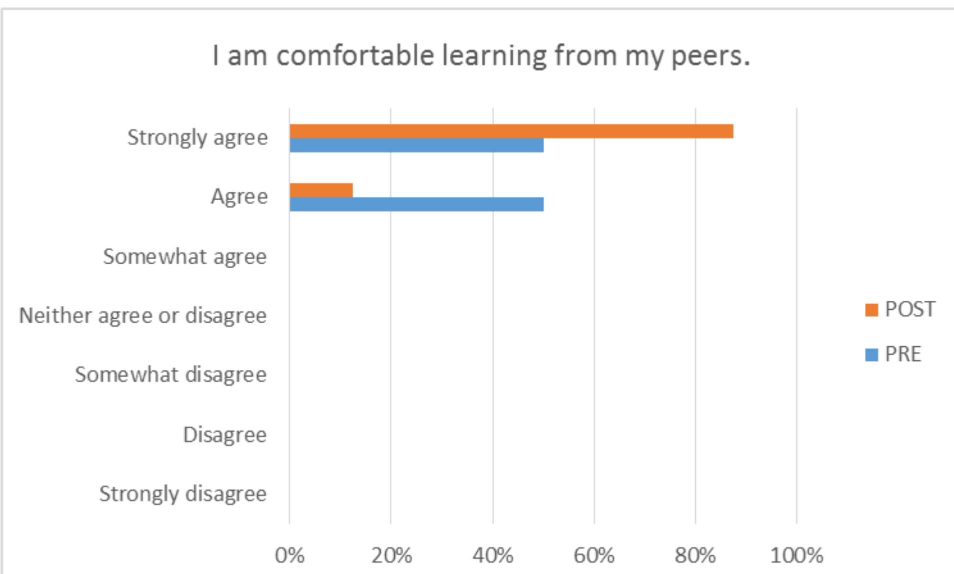
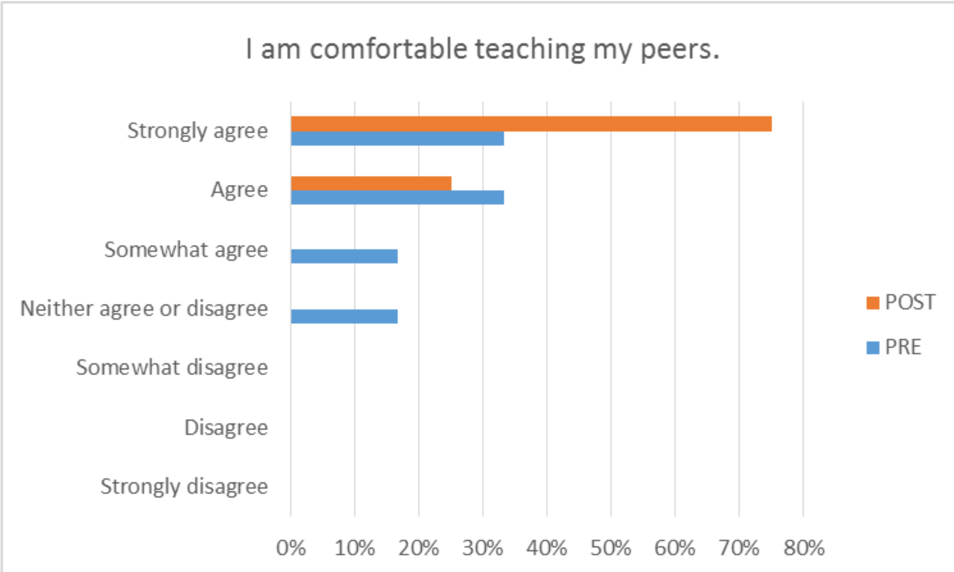


Figure 5D. (Survey Question #15)




### iii. Midterm & Final Evaluation

Results from the midterm and final evaluation of the course revealed an overall satisfaction for students (Figure 6A-D). 8 out of 12 students responded to the midterm and final evaluation and results are presented by number of students.

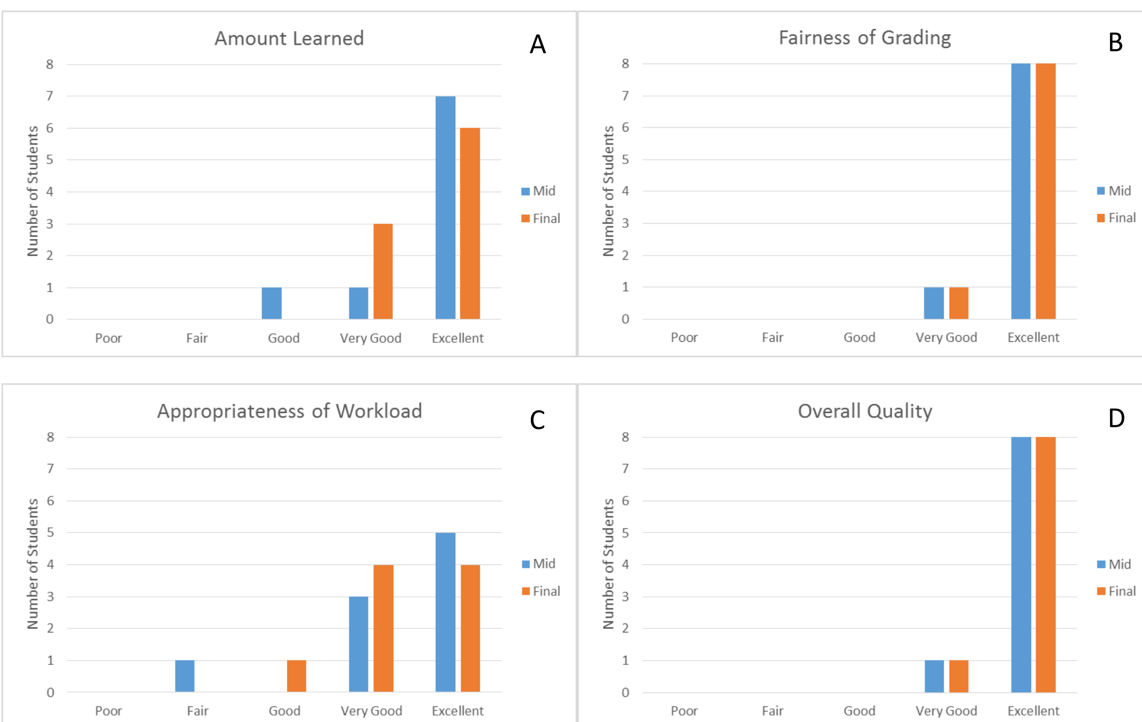



Figure 6. Student course evaluations

Student comments revealed some concerns about the workload of the 1-semester format but were overall happy with the design and content of the course. Representative comments grouped by theme are shared below.

Regarding workload:

> "The workload is quite a bit, but I do understand why it is so much and that it really needs to be this much to come up with a quality product."

> "This course is awesome. I am learning so much and just wish I had more time to put even more work into it!"

> "It does take a lot of time to do all of the work and do it right, but it is worth it!"

> "Difficult to build a whole prototype from nothing in one semester."

Regarding design and content of course:

> "The instructor is so organized and clever with the design of this course. I feel lucky to have had the opportunity to take this class."

> "It's the first class I've taken that I know I'm gaining real engineering experience."

> "It is clear that the instructor has worked very hard to organize this course and make it a great learning experience for Master's students. It has been the most valuable course I've taken here."

## Reflections on a Technology-Enhanced Graduate-Level Design Course

This article discussed the development of a new graduate-level course, utilizing a new approach to teaching design based on blended learning pedagogy. Overall, the blended learning structure and use of technology was successful in meeting the unique educational needs of Master's students in this tech savvy generation. Reflections on the course including lessons learned and challenges faced are discussed below.

*Undergraduate and Graduate Design.* While this course was designed to specifically meet the needs of our Master's students who are completing an accelerated program in Biomedical Engineering, we believe that this method of teaching would also be suitable for our undergraduate students. Introduction of material prior to class, allows students to familiarize themselves with concepts, and make in-class time more productive and more specific to higher order thinking and application of these concepts with facilitation by the instructor. One key difference in content is that workshops would not be necessary for our undergraduate students, because they are exposed to the equipment and prototyping prior to their Senior design sequence.

*Use of Technology*. The three main technologies (video, project management, brainstorming/concept mapping) were successful in enhancing interactions, organization, and creativity for the students.

Traditional lectures are limiting in two ways: 1) it is often difficult to assess student learning and 2) there is limited time for application. By utilizing short video lectures outside the classroom, we were able to assess the student's initial understanding real-time with the embedded quizzes. The video quizzes also forced them to pay attention during the video and nicely highlighted the main takeaways. Student questions were addressed and uncertainties clarified during the beginning of class time and throughout the class period during the designated activity. Students liked the fact that they received the information early (through video lecture) and were able to apply and refine these concepts in several different ways (including in-class activities, guest speakers, and group work outside of class) with the support of the instructor and TA. The main challenges with the video technology were initial technical difficulties with videos and finding the time to prepare the videos in advance (~1 week before the actual class).

The project management and brainstorming/concept mapping tools were effective in encouraging group collaboration and providing a platform for organization of materials and enhanced creativity. Overall, implementation of this blended learning strategy was smooth and well-received by students.

*Fostering Community*. Because of a growing concern that the technological changes being brought into the classroom might have divided and/or burdened the students, a pedagogical framework[4] aimed towards developing a deeper sense of community among students was implemented. As students were now being expected to work together before and after class, and to use technology in new and different ways (for many of them), it was paramount that the value of the group work and technologies were made explicit. It needed to be fully articulated that working together and helping each other, as a community, would reap many more rewards than working individually. Therefore, emphasis was placed on creating an environment that promoted and sustained open communication and the free exchange of ideas. Constructive feedback was encouraged throughout the semester, allowing students to understand and appreciate the iterative nature of design. Students were also encouraged to teach and learn from each other. Specifically, teams had the opportunity to share and interact regularly with the larger class, providing opportunities for collaboration, engagement, and feedback across teams and fostering a peer learning environment and community of inquiry.

*Course Development and Delivery.* The greatest benefit received from the faculty grant provided by the Columbia University Office of the Provost was the formation of a collaboration with an educational technologist (ET) from CTL. The ET not only assisted with the technology and its implementation but also helped in designing the course and developing teaching objectives and assessment strategies. This collaboration was critical to the success in this course and allowed for the instructor to get comfortable with the technology and efficiently deliver the material, assess student learning, and receive feedback.

*Evaluation.* Evaluation of the course structure was achieved through carefully designed surveys and the use of a critical incident questionnaire (CIQ). In order for the design implementation to be most effective, it was imperative to have a clear and unbiased understanding of the student experience. Because lecture material was now being delivered online, it was necessary to understand how students were experiencing the role of the instructor. It was also necessary to understand how students were experiencing their own role in the learning process. By chronicling and capturing this information throughout the semester through delivery of the CIQ, improvements could be made to the course in real-time. Here are some reasons for eliciting periodic, anonymous feedback in the form of the CIQ when designing a new course:[12]

1. **The CIQ can alert instructors to problems and issues early**: course evaluations administered at the end of the semester, while valuable, fail to notify instructors to problems that perhaps can be solved had the instructor known of them. The CIQ affords the instructor a gateway into the students' experiences while the class is active, thus providing the time to intercede and make the necessary changes
2. **The CIQ encourages students to be reflective learners**: Encouraging students to articulate their classroom experiences can help them to better understand the issues they're facing, as well as what is required of them in the newly designed learning environment.
3. **The CIQ can help to build trust**: Giving students an opportunity to freely express their thoughts and attitudes, and then ensuring that their feedback will be addressed, builds trust and community. The students become co-creators of the course.
4. **The CIQ can help to make changes to the class**: The iterative design process requires feedback in order to improve upon itself. The CIQ is an efficient and easy way to get that feedback.

*Did we get it right?* Based on the positive feedback from students and continued success of the teams (50% of the technologies developed in the course are still active and a company has formed around them), it is clear that the course accomplished the overall goal of providing students with a real-world design experience. The course was able to cover the same material as the undergraduate Senior Design course in 1 semester compared to 2 semesters and was able to offer Master's students the unique opportunity to interact and network with the instructor, their peers, and visiting experts in an intimate setting.

## Conclusions

This paper has focused on a newly developed biomedical design course. This class was designed specifically for Master's students completing an accelerated program of study; however, we feel that the course format would also be suitable for undergraduate design courses. The technology-enhanced pedagogical approach allowed for students to have enhanced interaction with course materials, instructors, and visiting experts, improving their learning and networking experiences and increasing their overall satisfaction with the course.

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## APPENDIX

**Appendix A**. Pre- and Post-Course Survey

Responses (Strongly Agree, Agree, Somewhat Agree, Neither Agree or Disagree, Somewhat Disagree, Disagree, Strongly Disagree)

1. I am comfortable using technological tools to organize and disseminate information such as Google Docs, Basecamp, LucidChart, etc.
2. I am comfortable collaborating online with tools such as Google Docs, Basecamp, LucidChart, etc.
3. Watching videos prior to class will be an effective method of preparation.
4. Watching videos prior to class can be an effective complement to, or replacement for, the traditional readings that are usually assigned.
5. I am familiar with or knowledgeable about all aspects of the biomedical design process.
6. I am knowledgeable about the regulatory issues that accompany a biomedical device.
7. I am knowledgeable about the intellectual property issues that accompany a biomedical device.
8. I am knowledgeable about how to evaluate the business opportunity for a biomedical device.
9. I am comfortable giving a presentation to an audience.
10. I can communicate in writing my scientific knowledge effectively.
11. I can verbally communicate my scientific knowledge effectively.
12. I am able to work in a team environment effectively.
13. I am comfortable with resolving team conflict.
14. I am comfortable learning from my peers.
15. I am comfortable teaching my peers.
16. The technology used this semester enhanced my learning in this course.[c]
17. The collaboration used this semester enhanced my learning in this course.

[c] Statements added for post-course survey ONLY