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Design and Evaluation of a New, Student-Centered Multidisciplinary Course in Mechanical Engineering: Artificial Organs

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Abstract:

There is a growing need for healthcare applications across various fields, particularly in STEM. For mechanical engineering students, their future prospects extend beyond traditional areas such as energy, manufacturing, mechanical design, and control, and encompass opportunities in pharmaceuticals, biomedical engineering, and healthcare consulting, providing an imperative for mechanical engineering students to be trained at the intersection of healthcare applications. To support this need, this paper describes the development of a new, unique multidisciplinary course titled "Artificial Organs" in the Mechanical Engineering department at a large public institution in the northwest. The development and teaching of this course were designed and led by both a graduate student and a faculty instructor. This new course aims to broaden the horizons of mechanical engineering students by addressing challenges and applications related to artificial organs. It seeks to meet the demand for training the next generation of mechanical engineers with advanced skills to excel in interdisciplinary challenges and a competitive job market. This paper will discuss the course contents and pedagogical approach employed to deliver the new course successfully. Using backwards design, our goal was to create a student-centered learning environment through which students explored complex, interdisciplinary concepts through peer discussions and teamwork, resulting in a final project and presentation.

Keywords: Course design, multidisciplinary course, mechanical engineering, healthcare, engagement

I. Introduction

The traditional curriculum structure of mechanical engineering (ME) in the United States predominantly focuses on four key subjects: manufacturing, control, thermal & fluids, and materials [1, 2]. However, the biomedical and healthcare devices market has experienced significant growth, reaching $542.21 billion in 2024, and is projected to increase to $886.80 billion by 2032 [3]. This expansion underscores a growing demand for higher education programs that provide interdisciplinary experience, particularly in STEM fields. Concurrently, the number of organ failure patients is on the rise, with many individuals suffering and awaiting transplants. In the United States, nearly 110,000 people were on the national transplant waiting list in 2021 due to end-stage organ diseases, including kidney, liver, lung, and heart failure. Although over 40,000 transplantations were performed in 2020, the shortage of matched organs still resulted in approximately 17 deaths per day [4]. This stark statistic highlights the urgent need for solutions to address the critical shortage of transplantable organs. This situation highlights the critical need for artificial organs, positioning them as one of the most crucial biomedical devices needed both in the US and globally. However, traditionally, ME courses have placed less emphasis on biomedical and healthcare devices and there is a gap between the ME curriculum and healthcare applications [5, 6].

A student-centered learning environment is crucial because it actively engages students in their own education, tailoring the learning experience to their individual needs, interests, and learning styles. This approach fosters a deeper understanding of the material, enhances critical thinking skills, and promotes lifelong learning habits. Dong indicates that student-centered classrooms significantly boost student engagement and motivation [7]. Kerimabayev mentioned student center learning environment is critical in development of critical thinking and problem solving skills [8]. Cuccolo also published data about the effectiveness of student-centered learning in K-12 education, which emphasizes the collaborative learning is a key component of student-centered environments [9]. In addition, student-centered learning can increase the autonomy and responsibility [10]. In summary, implementing a student-centered learning environment not only enhances academic achievement but also equips students with essential skills for personal and professional success.

Thus, we were aiming to build a bridge between the ME major and the increasing number of job positions in biomedical field. The artificial organs class was designed in 2023 as a 400-level elective class in the ME department, targeting the patient's needs, history, and development as the current research and future trends of the artificial organs. While the course was open to both graduate and undergraduate students, the course was also structured so that graduate students play a pivotal role in the course by leading discussions and inviting guest lecturers working on their Ph.D. dissertations in artificial organs and healthcare applications. It brings a new teaching method and aims to create a student-centered learning environment in both the teaching and learning aspects. Aligned with the needs of the field, the course covers various aspects of artificial organs, including critical organ failure, increasing demand for artificial organs, history and development, challenges and innovation, and mechanics. Upon completion of this course, students should be able to identify various issues related to the design and development of artificial organs, utilize the appropriate mechanical engineering concepts in the design of artificial organs, and use mechanical engineering skills to develop a prototype for a specific application.

In addition to the course design, we also present evaluations of the effectiveness of the course. The course was first offered to both undergraduate and graduate students in the fall quarter of 2023. It attracted students from mechanical engineering, bioengineering, and industrial engineering. The effectiveness of the class is evaluated through assessing students' achievement of the course assignments, such as their assigned projects and team-based presentations, informal student feedback collected throughout the course, and the formal course evaluation. Based on the evaluation results, we present our plans for continuous improvements to future offerings of the class. While we will continue to make modifications and adjustments, the "Artificial Organ" course represents an innovative educational initiative aimed at equipping the next generation of engineers with the knowledge and skills necessary to tackle complex biomedical challenges.

This paper details our course design in artificial organs connecting ME students to the current job market needs. Further, the course was conducted in a student-centered teaching and learning environment. Later the course was accessed by course evaluation to understand further the students' needs.

II. Course Development and Assessment Methods

The motivation for building this class was to provide an elective class in the biomedical field for mechanical engineering students. To design our course, we used the three steps of backwards design framework [11-14]. We first identified desired learning outcomes and then determined the acceptable evidence (assessments) to support those outcomes. Finally, we planned instruction, tasks, and experiences that support the outcomes (learning activities) [15]. The three phases are described below.

Step 1: Course Learning Objectives

We started our course design by developing 5 learning objectives that we wanted students to achieve by completion of the course:

1. Recognize the mechanism of artificial organs in different development stages.
2. Identify key issues associated with the design and development of artificial organs.
3. Apply relevant mechanical engineering concepts to the design of artificial organs.
4. Develop a prototype for a specific application using mechanical engineering skills.
5. Research applications to other types of article organs and tissues, such as an artificial pancreas and an artificial skull.

To achieve these learning objectives, we first need to identify what critical organ failure is and its major cause as well as the rising need for artificial organs. From that, we learned that artificial organs are a solution to organ failure. While there are many types of artificial organs, we chose to focus the course on four vital human organ replacement systems: artificial kidney, liver, lung, and heart. The history of each type of artificial organ is illustrated by old photos and literature results. Then, the current artificial function and its limitations are presented, and the students brainstorm how to overcome them, such as the effectiveness, cost, and patient feeling. With the support of the graduate students enrolled in the course, current innovations and recently published results of artificial organs are presented, and the graduate students lead lectures and group discussions to identify potential solutions to the current challenges. The course culminates in a group project where students research applications of artificial organs and develop a prototype for their selected application using mechanical engineering skills.

Step 2: Course Assessment

We used both formative and summative assessments throughout the course to check students' understanding and achievement of the learning objectives. While the formative assessments help students to learn and practice throughout the course, the summative assesses student performance at the end of the instructional period. The formative assessments include:

1. Pre-test questions at the first lecture about students' biology background to gauge their prior knowledge about course topics.
2. In-class exercises and conceptual questions to continually gauge students' understanding and progress throughout each lecture and allow them to practice skills
3. Peer Teaching: Students explain their understanding or perspective on a topic to a classmate, helping both the teacher and learner to assess comprehension. Additionally, graduate students in the course and ME department deliver guest lectures.
4. Teachers observe students during activities and take notes on their performance and behavior.
5. Spontaneous or planned Q&A sessions to probe students' understanding of the subject matter.
6. Students work in groups and receive feedback on their collaboration and understanding of the content.

We used the final project, including the term paper and presentation, as the summative assessments for the course, to evaluate overall achievement of the learning objectives. For the final project, students work together in teams to write a term paper and prepare a presentation on a topic of their choice. Students were tasked with exploring lesser-known artificial organs/tissues, applying the same analytical approach used for major artificial organs discussed in the class. This assignment tested and developed their ability to independently understand the logic behind biomedical devices, as well as their presentation skills and ability to coordinate as a team. The outcome of building independent research skills is tested by the final presentation and prototype.

Step 3: Learning Activities

All the learning activities are aimed at fostering deep understanding and collaborative skills, which are essential for mastering the course content and shaping an idea for ME major students about the importance of ME in the biomedical field. Learning activities performed during the class are below:

1. Group discussions and brainstorming sessions during the lecture
2. Think-Pair-Share: Students think about a question individually, discuss their thoughts with a partner, and then share their conclusions with the class.
3. Introducing graduate students at guest lectures/seminars to undergraduate students to create a peer-learning environment

4. Ask students to choose the interesting topic under the article tissues and organs for their final project
5. Conduct the final project and presentation in teams

Engaging students in the classroom requires a variety of strategies tailored to foster active participation and learning [16]. These strategies can include employing active learning techniques, utilizing flipped classroom methods, encouraging collaborative project work, incorporating educational games, and tackling real-life problems [17]. Each approach helps create a dynamic learning environment where students are more involved and motivated to learn. Thus, on the teaching side, we invited graduate students who focus on pushing the boundaries of artificial organs to give guest lectures discussing their original goals, challenges in their research, and their development of artificial organs. With the lead from graduate students, it provides first-hand resources and insight to undergraduate students, which helps them understand if they want to continue in graduate school and what research looks like. For the learning side, we built a discussion-friendly environment by having the students discuss how they are going to solve the problem at each historical challenge, analyze its feasibility, and compare to later solutions with those pioneers.

Course Evaluation

The course was evaluated through various metrics including enrollment numbers and majors, participation rates, the quality of the final term paper and presentation, and both formal and informal course evaluations. Formal evaluations were carried out using anonymous paper forms provided by the registrar's office, ensuring structured and standardized feedback. We also administer our own anonymous course survey to the students to gather additional feedback beyond the questions asked in the formal course evaluation. Informal evaluations were conducted through casual conversations between students and graduate students toward the end of the course, providing immediate and personal feedback. Both the formal and informal evaluations were used to evaluate the students' overall satisfaction with the course.

We used the number of enrolled students to indicate the course's popularity and student interest. The diversity of their majors was used to reflect how broadly students were interested in STEM disciplines, as is offered to all engineering majors. The participation rate serves as a partial indicator of how engaging and innovative students finds the class. The final project and presentation were collected and recorded to evaluate their quality.

III. Results and Discussion

The total enrollment for the first iteration in fall 2023 of the class was 22, with students coming from three different majors, including ME, bioengineering, and industrial engineering. The overall course evaluation was 4.6/5, which indicates the overall students' satisfaction with the newly applied student-centered learning environment. In addition, 88% of students reported they liked the instructor's enthusiasm. Besides the formal course evaluation, the feedback from informal students' conversation includes both the areas of strength and area of need improvement:

They mentioned areas of strength include:

1. Very interesting topics
2. Comprehensive course contents
3. Engaging learning environment.

The area of need for improvement is:

1. Lacking fundamental knowledge about biomedical devices
2. Hard to follow in the equation derivation
3. Some students are not very participatory in group discussion

Additionally, students mentioned they will refer this class to their friends, which could lead to about 20 more students enrolling in the current iteration in Spring 2025, having about 20 more students than the first iteration.

During the course design process for the artificial organ class, we carefully analyzed students' needs and leaned deeper into student-centered teaching approaches by hearing their feedback after the class and at the end of course evaluation. The diverse academic backgrounds of the enrolled students highlight the popularity of artificial organ and biomedical device courses among engineering students [18]. This observation suggests a growing need to tailor the curriculum specifically for mechanical engineering majors to better address their educational requirements [19, 20]. Furthermore, we identified a significant gap in students' fundamental biological knowledge from the pre-test question at the first class and observation during the in-class oral questions and they showed a confused face about the biological term and biomedical device design criteria, which can be attributed to their primary focus on disciplines other than biology or bioengineering. Addressing this gap through thoughtfully integrated foundational biological concepts will be essential for enhancing student comprehension and engagement in future course iterations [21]. However, by the end of the quarter, students successfully achieved all learning outcomes, as evidenced by the average grade of 3.41/4 on their final grade.

From the formal student feedback, we have noted that improvements are needed in the organization of the course and the engagement of students through questions during class. For instance, simplifying the Canvas page and restructuring the formation of discussion and project groups could enhance clarity and interaction [22]. Additionally, while attendance is generally high, over 90% through the attendance sign-in form, some students (about 3-4) did not ask questions throughout the entire quarter. Regularly gauging students' understanding by asking questions randomly following their discussions could prove beneficial in promoting active participation [23, 24]. Considering a similar class format for another elective course could be advantageous since graduate students are often immersed in research involving the latest cutting-edge technology [25, 26]. In addition, they can create a vibrant brainstorming environment that stimulates the thinking of undergraduate students [27]. This approach enriches the learning experience for undergraduates and provides graduate students with valuable opportunities to sharpen their presentation skills and improve their interactions with students [28, 29]. This dual benefit enhances both teaching and learning outcomes.

IV. Conclusion

The artificial organs class, structured using the backward design approach, has proven successful, as evidenced by formal course evaluations. Additionally, the fact that students recommend this class to others highlights their interest and approval. After completing this course, students show increased interest in biomedical applications and gain a deeper understanding of the development process from a mechanical engineering perspective. Moreover, they excel in independent research and presentations, demonstrating enhanced skills in both critical analysis and effective communication. The class bridges the gap between mechanical engineering and healthcare applications, which might bring more mechanical engineering students to biomedical device development, such as artificial organs, biosensors, and integrated medical devices.

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