BOARD # 29: Work In Progress: Redesigning a biomedical engineering course to enhance design mindsets and skills

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Introduction

In the field of biomedical engineering (BME), the ability to think critically, collaborate effectively, and design innovative solutions is critical. Yet, traditional approaches to teaching design often fall short of bridging the gap between theory and practice. Recognizing this, BME 2081, a one-credit, year-long seminar at Cornell taken by BME students typically during their sophomore spring and junior fall semesters, is undergoing a transformative redesign to develop the skills and mindset needed to tackle complex, real-world challenges in biomedical design. We aim to address the question of how the middle years of college (sophomore and junior years) serve as a bridge between foundational learning and advanced application of BME design attitudes, beliefs, mindsets, and skills.

This course is designed to guide students in reflecting on their strengths, areas for growth, interests, and past experiences while creating an online resume. Through weekly 50-minute sessions, the seminar addresses ABET Student Outcomes 1–7, fostering a reflective approach to learning in BME. However, the course's impact has been limited by insufficient engagement with real-world biomedical engineering challenges and the biodesign process. This presented an opportunity to redesign the course to strengthen students' design thinking skills by integrating practical, real-life applications of BME. The redesign aims to create a transformative learning experience that equips students with the skills and perspectives necessary to excel in a rapidly evolving field. By prioritizing authentic engagement with real-world problems, the course seeks to inspire creative solutions that are ethical, user-centered, and sustainable, preparing students to make meaningful contributions to the future of biomedical engineering. Assessment of the impact of the redesigned course will involve a mixed-method analysis, incorporating pre/post surveys, course artifacts (e.g. weekly deliverables ranging from literature reviews to concept maps), student evaluations, weekly reflection questions, and post-course interviews conducted longitudinally across the first-year introduction to BME course, this course, and BME Senior Design. For the purpose of this paper, we will be discussing initial results from a course artifact in Module 3.

Leveraging backwards design, an evidence-based pedagogical method [1], [2], [3], [4], [5], the course structure has been reimagined to align each learning activity with key outcomes such as enhancing design thinking, building resilience through iteration, and fostering an empathetic approach to engineering challenges. Through collaborative teamwork, reflective exercises, and scaffolded project-based learning, students are empowered to navigate ambiguity, develop innovative solutions, and connect their learning to real-world impact.

Methods

Course Design

Using the backwards design approach, BME 2081 was completely transformed with specific learning objectives in mind: enhancing metacognitive skills, employing empathetic engineering, and developing expert-like BME epistemologies. These objectives were continuously emphasized throughout the course via the four modules shown in Table A1 in the Appendix.

Each module spans two to four weeks, and each week consists of a class deliverable and reflection survey. See table A2 in Appendix for a detailed breakdown of the course material.

Collaborative learning was also fostered throughout the semester by creating small groups of four to six students and prompting teamwork through guided worksheets requiring group discussions. Additionally, emphasis was placed on developing expert-like epistemologies surrounding BME, as research has indicated that there is a connection between students' beliefs about science and engineering and learning in STEM courses [6], [7], [8], [9]. To achieve this, we encouraged comfort with failure as well as an understanding of the importance of iteration through activities like the "desert island" scenario in Module 1 and the exploration of the blood pressure datasets in Module 3.

A major goal of this course transformation was to foster confidence in translating skills learned to future careers. To achieve this, we dedicated one class session to reflecting on both technical and non-technical skills acquired from all courses, as well as additional experiences such as student organizations, internships, and jobs.

Select activities were piloted over the summer with a group of student volunteers prior to the first full iteration of the course. The first iteration was conducted during Fall 2024 as a ½-credit course with 55 third-year students who had completed the first half of BME 2081 in Spring 2024 (see Table A3 in Appendix for further demographic information). The second iteration will be conducted in Spring 2025 as a single semester 1-credit course. The research study was approved by Cornell's Institutional Review Board (IRB0148499).

Preliminary Results and Discussion

Weekly student reflections and surveys were used to gauge the impact of the redesigned course activities and learning objectives for BME 2081. For example, we saw clear evidence of enhancement of metacognitive skills from student reflections regarding a learning progression diagram activity. Students were tasked to illustrate how skills learned in class (e.g., creative thinking, effective team strategies) could integrate with other past experiences and be leveraged in future BME work. For this work in progress study, results were drawn from an assignment in Module 3 where students were asked to reflect on technical and transferable skills learned in this course so far, as well as from other courses and any external experiences, and how they can translate to skills required for their future careers as biomedical engineers. From these reflections, 17 students discussed how they developed advanced teamwork and collaboration skills from this course. For example: *"BME 2081 further enhanced my ability to work collaboratively and approach problems with a solution-oriented mindset, preparing me for interdisciplinary team efforts."*

Additionally, 10 students discussed the improvement of their communication skills from this course, describing how working in groups for nearly all class activities allowed them to practice presenting in front of small groups and how to clearly communicate their research findings and ideas. For example: *"I feel that this class allowed me to be involved in a lot of open and judgment free communication."*

In terms of more technical skills learned as a result of this course redesign, 13 out of the 55 students highlighted the value of Module 3 in giving them the opportunity to experiment with

data processing and R programming when reflecting on transferable skills acquired through this course. While students initially expressed frustration during this module due to the intentional lack of clear direction on how to analyze and interpret real raw data, many ultimately recognized the value of this approach. By the end of the module, many appreciated how it encouraged creative thinking and helped them become more comfortable with failure. As part of their reflections for the final week of Module 3, students were asked to describe a challenge of this module. One student said, *"It was challenging to come up with a research question that actually reflected the data at hand. It is easy to try and come up with a general question that seems interesting; however, once I actually looked at the variables in the hypnos package, I reevaluated my research question. This taught me that it is important to understand the data at hand and what data is feasible to obtain when thinking of a research question."*

While the primary objectives of Module 3 were to become more familiar with R programming, data verification, and analysis, student reflections showed that they went beyond these goals. They demonstrated high-level engineering thinking by refining and reevaluating their approach when formulating actionable and appropriate research questions. Building on the skills and experiences gained from Modules 1-3, students participated in a collaborative brainstorming session aimed at developing innovative and "disruptive" design solutions for blood pressure monitoring. By carefully analyzing diverse user needs, current market offerings, and real-world data highlighting areas for improvement, students developed evidence-based solutions that demonstrated their ability to abstractly conceptualize and address a complex biomedical engineering challenge.

Conclusions and Future Work

Overall, we found that the course redesign efforts provided a more authentic experience for BME students, enabling them to gain valuable skills that were not achievable in the previous version of the course. This is evidenced by student reflections on their experiences in BME 2081. However, further iterations are needed to address specific areas for improvement.

This is only a preliminary analysis and looking ahead, we plan to use longitudinal mixed-methods to triangulate the long-term impact of this course transformation using course artifacts, surveys, and focus groups/interviews as students continue their careers through senior design and beyond. This preliminary analysis is limited by the fact that we only used course artifacts which were graded assignments and therefore could impart some bias due to power dynamics or hesitancy to speak freely. As we continue this course transformation, we are interested in investigating students' thoughts on the importance and intrinsic value of BME design attitudes, beliefs, mindsets, and skills. This will further align our current and future work with existing epistemology literature and research. While many students exemplified intended learning outcomes, the half-credit format for this course was not always conducive for students to deeply immerse themselves in situated learning environments due to time constraints. As this course transitions to a one-credit, single semester format, additional activities will be incorporated to enhance class session preparation. This will create a more immersive in-class experience, offering students an opportunity to engage in a learning environment that mirrors real-world engineering projects.

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Appendix

Table A1 Course outline and key learning objectives for redesigned BME 2081 course.

Module	Key Learning Objectives	Example Activities
1	-Develop communication, problem-solving, creativity, and conflict resolution skills in a fast-paced setting. -Conduct rapid, low-fidelity prototyping and validation testing. -Apply and reflect on core ethical values to build effective teams. -Cultivate comfort with failure in engineering design.	"Desert island" scenario: students were given different personas (e.g., pharmacist, surgical intern, pilot) and tasked with saving a patient using limited resources such as part of a life vest, first aid kit, and office supplies.
2	- Identify gaps in current technology where there is potential for innovative designs through clear problem definition. - Evaluate how user needs and system constraints impact device design.	Device dissection/reverse engineering of blood pressure monitors. Conducted scaffolded literature reviews and medical device history timelines

3	- Develop comfort with device verification studies through data analysis. - Engage in pair programming to enhance collaboration. - Develop design solutions for disruptive and innovative blood pressure monitoring systems.	Analysis of real-world blood pressure datasets using R programming. Class-wide brainstorming session of disruptive ideas and solutions to improve blood pressure monitoring.
4	- Understand the regulatory bodies involved in biomedical engineering. - Develop an ethical reasoning framework.	Exploration of regulations associated with selected medical devices. Stakeholder role playing in the development of an AI nebulizer.

Table A2 Complete Course Outline

Date	Module	Description	Learning Objectives	Class Deliverables
8/30	1	Course Overview & Desert Island Scenario	- Review the syllabus and understand the course objectives. - Develop communication, problem-solving, creativity, and conflict resolution skills by working with an interdisciplinary team during a simulated crisis. - Implement rapid, low-fidelity prototyping and validation testing.	Core values worksheet
9/6	1	Rapid Prototyping	- Apply core values to foster a successful teamwork environment. - Understand when to use the fail/fast fail/quick philosophy and compare it to other design philosophies. - Develop comfort with failure and iteration during the design process.	Methodology and iteration worksheet

9/13	2	Reverse Engineering	- Validate hypotheses about device function through analysis of individual components of blood pressure monitoring devices. - Develop engineering intuition and tinkering skills through dissection of blood pressure monitoring devices using hand toolkit. - Generate a schematic diagram of a blood pressure monitoring device containing the minimum required components.	Device dissection worksheet
9/20	2	Literature Review	- Recognize the importance of background research and a thorough understanding of the physiological problem. - Develop skills for conducting a literature review as a necessary part of the design process.	Literature search worksheet
9/27	2	Device History & Iterative Design	- Evaluate the different types of BP devices throughout history and produce a storyboard timeline in order to demonstrate the iterative nature and life cycle of medical device design. - Identify gaps in current technology where there is potential for innovative designs.	History worksheet and storyboard
10/4	2	User Needs	- Evaluate how user needs and system constraints impact device design. - Develop a problem statement including scope, user need, and intended outcome.	User needs worksheet
10/11	3	**No class**	- Download R studio and read through the R tutorial worksheet in preparation for module 3.	
10/18	3	Coding with R *bp* package & pair programming	- Implement coding skills in R for data and statistical analysis of human subjects data. - Generate visuals from processed data to analyze real bp measurements. - Engage in pair programming to enhance understanding of dataset and improve quality of code.	R tutorial worksheet

10/25	3	Data analysis and validation	- Construct problem statements and use data to understand the medical need. - Develop comfort with device verification studies through data analysis. - Engage in pair programming to enhance understanding of dataset and improve quality of code.	Data validation worksheet
11/1	3	BP device - communicating findings	- Reflect on how verification studies and competitive benchmarking can inform the design process of blood pressure devices.	Data validation worksheet
11/8	3	BP device - redesign	- Develop design solutions of disruptive and innovative blood pressure monitoring systems. - Reflect on how module 2 and 3 allowed for concept generation.	Brainstorming worksheet
11/15	4	Mapping skills to BME careers	- Enhance career preparation and planning through reflection of essential skills attained and their application for biomedical engineering career pathways. - Illustrate how job application materials may be created for specific positions.	Resume revision + reflective narrative
11/22	4	Standards, safety regulations, and IP	- Understand how to read a standard code and the types of standards common for biomedical devices. - Evaluate standards and safety regulations associated with nebulizers. - Understand the importance of IP in biomedical engineering design. - Conduct a patent search and understand how to read and write patents.	Standards + IP worksheet
11/29		Thanksgiving break, no class		
12/6	4	Ethics	- Develop an ethical reasoning framework. - Apply bioethics, medical ethics, and engineering ethics principles to case studies related to biomedical design.	Ethics worksheet

Table A3 Percentage Demographics for Students Participants in BME 2081 (n=38)

Gender	Man	Woman	Prefer not to say			
	26.3	71.1	2.6			
Race or Ethnicity	Black or African American	East Asian	Middle Eastern or North African	Hispanic, Latino, or Spanish	South Asian	White
	7.9	31.6	13.2	15.8	10.5	39.5
Education level of parent/guardian #1	Less than a high school diploma	High school diploma / GED	Some college or an associate/trade degree	Bachelor's degree	Master's degree or higher	
	2.6	10.5	5.3	21.1	60.5	
Education level of parent/guardian #2	Less than a high school diploma	High school diploma / GED	Some college or an associate/trade degree	Bachelor's degree	Master's degree or higher	
	2.6	10.5	5.3	21.1	60.5	
Years as a student	Three years	Four years				
	94.7	5.3				