Student Learnings and Teaching Insights from a Multidisciplinary Engineering Design Course

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Abstract

This paper presents an analysis on student learnings and a reflection on teaching in a multidisciplinary design course. With the rapidly changing global economy and workforce, engineering students need to be prepared to work on complex problems within multidisciplinary teams and design solutions with diverse social and ethical considerations in mind. To address this need, the Whiting School of Engineering at Johns Hopkins University initiated a Multidisciplinary Design Program. Currently, the program offers a two-semester sequence where teams of multidisciplinary engineering students are engaged in design challenges with project partners from medicine, industry, or the social sector. Students are mentored through a human-centered design process to (1) conduct technical, contextual, and user research, (2) focus the challenge, (3) ideate, and (4) prototype and test their solutions. In this paper, we focus on the first semester course from Fall 2022 by discussing the course goals and learning outcomes, the structure of the course, and the course projects. Evaluation data of specific course goals will be analyzed to understand student experiences and perceived learnings in the course. This will provide evidence for the effectiveness and achievement of the desired course outcomes. Insights from the teaching team on the approaches to support the success of students throughout their multidisciplinary design experience are also discussed. Understanding the student learning experience along with insights from the teaching team of the course can also inform the development of a wide range of design experiences for undergraduate engineering students.

Introduction

Design is a core activity for engineers and central to the criteria that evaluates and accredits engineering programs [1,2]. Engineering students need to be able to design solutions that are both innovative and grounded in the needs of the end user. With the rapidly changing global economy and workforce, engineering students need to be prepared to work on complex problems within multidisciplinary teams and design solutions with social and ethical considerations in mind [3, 4]. Engineering education scholarship is rich with examples of design courses in engineering [5]. The most common design courses in engineering are first-year design experiences in which students are exposed to various engineering fields and are engaged in a hands-on project [6-9], and (2) culminating senior design experiences in which students apply what they have learned throughout their engineering undergraduate experience to a final project [10-13]. These culminating senior design projects vary from being within the same discipline to multidisciplinary, with research showing the benefits and need for more multidisciplinary design experiences [14,15]. Although design courses, and specifically multidisciplinary design courses in engineering, are not new, there is still a need for continuous design experiences throughout the undergraduate curriculum.

To address these needs, the Whiting School of Engineering at Johns Hopkins University initiated a Multidisciplinary Design Program, in which design courses can be integrated throughout undergraduate engineering curriculum, rather than just as an introductory design course in the first year or as a culminating design experience in the fourth year. The goal of the program is to create a suite of courses that support different aspects of design learning to create the opportunity for an applied, hands-on design thread throughout the engineering curriculum.

Multidisciplinary Engineering Design Course

Currently within the Multidisciplinary Design Program, a two-semester sequence is offered where teams of students from multiple engineering disciplines and varying academic levels are engaged in design challenges with project partners from medicine, industry, or the social sector. Student teams are supported with money to cover spending on supplies, a faculty mentor that provides expertise and guidance, and a lab space where students can prototype their designs. Figure 1 visualizes this model for the Multidisciplinary Engineering Design course.

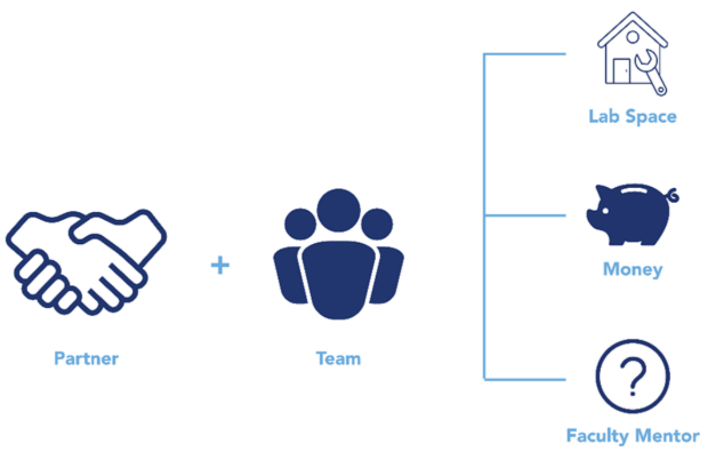

Figure 1: Multidisciplinary Engineering Design course model.

Design Process

Students are mentored through a human-centered design process where they are engaged in creative problem-solving focused on the needs of the end user. Students learn to (1) conduct technical, contextual, and user research, (2) focus the challenge, (3) ideate, and (4) prototype and test their solutions. The first semester is primarily scaffolded and structured so that teams gain an understanding of the human-centered design process shown in Figure 2. As seen in Figure 2, reflection occurs to help students unpack, understand, and learn to apply their new learnings moving forward after each phase in the form of written and/or group reflective discussion.

Significant research has shown the benefits of reflective practice in enhancing learning by helping students make connections between experiences and academic content [16, 17].

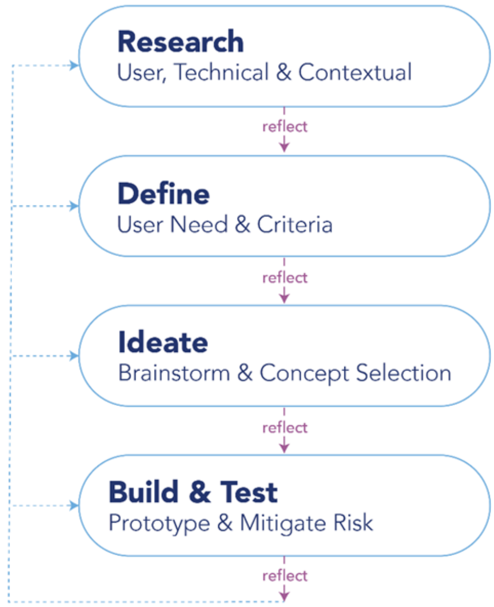

Figure 2: Human-centered design process for the course.

To properly focus on the correct aspects of the problem, students are taught to seek a deep understanding of their end users and their context, as well as the technical background of the problem. Once the problem is properly defined and user criteria are developed, teams move through a concept ideation and selection process of potential solutions. Next, teams conduct two iterative rounds of prototyping and testing solutions. They are encouraged to prototype and fail quickly so they can either (1) confirm they are heading in the right direction, or (2) quickly pivot to another solution concept. In the second semester, teams have freedom to manage their own project timelines and activities based on their project needs. They transition their low-fidelity prototypes into functional prototypes that can be tested according to their specifications with their end users and in technical bench tests. This paper focuses on the first semester experience by discussing the course goals and learning outcomes, the structure of the course, the course projects, and an analysis of the perceived student learnings based on course evaluations. We have one main guiding research question: *What are the perceived learnings of students in the first semester of the Multidisciplinary Engineering Design course, and do they align with the course goals?*

First Semester Course

Course Goals and Learning Outcomes

As stated previously, the first semester is scaffolded for students to experience and learn the design process and develop critical thinking skills in an authentic, multidisciplinary engineering context. The specific learning outcomes we strive for students to achieve by the end of the semester include the following:

1. Confidently address problems (in engineering and beyond) with a robust design process and mentality
2. Conduct qualitative interviews to better understand the perspectives of end users
3. Synthesize findings from interviews into actionable design criteria
4. Prototype quickly and effectively to learn, communicate ideas, and get feedback from end users
5. Demonstrate a new technical skill from their discipline or another, learned from a teammate, technical advisor, or self-study
6. Communicate and contribute effectively in a team
7. Convey solutions clearly and deliberately to an outside audience
8. Consider the ethical implications of their design projects

The Intro Project

The students are first engaged in a quick 2-week, intro design project before transitioning to the main project for the remainder of the semester. During the 2-week project, students go through a full design cycle to gain a holistic sense of the design process trajectory. The goal of this intro project is two-fold: 1) for students to begin learning the design process and make mistakes early on before working on their main projects, and 2) for the teaching team to learn more about the students in the course. Learning about the students in the course helps us form teams for the main projects and helps with the teaching process as we gain insights on the capabilities and prior knowledge the students bring to the course.

The Main Project

After the quick intro project, students are assigned to their main project teams and given more guidance and structure to work through a design challenge for the rest of the semester (11 weeks) and the second semester of the 2-semester design experience. The primary goal for the first semester of their main project is to establish a deep understanding of their end users, the historical and current context of the challenge, and any relevant technical knowledge, so that teams can properly focus on the correct aspects of the problem. They are expected to move through two iterations of prototyping and testing solutions that affirm if they are on the right track or encourage them to pivot solution directions. Throughout the course, students are taught and mentored in new ways of thinking and learning. Specifically, students are encouraged to maintain a design ethos in which they are (1) learning from others, (2) embracing ambiguity, (3) biasing towards action, (4) learning from failure, and (5) communicating deliberately [18].

Fall 2022 Projects

The intro project is an internal project to Johns Hopkins University in which students are presented with an open-ended challenge relevant to their experience as students. In Fall 2022, teams of 4 all worked with the same partner, the JHU recycling office, to design ways to encourage the reuse of mugs, bottles, and utensils among students on campus.

Table 1: List of the projects, partners, and descriptions of the design challenges for the main projects during the Fall 2022 semester.

Project	**Partner**	**Description**
A	Local non-profit organization	A way to integrate the long white cane with new mobility solutions for blind individuals who experience challenges using a cane
B	Local zoo	A way to create opportunities for giraffes to find food based on their behavior to mimic what they might experience in the wild.
C	Local community partner	A way to create a specific bokashi formulation and development process that suits the wants and needs of prospective users.
D	Medical device start-up	A way to confirm the correct placement of short-term feeding tubes in real time.
E	Orthopedic surgeon	A way to decrease the invasiveness of rotational osteotomy procedures to reduce blood loss, incision size, and recovery time.
F	Global sporting company	A way to make all parts of shoes sustainable, either through reuse or recycling.

Before assigning students their main projects, they get a chance to learn about the projects and talk with the project partners during a project pitch event. Students are then asked to fill out a preference form in which they rank their top choices for projects and inform us of the skills they bring to the team. Based on this information and our observations during the intro project, the teaching team assigns students to projects, ensuring that each project has a mix of disciplines and expertise. During the Fall 2022 semester, a total of 26 students were spread among 6 different projects, which are described in Table 1.

Methods

At the end of each semester, students are asked to fill out a course evaluation consisting of a range of quantitative, Likert questions and qualitative, open-ended questions about the quality of the course and their learnings in the course. For this study, we focused on answers to the question: “What was the most important concept you took away from this course?” This was an open-ended question. Therefore, an inductive thematic analysis [19] on the responses was used to code each response independently and analyze the data for emerging themes. The data from the open-ended question can be a rich source of student perspective because they were given autonomy to write about what meant most to them rather than being prompted and choosing from a list of concepts. All the responses were read multiple times by each researcher. After distinguishing and developing themes among the data, the responses were coded, and example quotations were identified. Differences in coding among the researchers were resolved through discussion and iteration on the coding schemes.

Findings

In the next section, we present the themes that resulted from the inductive thematic analysis on 25 responses. A total of three themes emerged: (1) design process, (2) design ethos, and (3) working in a team. This section will focus on unpacking each theme with supported quoted evidence from the responses. A complete list of the responses and how they were grouped in each theme can be found in the Appendix.

Theme 1: Design Process

Many of the responses highlighted a phase of the design process as the most important concept they learned in the course. The most common phase of the design process that was mentioned was the research phase in which students learned about the importance of user research. Student responses specifically highlighted the importance of understanding end users in design. For example, one of the students stated, “user interviews and feedback are the core to designing a good product.” Another student mentioned, “it's important to build empathy for users.” While another response was, “to work with teams to prioritize client needs and designing solutions to meet that.”

After user research, problem synthesis and definition was the second most common phase students highlighted within the design process. Some students stated, “the importance of structuring a project correctly,” “defining a problem,” and “how to synthesize knowledge” as the most important concepts they took away from the course. Prototyping was another phase of the design process students highlighted in their responses. One student realized their prior understanding of prototyping was different by saying, “how prototyping actually works,” while another mentioned how prototypes help communicate results by saying, “prototypes are important to showcase your findings.” There was also a mention of learning about ideation and how brainstorming is about quantity and not quality. Along with phases of the design process, some students mentioned aspects of our design ethos as the most important concepts they took from the course.

Theme 2: Design Ethos

Some of the responses highlighted an aspect of our design ethos to keep while designing as the most important concept they learned. While one student mentioned design ethos in general, the most common mindset among the responses was the idea of learning from failure. One student wrote, “it's okay to fail and try again,” while another explained, “iteration, failure, and pivoting are super important going from the problem defining to ideation to mechanical prototyping stages.” The other two mindsets mentioned were the importance of communicating and to keep an open mind. As one student exclaimed, “I think keeping an open and creative mind (to not limit your options) is the biggest takeaway, as well as the fact that everyone has different ideas and can contribute in different ways!” Along with different design ethos and mindsets, some students mentioned working within a team as the most important concept they took from the course.

Theme 3: Working in a Team

Some of the responses focused on the aspect of working in a team as the most important concept. Students' responses included, “How to solve problems within a team,” and “The importance of taking initiative but also relying on teammates.”

Discussion

In the following section, we will address the research question by discussing the most important concepts students took away from the course and how that aligns with the course goals. We will also triangulate the teaching team’s perspectives on learnings, teaching approaches, and challenges in a multidisciplinary design course. Lastly, we will highlight the limitations of the approach and suggest areas for future work.

<u>Student Perceived Learnings</u>

Insights on the perceived student learnings were gained based on the analysis on the responses to the question "What was the most important concept you took away from this course?" on the Fall 2022 course evaluation. The learnings spanned 1) the design process, 2) design ethos, and 3) working in a team. The perceived design process learnings align with the first four course learning outcomes:

1. Confidently address problems (in engineering and beyond) with a robust design process and mentality
2. Conduct qualitative interviews to better understand the perspectives of end users
3. Synthesize findings from interviews into actionable design criteria
4. Prototype quickly and effectively to learn, communicate ideas, and get feedback from end users

As learning and applying the design process is the core of this Multidisciplinary Engineering Design course, it was good to see this as the most common theme among the perceived student learnings. Along with teaching students a design process, we mentor them to maintain a design ethos in which they are (1) learning from others, (2) embracing ambiguity, (3) biasing towards action, (4) learning from failure, and (5) communicating deliberately. Although not all the design ethos areas showed up as the most important concepts students took away, the areas mentioned align with 3 of the 8 course learning outcomes. They include:

1. Confidently address problems (in engineering and beyond) with a robust design process and mentality
2. Communicate and contribute effectively in a team
3. Convey solutions clearly and deliberately to an outside audience

Along with learning and applying a design process and maintaining a design ethos, students are working together in teams for the whole semester. Throughout the semester we assist students in developing team contracts, communication strategies, and feedback tools that teach them how to work in a team. Since team dynamics are emphasized through the semester, we were pleased to see this area identified as an important concept learned by students. This perceived learning of working in a team aligns with one of the course learning outcomes: communicate and contribute effectively in a team.

The three themes of 1) design process, 2) design ethos, and 3) working in a team align to 7 of the 8 course learning outcomes. The only outcome that did not align with the perceived student learnings was the outcome focused on ethics: consider the ethical implications of their design projects. Although this did not show up as one of the themes, it does not mean it is not a concept they did not learn. Our study is limited in that it only assessed the perceived learnings based on one question from the course evaluation. The course evaluation question also asks students about the *most important* concept they took away, so they may have learned the ethical implications in design and other concepts but did not mention it as the most important. Future research could be conducted to see if ethical implications were grasped and understood from the course. Currently, we engage students in ethics with a lecture on design equity and ongoing discussions in team meetings. Specific reflection or additional structured learning activities can be implemented in the course to further this learning.

Teaching Team Insights

As stated before, the three themes for the perceived student learnings align with the core elements of the course. which provides evidence for the effectiveness and achievement of the desired course outcomes. However, there are still some elements we desire to further develop and evolve as we continue to grow the course and expand course offerings to create a suite of design courses that can be integrated into the engineering curriculum. In this next section, we reflect on those opportunities to evolve and expand and the challenges we face.

Thinking vs Doing

A tension in teaching a design process through step-by-step phases implies that designing is a linear process with reliable and consistent results. Students may not be prepared for the ambiguity of applied learning and believe, incorrectly, that the design process is a step-by-step formula for discovering solutions. In the first semester of the course, students spend a relatively short amount of time building tangible solutions (prototypes) and a relatively large amount of time conducting research and analysis. This is partially a logistical constraint given the two-semester span of the course, but students do appear to develop paralysis after working through their research and synthesis. When we get to the prototyping phase, students begin to show the most uncertainty, which could mean we need to be prototyping earlier, more often, and in a variety of ways. It may be necessary to develop scaffolded learning activities that encourage 'making' as a means of thinking. We wonder about the value of designing ways for students to construct journey maps, synthesis, and empathy maps by building, sculpting, and performing. We want to continue to investigate ways to encourage more 'making' as part of the design process, however a challenge we face with activities during class time is *time*.

Course Timings

We strive to provide active-learning experiences and time for teams to work on their design projects. The 75-minute class time often feels rushed as we provide some content, launch a learning activity, and check in with the teams. For the first time next year, we will try one 2.5-hour session per week with a 1-hour section time for each team. Through this arrangement, we hope to provide more time for teams to dig deeper into design activities and teamwork, and also allow for logistical meeting time and mentor check-ins during the sections. We hope to encourage more time for 'making' throughout the design process, but we do worry if this larger portion of time will become an obstacle for students interested in taking the course.

A significant challenge in running and scaling a course across eight engineering disciplines and three academic years is finding a time that can accommodate a diverse group of student schedules. Because we have primarily 3rd and 4th year students, we have mapped out all required courses for those academic years across the eight departments and found the most available time slot.

Equal Buy-in Across Departments

To increase course participation, we need to cultivate equal buy-in across all engineering departments, which has been a challenge. The Multidisciplinary Engineering Design course is designated differently across engineering departments. Currently, the 2-semester sequence is offered as an option for a capstone design requirement for two departments: Chemical and Biomolecular Engineering (ChemBE) and Biomedical Engineering (BME). Computer Science and Mechanical Engineering count the two courses as department-specific electives, and the course is considered a general engineering elective by the rest of the departments (Civil Engineering, Environmental Health & Engineering, Materials Science & Engineering, Electrical and Computer Engineering, and Applied Math and Statistics). Because of this, students in ChemBE and BME accounted for 68% of our registrants for our Fall 2022 course. CS and ME made up 25% of registrants, and the remaining 4 departments combined for 7% of registrants. We strive to see departments more equally represented among our multidisciplinary cohorts, however, cultivating equal buy-in across engineering departments has been a challenge. We will continue to reach out to each department to discuss ways our courses might fulfill requirements for designations that are more attractive to students.

Community and Psychological Safety

At the forefront of our teaching approach is establishing a classroom community that fosters psychological safety. When students feel safe in a learning environment, they are more willing to take risks and fail, and they are more open to giving and receiving critical feedback. The course is taught by a dynamic group of educators from different backgrounds, which begins to model to students the value of working on a multidisciplinary team. Throughout the semester, we include several conscious choices for developing an encouraging classroom environment. For example, we launched the first day of class with a fun escape room challenge that encouraged teams of students to work together. Early on, we sought to foster an environment where failure is encouraged as part of the learning process so that students experiment and take risks in their design work. We also incorporate group reflections so that students have space to learn from others and also make meaning from their own experiences.

We are committed to ensuring an equitable design experience for all students, which is why we prioritize team building and communication strategies. We recognize that vulnerable students may have unique needs that are sometimes overlooked in a team setting, and we take intentional measures to address and accommodate these needs. We assist students in developing team contracts, communication strategies, reflections, and feedback tools that teach them how to work on a team. As faculty mentors, we are available for assistance, listening, and conflict resolution when necessary. This relationship between faculty mentor and team is critical to the sense of wellbeing for our students. As we continue to develop the course, we hope to also evolve the ways in which we build a community that fosters psychological safety in the classroom.

Conclusion and Future Work

This paper focused on the first semester of the Multidisciplinary Engineering Design course in the Multidisciplinary Design Program at Johns Hopkins University. An analysis was conducted on the perceived student learnings based on course evaluations, as well as the teaching approaches and techniques employed to support students' success throughout their multidisciplinary design experience. We found evidence for the effectiveness and achievement of the desired course outcomes, and we hope to use these findings as we evolve and expand the program to a suite of courses that create an applied, hands-on design thread throughout the engineering curriculum. Understanding the student experience and learnings along with insights from the teaching team of the course can also inform the development of a wide range of design experiences for undergraduate engineering students.

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Appendix

The following is a table of the three themes and the student responses grouped within each theme.

Theme	**Student Responses**
Design Process	<u>User Research</u> • How to talk to someone and extract key takeaways and insights that will dictate my next steps. Also how to work around my own assumptions • Centering the user in design decisions. • It's important to build empathy for users • It is important to always continue doing research at every step of the project in order to check your assumptions and ensure the direction your project is heading makes sense. • User interviews and feedback are the core to designing a good product. • The importance of multiple perspectives • User research is incredibly important. <u>Problem Synthesis and Definition</u> • To work with teams to prioritize client needs and designing solutions to meet that. • defining a problem. • how to synthesize knowledge • The importance of structuring a project correctly. <u>Ideation</u> • When brainstorming ideas, quantity is more important than quality. • Design Skills such as ideation and prototyping <u>Prototyping</u> • Prototypes are important to showcase your findings. • how prototyping actually works!

Design Ethos/Mindsets	• Iteration, failure, and pivoting are super important going from the problem defining to ideation to mechanical prototyping stages • Design thinking principles • It's okay to fail and try again • Things will go wrong (sometimes very wrong) so keeping spirits and morale high is key when tackling design projects. • I think keeping an open and creative mind (to not limit your options) is the biggest takeaway, as well as the fact that everyone has different ideas and can contribute in different ways! • The importance of visually communicating information
Teamwork	• teamwork • The importance of taking initiative but also relying on teammates • Team dynamics and how so buff time is spent planning • How to solve problems within a team.