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A Perspectives-Making Approach to Biomedical Engineering Design: Entrepreneurship, Bio-Inspired Design, and Arts

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Bridging the Gap: A Real-World Learning Intervention in Biomedical Engineering Education to Enhance Workplace Preparedness

Abstract

Many engineering students have reported feeling a disconnect between the curriculum they learn at school and the skills they need to be successful in their first job. As a result, engineering graduates can feel unprepared or underprepared to handle challenges in the workplace. It is proposed that the main driver of this problem is the lack of real-world learning opportunities in higher education. In response, the authors implemented a five-week learning intervention in a biomedical engineering course (Mechanics of Materials) with the aim of providing students with multidisciplinary open-ended, real-world project experience. To assess student perceptions of the new curriculum intervention, reflections were collected and qualitatively analyzed resulting in 3 overarching themes, including creativity in user-centered design, time management, and communication/collaboration. These themes demonstrate that students felt they acquired or expanded skills that are considered vital in a work environment. Therefore, applying this project experience on a larger scale can alleviate some of the unpreparedness that engineering students feel as they leave school and enter the workforce. The intervention details will be provided to encourage other engineering instructors to implement similar real-world learning strategies in the higher education classroom.

Introduction

Many engineering students feel underprepared when going into the workforce, due to a lack of real-world application of the college curriculum and the lack of necessary skills to confidently make engineering and business decisions [1-3]. Consequently, the transition between college and one's first job can be difficult for many graduates [4]. This causes many to seek jobs outside of the engineering profession altogether; according to one study, only one-third of engineering graduates seek jobs in an engineering field [5]. Furthermore, a study by the Carnegie Foundation found that engineering schools primarily focus on the acquisition of technical knowledge, leaving little attention to real-world application or preparing for employment [6].

To combat this issue, the authors incorporated a multi-disciplinary project experience that involved skills used in business, art, and environmental science into the standard curriculum for engineering students. This involved a five-week project experience that incorporated aspects of the entrepreneurial mindset (EM), bio-inspired design, and the arts. The project aimed to give sophomore biomedical engineering and engineering design students the opportunity to work on an open-ended engineering problem in which they not only worked towards designing the lightest weight prosthetic arm using MATLAB coding, but also tackle the project at the intersection of EM, arts, and bio-inspiration aspects.

Additionally, this project encouraged creative user-centered design by asking students to 1) choose a break-dance pose that allows them to calculate the torque that would be applied on the arm, 2) suggest an artistic addition to make the prosthetic aesthetically pleasing while keeping in mind the selected pose and how it may fit the kid dancing, 3) choose bio and man-made materials and compare them while keeping in mind the weight, and some other factors such as cost, life expectancy, allergic reactions on the skin, potential supply chain issues and availability, manufacturability, technical feasibility, recyclability (at the end of life) and maintenance/cleaning.

At the conclusion of the project, participants responded to photovoice reflection prompts survey, showing evidence of perceived student learning. The collective efforts of the authors respond to the following research question:
Q1. What are the students' perceptions of participating in a multi-disciplinary project experience that involves EM, arts, and bio-inspired design?

Literature Review

The disconnect between engineering education and the workplace has been a topic of conversation for the last couple of decades [7-9]. The recent globalization due to the internet age has made non-technical professional skills, such as communication and collaboration, a must in the engineering workforce [10, 11]. In a rapidly advancing world, the working expectations of engineers are not limited to routine technical tasks, but instead, today engineers must be able to innovate and come up with solutions to complex problems and see them through. Despite this, engineering education has failed to keep up with the changing demands in the workplace [12, 13]. Nearly 25% of employers reported that recent graduates were less capable in tasks like problem-solving than their counterparts from 10 years earlier [14]. Another study [15], found that 3 out of 10 engineering students remained unsure of what engineering even is or what it means to be an engineer, despite having taken four years' worth of undergraduate engineering classes. In a study using student reflections to analyze their conceptions of engineering, most respondents saw the school in stark contrast to the "real world" [16]. In response to this problem, many solutions have been proposed and attempted, but gaps remain.

One such solution is the National Academy of Engineering's (NAE) Grand Challenges. The Grand Challenges consist of 14 primary goals to sustain human life. These goals were selected by a committee of 18 distinguished leaders across various fields, with input from a diverse group of experts from around the world. This program has had far-reaching effects, even in the educational sector. The Grand Challenges have encouraged engineering education to be more hands-on and collaborative. For example, in the US, a Grand Challenge Scholar's Program was created to encourage students to participate in finding and designing solutions for the challenges, with more than 160 scholars having graduated [17].

Another solution similar in scope to the Grand Challenges is the UN Sustainable Development Goals. In 2015, the UN General Assembly adopted a resolution for 2030 that included Sustainable Development Goals (SDGs). These SDGs have prompted changes to the engineering field to solve these broad issues by increasing the capabilities and capacity of engineering through the involvement of young, student populations. It also prompts a change in engineering education to focus more on sustainability in the curriculum [18].

One final solution is the National Science Foundation's (NSF) Strategic Plan. The NSF has supported multiple engineering education programs, such as Engineering Research Centers

(ERCs) as well as the Research Experience for Undergraduates (REU). The main goal of these programs is to support research opportunities for students in both undergraduate and graduate programs. This research experience allows students to gain important experience in engineering that they would not otherwise receive [19].

These approaches, while they are well-intentioned, do not have specific, classroom-level plans to implement any of their overarching goals. All of these programs present high-level challenges, goals, and strategic objectives to better the world as a whole, and they encourage students to participate according to their associated agendas. Not all students can be in the Grand Challenge Scholar's Program or have the opportunity to participate in an REU. This makes it difficult for students to participate and gain the real-world experience that they need. Instead, what is needed is a systematic way to include all engineering students in a program that will encourage the application of engineering concepts and help them gain experience with non-technical professional skills.

In response to the lack of real-world application in the engineering classroom, our study aims to overcome the gaps associated with current approaches by incorporating an interdisciplinary project into the engineering/STEM/university classroom via three perspectives: EM, Bio, and STEAM.

The entrepreneurship mindset (EM) is difficult to define and has been given many different definitions in the past. In this paper, the entrepreneurship mindset will be defined as it was by Kuratko *et al.* [20] to include three aspects: cognitive, emotional, and behavioral. Cognitive entrepreneurship refers to the ability of an entrepreneur to assemble and analyze previously unrelated information to create a new product or service. Behavioral entrepreneurship refers to the way that entrepreneurs can recognize new opportunities while also being willing to pursue these opportunities with energy and passion. The emotional aspect simply refers to the emotions that entrepreneurs feel that drive them to pursue opportunities and business that they encounter or presented to them. These aspects together create what is known as the entrepreneurial mindset [20]. Integrating EM into the engineering/STEM/university classroom benefits students by forcing them to think outside of mathematical equations and look more at the big picture. Making students think on a larger scale will help them realize that engineering and entrepreneurship are interconnected, and that engineering is meant to help people and society. This provides some necessary perspective when many STEM courses are focused solely on technical information.

Bio-inspired design is loosely defined as it sounds: designs inspired by biology. More formally, it is defined as drawing on the function, form, or process of naturally occurring phenomena [21]. Integrating bio-inspired design into the engineering/STEM/university classroom benefits students by encouraging them to think creatively and look beyond traditional engineering norms or ideas to discover something new and innovative. This will enhance their problem-solving skills and give them a new perspective on what is possible in design.

STEAM (science, technology, engineering, arts, and math) is a term implying the integration of art into traditional STEM, to encourage innovation and creativity [22]. Integrating STEAM into the engineering/STEM/university classroom benefits students in similar ways to bio-inspired design, by encouraging creative thinking outside of traditional engineering practice. In these ways, students are encouraged to develop a versatile skill set that will aid them in a constantly changing world and workplace.

The next section will explain our approach to incorporating this interdisciplinary project (integrating the EM, Bio, and STEAM) into the Mechanics of Materials classroom.

Methods

At Rose-Hulman Institute of Technology, sophomore biomedical and engineering design students take a compulsory Mechanics of Materials (BE222) course. In the winter quarter of 2022-23, all students enrolled in BE222 participated in a five week-long project experience focused on identifying the best mechanical criteria for a prosthetic arm for a 'break-dancing' child. As stated above, this required them to incorporate entrepreneurship, bio-inspired design, and arts to find the optimal solution. The project was divided into five parts. Prior to assigning each part, the course instructor introduced the part and discussed with students the main constraints and requirements. Additional resources were shared with students on the course portal. The study design was approved (IRBNet #: 2056214-3) by the Institutional Review Board (IRB) at Indiana State University.

The participants were full-time sophomore biomedical engineering (*n=31; 19 females and 12 males*) and design engineering (*n=8; 3 females and 5 males*) students at Rose-Hulman Institute of Technology. The photovoice reflection questionnaire was shared with all enrolled students (*n=39*) and filled out individually with a response rate of 100%.

The study design for this research follows a similar approach to previous photovoice research [23], which is a qualitative approach that explores the data as it gives a unique depth of understanding to the research questions explored. The participants had to complete a questionnaire [24] consisting of three (3) photovoice reflection prompt questions (part 1) and three (3) metacognitive open-ended reflection questions (part 2). For part 1, students were asked to provide three pictures that best describe their response to each question. In addition, each picture was supplemented by a short narrative (200-word minimum per question) to explain the choice of image. The photovoice reflection questions are as follows:

- Photovoice Reflection Prompt A (Entrepreneurial Integration): The entrepreneurial mindset is defined as "the inclination to discover, evaluate, and exploit opportunities." Explain how participating in the newly developed curriculum integrated the entrepreneurial mindset, and lessons learned relevant to the entrepreneurial mindset.

- Photovoice Reflection Prompt B (STEAM): STEAM (science, technology, engineering, arts, math) goes one step beyond the well-known STEM to acknowledge the importance of integrating the arts and humanities into more analytical coursework such as that found within engineering. Art can be incorporated through pieces, process, and movements. Explain how participating in the newly developed curriculum incorporated STEAM (specifically, the arts), and lessons learned relevant to STEAM (specifically, the arts).

- Photovoice Reflection Prompt C (Bio-Inspired Design): Bio-inspired design uses the nature-focused context of sustainability, security, and/or biomedicine and health outcomes to motivate analogical thinking and improve the engineering design process. Explain how participating in the newly developed curriculum incorporated bio-inspired design and lessons learned relevant to bio-inspired design.

In part 2 of the questionnaire, participants were asked to answer the following three metacognitive open-ended questions (200-word minimum per question):

- Open-Ended Reflection Question A (Interdisciplinarity): The interdisciplinary approach of integrating the entrepreneurial mindset, STEAM (specifically, the arts), and bio-inspired design has been shown to improve student engagement, motivation, and learning outcomes. How did this interdisciplinary learning experience affect your ability to engage with the newly developed curriculum?

- Open-Ended Reflection Question B (Debrief): What went well? What didn't go so well? What will you do differently next time?

- Open-Ended Reflection Question C (Connect to Real World): What skills did you learn? Please consider both professional skills (e.g., communication, collaboration, etc…) and context-specific skills (e.g., topic area). Why are these skills important for engineers in the real world?

The data (including pictures and narratives) were stored on a common shared drive within a folder, which could be accessed by all authors involved in this study. To perform data analysis, the authors used the collected data from the completed questionnaire to explore potential themes (*n=3*). After the themes were identified, direct quotes (*n=4*) from the anonymous student reflections were taken to validate each theme.

The main goal of this study was to use a foundational qualitative method (thematic analysis) to discover patterns within the data [25]. One author conducted the data analysis to generate three themes along with five pieces of evidence from student comments. Then, the lead author reviewed all themes and wrote a summary of each theme. The authors relied on providing direct quotes from student comments along with a short summary on each theme to provide readers with evidence and to allow them to make their own judgment on the accuracy, fairness, and credibility of the collected responses [26].

Results and Discussion

Analysis of the qualitative data led the authors to identify three core themes related to incorporating arts, entrepreneurship, and bio-inspired design in technical engineering classes: (1) creativity and free-thinking, (2) time management, and (3) communication in teamwork.

(1) Encouraging Creative User-Centered Design

Several students acknowledged that creativity in solving complex problems is necessary for success in engineering. Furthermore, the students added that some of the creative skills related to visual design are often overlooked in engineering subjects, while a greater emphasis on such skills is very important. The students agreed that the inclusion of arts in engineering projects could encourage creativity and free-thinking and allow them to produce user-centered products.

"The stereotype of STEM course is that it takes away all the creativity from the student and makes them think a certain way. In Rose-Hulman, we are taught to think like an engineer which might seem closed-minded with ridged approaches to everything, but it is quite the opposite. Thinking like a true engineer means coming up with creative approaches to create solutions to solve complex problems."

"I personally enjoyed the inclusion of S.T.E.A.M. because it allowed me to make sure of my artistic creativity in a field where that is rare. I think that it is also extremely beneficial because once engineers start considering art designs that are more visually pleasing and aesthetic, they will start creating products leading to enhanced customer satisfaction."

"I enjoyed getting to design how the tubular section of the prosthetic would look from an artistic perspective. It helped remind me of whom the design was intended for, and it was also fun to use my creativity."

(2) Time Management

Several students recognized that this project gave them the opportunity to improve their time management skills and accountability. Furthermore, several students mentioned that it was important to take a closer look at the different project parts and estimate the amount of time it would take to complete each part for three reasons, 1) to avoid getting surprised by the amount of time each part takes close to the submission deadline, 2) improve quality of submitted work, 3) different team members have different assignments and deadlines (outside and inside school) and it is important to be respectful of their availability.

"Managing five separate classes and this project tested my time management but overall made me more accountable and skilled."

"Given the diverse nature of our project, it was vital that we communicated and worked effectively together to achieve our goals. Furthermore, the project required me to develop stronger time management skills to balance my other coursework with the project work."

"My time management on this project was severely lacking. I have extremely poor estimation skills on how long I think things will take and often start too late to finish before the deadline. Additionally, I don't work at peak efficiency because I think I am making great progress and thus fool myself into feeling that I have loads of time when in reality I don't. Next time I will start all my assignments earlier than I think and impose false deadlines to create an artificial sense of urgency which will make me work more efficiently and with more vigor."

(3) Communication and Collaboration

Several students indicated that it is easier to solve complex problems with a more supportive and efficient team than with a team that cannot communicate or collaborate. Typically engineers in the field are not sitting in an isolated cubical, rather they are working in teams. Successful engineers are the ones who get their hands 'dirty' and try to figure out things by experimenting and collaborating with other team members. This is especially important in multidisciplinary fields such as biomedical engineering. The students expressed that this project helped them improve their communication skills especially when they had to work with a team member for the first time.

"Through this project, I have learned new collaborative and communication skills. Since the majority of this project was done outside of the classroom, my teammate and I had to schedule times that were compatible with both of our busy schedules."

"I think my partner and I had excellent communication and we worked well together. Often, we split up the work evenly and met outside of class in person to complete it well before the due date. We distributed the work in a way that took advantage of our individual strengths and that made the project go much smoother. Moreover, because our communication was good, we could collaborate on certain deliverables efficiently or get each other's opinions on something quickly."

"I felt I have always been good with communication, but I was put to the test. There were many late nights working on this project and keeping good communication with my group mate was essential. Without improving my communication skills, there would be no way we would have met the deadlines for this project."

The qualitative analysis of photovoice data resulted in three main themes (**Figure 1**) related to the impact of incorporating EM, STEAM, and bio-inspired design in a mechanics of materials class. These themes are 1) Creative user-centered design, 2) Time management, and 3) Communication and Collaboration.

The study results provide evidence that this project provided students with skills that allowed them to work on an open-ended project and gain some useful skills that are deemed important for the job market. Students usually do not interact with 'wicked' engineering problems until they graduate and face the job market needs. Open-ended problems come with challenges for both faculty and students. It is somewhat challenging for the faculty member to know which route students will take when it comes to these 'wicked' engineering problems, what questions they may come up with, and simply to come up with a rubric that ensures fairness amongst all students. As for students, they find it challenging to start on a project that is open-ended, and they are usually concerned about their grades. Additionally, open-ended projects require research and spending a significant amount of time with team members to figure out the problem and find a solution, team members may be not as collaborative and different schedules may all results in problems limiting the success of these open-ended projects.

This project aimed to give students the opportunity to work on an open-ended engineering problem in which they not only design the lightest weight prosthetic arm using MATLAB coding, but also tackle the project from an EM, arts, and bio-inspiration aspects. As mentioned earlier, this required the faculty member mentoring the project to see students fail, meet more regularly with them, assist them on how to complete different parts of the project, and simply keep motivating them and reminding them that this is how it works in the real world.

Creative user-centered design is the main theme that emerged from this study indicating that students realize the importance of designing what is not only functional but also user-centered. This means that engineers should approach any problem backwards keeping in mind what the user wants instead of limiting their thinking to what resources they have on hand. As a metaphor, once students know that they have access to ten of their neighbors' garages (not knowing what's in them) instead of only their garage, then they will think more creatively without any limitations. This project encouraged creative user-centered design by asking students to 1) choose a break-dance pose that allows them to calculate the torque that would be applied on the arm, 2) suggest an artistic addition to make the prosthetic aesthetically pleasing while keeping in mind the selected pose and how it may fit the kid dancing, 3) choose bio and man-made materials and compare them while keeping in mind the weight, and some other factors such as cost, life expectancy, allergic reactions on the skin, potential supply chain issues and availability, manufacturability, technical feasibility, recyclability (at the end of life) and maintenance/cleaning.

Time management is not a skill that can be improved over a day or two. It takes time and self-discipline to be good at time management. The photovoice data indicated that students were pushed to better manage their time when they were provided with deadlines that they had to meet. Some students simply indicated that it was important for them to recognize how long it would take a certain part without making any assumptions. They also indicated that procrastinating a certain part (that they assumed would take a short time) was not a good idea and that time management would be necessary to complete all parts in a satisfying way. Whether it was an improvement or simply a recognition, the authors believe that this is important for engineering students as they get frustrated and overwhelmed with the amount of work, not to mention their involvement in clubs, athletics, and on-campus or out-of-campus jobs.

Communication and collaboration skill development was another theme extracted from the photovoice data. Students agree that they improved their communication and team collaboration skills throughout this project. These skills are not only important in undergraduate engineering projects but for every job. Many of the 'wicked' engineering problems cannot be solved by a single engineer but rather by a team of interdisciplinary engineers. It is important to emphasize the importance of these skills for every engineer and to make sure they not only recognize their importance but also have the necessary tools to implement them in their work. One of the tools used in this project to improve student communication was the 'groups' option in Microsoft Teams. Each group had a private channel through which they communicate, post files, and work collaboratively on their submissions.

The three themes explored in this study align with and support the Accreditation Board for Engineering & Technology *(*ABET) student outcomes listed below:

- an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.

- an ability to communicate effectively with a range of audiences.

- an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives.

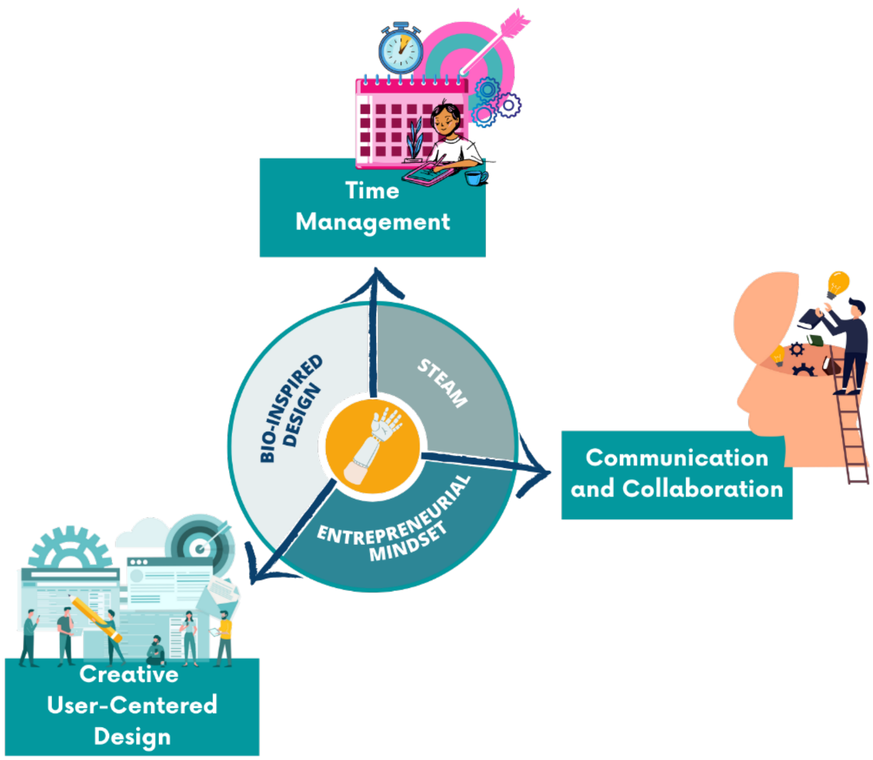

Figure 1: Infographic summary of themes obtained from student comments.

Conclusion

The objective of this study was to implement and get feedback on a novel multidisciplinary project experience to help better prepare engineering students for real-world engineering problems. In response to the research question, 'what are the students' perceptions of participating in a multi-disciplinary project experience that involves EM, arts, and bio-inspired design?', the authors have implemented a five-week learning intervention in a biomedical engineering course (Mechanics of Materials) with the aim to provide students with a multidisciplinary, open-ended, real-world project experience. After the project, students reflected on their own experience and three main themes emerged from their responses: creativity in user-centered design, time management, and communication/collaboration. Students learned or improved on being more creative in user-centered design, having effective time management, and learning the importance of communication and collaboration. These skills are a necessity in the workplace of today, validating the use of this project experience to better prepare engineering students for life after graduation.

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