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Bringing Entrepreneurial Mindset to the Design of Machinery through a Bio-Inspired Design Project with Aesthetic Objectives

Prof. Soheil Fatehiboroujeni, Colorado State University

Soheil Fatehiboroujeni received his Ph.D. in mechanical engineering from the University of California, Merced in 2018 focused on the nonlinear dynamics of biological filaments. As an engineering educator and postdoctoral researcher at Cornell University, Sibley School of Mechanical and Aerospace Engineering, Soheil worked in the Active Learning Initiative (ALI) to promote student-centered learning and the use of computational tools such as MATLAB and ANSYS in engineering classrooms. In Spring 2022, Soheil joined Colorado State University as an assistant professor of practice in the department of Mechanical Engineering. His research is currently focused on the long-term retention of knowledge and skills in engineering education, design theory and philosophy, and computational mechanics.

Dr. Lisa Bosman, Purdue University at West Lafayette (PPI)

Dr. Bosman holds a PhD in Industrial Engineering. Her engineering education research interests include entrepreneurially minded learning, energy education, interdisciplinary education, and faculty professional development.

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Abstract
Engineering students often lack sufficient opportunity to work on so-called wicked and real-world problems in their core technical engineering courses. One of the nationally recognized initiatives to overcome this challenge is the integration of the entrepreneurial mindset (EM) in various instructional activities of engineering programs. Yet, there are limited studies in the literature related to the effectiveness of the EM as a framework of curriculum design in the context of machine design and dynamics of machinery. This paper presents the development and implementation of a course project in a junior level mechanical engineering course on *Dynamics of Machines* to (1) give students access to real-world learning experiences and (2) explore and identify the ways in which an interdisciplinary design project that combines key components of EM, STEAM and bio-inspiration impacts students' learning. The results include initial findings from a thematic analysis of the data collected using *photovoice reflections*. Adopted from the relevant studies in the literature in the context of EM curricular activities, photovoice reflections combine pictorial and textual data and constitute a portion of the project's conclusion section submitted by students. The paper then discusses future steps on the use of interdisciplinary design projects which provide real-world experiential learning geared towards better preparation of engineering students for entering the workforce.

1. Introduction

Application of knowledge to solve real world problems is a critical skill for students' success and that of the engineering profession alike [1] and therefore identifying effective methods of teaching and learning real-world problem-solving skills remains an open problem. While real-world engineering problems are diverse and context specific, open-endedness and wickedness are often identified [2] as important characteristics of engineering problems across differences in scope and kind. The elusiveness of "best" or "optimal" solutions to engineering problems which is implied in the term wickedness stems from the fact that engineers themselves play an active role not just in solving, but in defining, scoping, and structuring complex problems. Engineering students often report that they enter the workforce under-prepared for working on wicked engineering problems embedded in social, cultural and economic systems. The reason for this is because on one hand opportunities for engineering students to gain practice working on problems under realistic conditions or requirements are typically limited to a handful of times throughout their entire education and on the other hand, instructors tend to focus on close-ended problems so that students can sufficiently learn and apply theoretical knowledge and formula-based calculations. The authors hypothesize that one reason for the continued focus on close-ended problem-solving is because of the limited guidance or literature on how to effectively integrate wicked, real-world problems into engineering courses at the level of technical core.

1.1 Current Approaches: Capstone Design and Co-op/Internship
It is known that capstone experiences instituted in various formats do provide an effective culminating opportunity to engineering students for gaining a real-world experience with the engineering design process. However, since capstone projects come at the very last semester(s) and since each project cannot cover the whole range of technical areas that students are expected

to learn in their degree program, this approach cannot be the only solution for creating learning experiences that support the growth of authentic problem-solving skills in students. Internships and Co-op experiences are also other examples of addressing this challenge. However, internships and Co-op programs are often optional and not all students go through such an experience.

1.2 Study Overview

The course project developed in this study has multiple objectives. First, it creates a set of activities on solving real-world open-ended problems with multi-faceted design objectives that span quantitative measures of kinematics features and functionality of mechanisms and machines, as well as qualitative measures of human (or user) satisfaction. Second, the course project designed here brings interdisciplinarity to a core technical course in mechanical engineering on *dynamics of machines* by combining key components of (1) Entrepreneurial Mindset, (2) STEAM, referring to STEM plus Art, and (3) bio-inspiration. The EM framework clarifies a set of methodological guidelines for students throughout the design thinking process. The STEAM provides instructions for students to evaluate the human-machine mediums of interaction and how aesthetic dimensions needs to be addressed. And finally, the bio-inspiration is defined broadly to create opportunities for students to explore the two-way relationship between technology and life, both at the level of outcomes (i.e. design for human health and safety outcomes) or at the level of structure and functions (i.e. bio-mimicry). Further details of each element of this course project are explained in the Methods section. To conclude this segment, we provide the research question pursued in this paper which has an exploratory nature:

Research question: How does bringing Entrepreneurial Mindset to the design of machinery through a bio-inspired design project with aesthetic objectives impact students' self-reported experiences?

2. Literature Review

2.1 Lack of Interdisciplinary Project-Based Learning Integrated Across Engineering Courses

Most engineering education today does not adequately equip students to address complex and ill-structured technical problems that involve different stakeholders, uncertainty in the success criteria, and interdisciplinary application of knowledge. Such problems are called wicked problems [3] and constitute some of the most critical challenges that today we face such as sustainability, health informatics, improving urban infrastructures, or engineering of tools needed for scientific discovery [4]. While over recent years and decades there have been continuing efforts to redesign and improve engineering programs with a project-based paradigm [5] such efforts remain hampered by a lack of research on how engineering education can prepare students to approach real-world wicked problems.

2.2 Current Approaches

Today capstone courses are commonly incorporated into engineering programs to better prepare graduates for engineering practice by increasing the design component of engineering curricula [6]. Capstone projects provide teams of engineering students the opportunity to solve real-world problems, funded by a sponsoring company (or party), and generally require the team to design and manufacture a solution. For these reasons, capstone projects are highly regarded as an important learning activity [7]. Since capstone projects come at the very last semester(s) and since each project cannot cover the whole range of technical areas that students are expected to learn in their degree programs, there remains a gap in creating learning experiences that foster authentic problem-solving skills in students.

2.3 Interdisciplinary Design Project Approach

One of the nationally recognized initiatives to address this problem, supported by the KEEN foundation, is the integration of Entrepreneurial Mindset (EM) in various instructional activities of engineering programs across the entire curriculum [8,9]. While there have been some studies on the evidence-based uses of this framework in engineering education [10], or on the development of instruments to measure the entrepreneurial mindset of students [11] there are limited studies in the literature related to the effectiveness of the EM as a framework of curriculum design in the context of machine design [12] and dynamics of machinery. To addresses this gap by providing informative evidence necessary for the further adoption of EM in core technical engineering courses, this paper presents the development and implementation of a course project in a junior level mechanical engineering course on *Dynamics of Machines*. Furthermore, to guide student efforts toward a real-world interdisciplinary context of problem-definition and problem-solving, two additional elements of bio-inspiration and STEAM were incorporated into the course project.

Engineering systems in general interact with living beings albeit at various levels and such interactions play a decisive role in the evolution of technologies. Therefore, to maintain the inclusivity of design projects toward a wide range of ideas that students may like to consider, students are asked to introduce a bio-inspirational aspect into their design activity through one of the following options:

1. directly, by working on health-related outcomes such as athletic or therapeutic systems,
2. indirectly, by working on problems that address the safety and efficiency of human-machine interface.

And finally, the interdisciplinary aspect of the project was developed through the integration of Arts and STEM, also known as STEAM. The literature on the integration of Arts and STEM shows several benefits of this approach [14-16]. Integration of Arts and STEM enhances students' skill in "problem-seeking" in conjunction with problem-solving skills - the former involving divergent interdisciplinary modes of thinking, shifting among various disciplinary perspectives, while the latter is focused on convergent analytical thought. STEAM experiences are also known to improve students' motivation towards STEM careers [14]. Following the taxonomical categories of National Core Arts Standards on "conceiving and developing new artistic ideas and works" [17] we require students to explicate and address an aesthetic objective in their design of machinery. Further details of this are presented in Section 3.1.

3. Methods

3.1 Description of the Course Project

The Fall 2022 *Dynamics of Machines* course explored a variety of applications and products for which linkages and mechanisms are used to generate desirable motion, function, or output path. The course includes full kinematic and force analysis of fourbar and sixbar linkages as well as their synthesis algorithms. Additionally, it covered gears, gear trains, flywheel design, balancing of machines, and an introduction to mechanical vibrations.

The course was project-based, and as students were learning the complete analysis and synthesis of mechanisms, they worked on a design project in three parts through three different submissions. This study is based on part one of the course project for multiple reasons. First, according to authors' experience from previous years, students are more likely to encounter fundamental challenges that can "make or break" their whole effort in the initial stages of the design process. In addition, the part one of the project necessitates a larger emphasis on the identification of the need, definition of requirements, specifications and design criteria, all of which directly connect to particular skills needed for addressing open-ended wicked problems. Main tasks in part one of the project are:

- to identify a need which can be satisfied using a machinery with sixbar or fourbar linkages,
- to formulate design criteria and constraints for the need, qualitatively or quantitatively,
- to ensure criteria and constraints include bio-inspiration and aesthetics of human-machine interface,
- and to develop two prototypes using graphical methods of linkage synthesis.

The learning approach included lectures, team-based problem solving in classes, and laboratory experiments. Students were introduced to eight different synthesis algorithms of various mechanisms. Each algorithm enables them to identify the exact dimensions of a fourbar or sixbar linkage which generates a prescribed output motion. In addition, they were introduced to critical features of linkage motions such as toggle positions, transmission angle, and time ratio for quick-return motion. Finally, during the lab sessions, students learned to model and analyze these basic features of fourbar and sixbar linkages using computer-aided design (CAD) software as well as 3D printed linkages combined with accelerometer sensors. In Appendix B the full list of all requirements of the design project part one is presented, as assigned to students.

3.2 Participants

All participants were enrolled full-time at the Colorado State University. Of all the students enrolled in the *Dynamics of Machines* course 34 students participated in the study. The study design was approved by the university Institutional Review Board (IRB) # 3837 As Exempt Category (1) in accordance with which, students were notified that the design project would be used for research purposes.

3.3 Data Collection Instrument

The research instrument used in this paper consists of photovoice reflection prompts given in the appendix section. These questions are designed by Bosman et al [13] to promote metacognitive reflections on the learning activity and the elements of the design process that students followed in the part one of their projects.

3.4 Data Analysis Procedure

This study is based on a qualitative approach using thematic analysis. As argued by Braun and Clarke [18], thematic analysis is a foundational qualitative method for the discovery of patterns within textual data. The process of thematic analysis is conducted via a sequence of intentional steps. First, the researcher gained an in-depth familiarity with the data to create initial codes, facilitated by the Excel Spreadsheet software. Codes demarcate aspects of data which have significance towards the research questions. Once coding is completed, the goal of analysis became the generation of themes which encapsulate common concepts behind various codes. And finally, the researcher revised the themes and developed the research report. In the Results section, for each theme, quotes are drawn from the data to provide readers with evidence of the content and the rationale, as well as enabling readers to make judgements on credibility, accuracy, and fairness by themselves [19].

4. Results

4.1 Gains in time management skills in a contextually specific manner

One of the most prominent themes observed in the data analysis belonged to the matter of time, its effective management, and reflective lessons that students learned on how these factors relate to the quality of their work as engineers. While several students directly notice their approach to time management is improved as a result of this course project (see quotes i and ii below) other students are more specific about changes in their thinking on the organization of time for different aspects of the problem-solving (see quotes iii to vi). This code had a frequency of 26.5%, meaning that it was observed in the responses of 9 distinct participants out of 34.

i. “The biggest skill that I learned while completing this project was time management. I used to be very bad at procrastinating and would always wait to the last minute to complete my homework, which created a lot of unnecessary anxiety. By starting this project with the right mindset, I was able to plan out little pieces of the project to complete each day until it was finished.”

ii. “Another skill gained is time management. While it still could be improved, this project did force me to start early and keep at it. I did not have the choice to do it in a day and am glad I didn’t.”

iii. “Through solving the different iterations and working with the constraints I got better at being able to see how the mechanism would move in my head. I found myself using less kinesthetic devices, so I was able to move through designs faster in my head. This will help when I am in the workforce because I will spend less time generating new ideas and more time solving them.”

iv. “I would have spent more time up front thinking about my design constraints and possible design issues that might arise before I committed to a design idea.”

v. “Choosing an idea so late, didn’t give me much time to do the project. Moving forward I need to be more proactive in finding an idea and starting sooner so I have time to get feedback and ideas from you on the project.”

vi. “I did a good job with my time until the very end. I felt as though I started early enough but towards the end, I started to become rushed which is unpleasant when you want to do your best in the creation of this design. I would change the amount of work and the kind of work I will do in the session I work. At first, I was just doing the fun stuff like coming up with ideas and working on rough prototypes which left all the harder report writing for the end. In the future I would like to more evenly balance these two aspects of many projects.”

4.2 Flexing the creativity muscle

For reasons such as the open-ended nature of this project as well as sufficiently structured steps involved in the identification, scoping, and eventually solving of a design problem students report to obtain a first-hand appreciation of what does it mean to be creative in solving engineering problems. The following quotes showcase this finding. This code had a frequency of 23.5%.

i. "Some professional skills I learned in this project included critical thinking, responsibility and creativity. [...] My creativity during this project has grown exponentially. I inherently am not a very creative person. I enjoy solving problems laid out in front of me and finding ways to solve them with methods I known and understand. This project has allowed me to break out of my shell and seek out a problem that I am interested in."
ii. "we have all been STEM focused since high school so many of my peers, including me, have not taken an art class, or done an art project in four or five years. It is a problem when art and creativity are vital to engineering design."
iii. "I learned that initial creativity and discovery followed by strategic searching for solutions was an effective way to approach an unknown problem."
iv. "Finally, the most important part of an entrepreneurial mindset is creativity. To be an entrepreneur you must think of a new innovative idea, which is not easy to do in 2022. The difficulty of producing an idea showed me just how important creativity is in the field of mechanical engineering."
v. "I find this exhilarating and motivating to better myself and sharpen my skills of creativity and embodying the engineering mindset."

4.3 Improving the ability to acquire and apply new knowledge

As formally stated in the ABET accreditation system, criterion three [20] imparting "an ability to acquire and apply new knowledge as needed, using appropriate learning strategies" is a necessary educational outcome of engineering programs. Data analysis shows that interdisciplinarity and the multi-faceted nature of solving real-world problems helps students become self-directed learners in the process of searching, obtaining, and applying new knowledge as shown in the following quotes. This code had a frequency of 17.6%.

i. "Because I had to take into account bio-inspiration and aesthetic appeal, I had to do research and more difficult thinking. I learned a lot of new information in doing my research that inspired my design. For example, I learned how dramatically homeownership for young people has dropped and how much sitting all day affects our health. I was able to apply this newfound knowledge to create a multi-purpose device that could improve the health of remote workers."
ii. "I learned about entrepreneurship by observing and discovering the flaw, I researched and evaluated the existing solutions and identified an opportunity to fix and improve the flaw based on my global knowledge."
iii. "Another skill I had to put effort into was applying knowledge to solutions. It is very easy to learn the material for an exam and let it leave your brain once the test is over. But the real challenge is taking what you have learned in a lecture and being able to apply it to every application you face. These skills are important in the real world because lack of decision making can lead to detrimental setbacks. In industry "due

dates" become hard set deadlines that if not met could lead to more severe consequences."

iv. "Another context specific skill I learned was how to create the same motion using different mechanisms. This is important to engineers in the real world as there are always multiple solutions to any problem and comparing them is the only way to find the best solution."

In Appendix C we present a few samples of students' submitted works to highlight both diverging and converging aspects of each student's work through this intervention.

5. Discussion and Conclusions

5.1 Theoretical Interpretation

Engineers are increasingly called to solve multi-objective, open-ended and interdisciplinary problems embedded in sociotechnical organizations. This requires them to spend a considerable portion of their time acquiring information, making observations, interpreting multiple types of data, and basically learning new skills. Self-directed and life-long learning is indeed the hallmark of learned professional activity. Two of the three main finding of the intervention proposed in this paper as illustrated in the results section tie directly into our research question: *how students were able to leverage the entrepreneurial mindset in the design of machinery through a bio-inspired project with aesthetic objectives*. Students report that (1) they navigate a problem-solving experience by making decisions on how they organize their time with respect to the specific demands of the problem they were defining to solve, and (2) they were able to explore various sources, materials and know-how in the light of aiming towards satisfactory accomplishment of the objectives and criteria they defined using the entrepreneurial mindset. Furthermore, due to the element of creativity required in STEAM perspectives and even surprisingly due to the fact that students were stepping into novel territories that each design problem demands of them, they mention the rewarding nature of coming through such challenging experiences, as shown in the following quotes:

i. "I am still not completely satisfied and I spent countless hours sketching on Solidworks until I got a working mechanism. However, after those many hours, I felt a rush of relief and happiness when I rotated the input link and the coupler went to all three positions. I felt a sense of success like a Wall Street guy when the Dow is up."

ii. "The Arts also present unique opportunities to engineers in the sense that designing a product to have a certain appearance while performing a certain action can be equally challenging and rewarding, often resulting in 'fancy engineering'."

5.2 Compare and Contrast

Compared to instructional activities in which engineering problems are presented in a reductively technical format, abstracted away from the human factors as well as cross-cutting dimensions of engineering practice (the interdisciplinary aspects), this intervention can be regarded as an improved, first step toward creating learning experiences that tie the core technical aspects of engineering curricula with broader professional skills and competencies in problem-definition and problem-solving.

5.3 Implications for Practitioners

The results presented in this paper reveal a concrete opportunity not only to support students in the formation of advanced metacognitive skills (planning, self-monitoring, critical thinking), but also to weave such reflective practices in applied technical subjects. During the project presented here students were able to practice (1) taking the ownership of their work, (2) forging their uniquely individual learning trajectory, and (3) becoming cognizant of effective approaches *they* can identify and use to deal with ill-defined and uncertain challenges of today's life around them. Given the wicked and complex nature of real-world engineering problems, and challenges associated with the pedagogical design and implementation of learning experiences that incorporate such problems into densely packed engineering curricula, the framework of entrepreneurial mindset can provide certain clarity to the key questions that engineering educators need to ask during the planning, design, facilitation, and assessment processes. To strike a right balance between giving students freedom in *authoring problems* as well as *synthesizing solutions* to those problems on one hand, and on the other hand guiding the learners through necessary stages of design thinking as well as core analytic skills is a challenge that requires further research and context-specific evidence. More specifically, during the next academic year, we plan to infuse EM, STEAM and bio-inspiration in part two and part three of this intervention and study the ways in which physical prototyping and detailed design activities can mesh with this intervention.

References:

[1] National Academy of Engineering, U. S. (2004). The engineer of 2020: Visions of engineering in the new century. Washington, DC: National Academies Press.

[2] Buchanan, R. (1992). Wicked Problems in Design Thinking. *Design Issues*, *8*(2), 5–21. https://doi.org/10.2307/1511637

[3] Lönngren, J. (2017). Wicked problems in engineering education: preparing future engineers to work for sustainability. Chalmers University of Technology.

[4] "Grand Challenges - 14 Grand Challenges for Engineering," Engineeringchallenges.org, 2019. http://www.engineeringchallenges.org/challenges.aspx

[5] De Graaff, E., & Kolmos, A. (2007). Management of change: implementation of problem-based and project-based learning in engineering. Brill.

[6] Dutson, A.J., Todd, R.H., Magleby, S.P. and Sorensen, C.D. (1997), A Review of Literature on Teaching Engineering Design Through Project-Oriented Capstone Courses. Journal of Engineering Education, 86: 17-28. https://doi.org/10.1002/j.2168-9830.1997.tb00260.x

[7] Todd, R.H., Magleby, S.P., Sorensen, C.D., Swan, B.R. and Anthony, D.K. (1995), A Survey of Capstone Engineering Courses in North America. Journal of Engineering Education, 84: 165-174. https://doi.org/10.1002/j.2168-9830.1995.tb00163.x

[8] "About | Engineering Unleashed," engineeringunleashed.com. https://engineeringunleashed.com/about

[9] Rae, D. and Melton, D.E. (2017) Developing an entrepreneurial mindset in US engineering education: an international view of the KEEN project. The Journal of Engineering Entrepreneurship, 7 (3). ISSN 2159-6948

[10] Blake Hylton, J., Mikesell, D., Yoder, J.-D., & LeBlanc, H. (2020). Working to Instill the Entrepreneurial Mindset Across the Curriculum. Entrepreneurship Education and Pedagogy, 3(1), 86–106. https://doi.org/10.1177/2515127419870266

[11] Development of the Engineering Student Entrepreneurial Mindset Assessment (ESEMA) Brunhaver, Samantha R.; Bekki, Jennifer M.; Carberry, Adam R.; London, Jeremi S.; McKenna, Ann F. Advances in Engineering Education, v7 n1 Fall 2018

[12] Fry, C., & Leman, G., & Jordan, W., & Garner, B., & Thomas, B. (2010, June), Bringing Innovation And The Entrepreneurial Mindset (Back) Into Engineering: The Keen Innovators Program Paper presented at 2010 Annual Conference & Exposition, Louisville, Kentucky. 10.18260/1-2—16942

[13] Bosman, L., & Shirey, K. (2022, August). Using Bio-Inspired Design and STEAM to Teach the Entrepreneurial Mindset to Engineers. In 2022 ASEE Annual Conference & Exposition.

[14] Michelle H. Land, Full STEAM Ahead: The Benefits of Integrating the Arts Into STEM, Procedia Computer Science, Volume 20, 2013, Pages 547-552, ISSN 1877-0509, https://doi.org/10.1016/j.procs.2013.09.317

[15] S. Riley, "What is Arts Integration?," The Institute for Arts https://artsintegration.com/what-is-arts-integration-in-schools/#definition

[16] Henriksen, D. (2017). Creating STEAM with design thinking: Beyond STEM and arts integration. The STEAM Journal, 3(1), 11.

[17] "National Core Arts Standards," Nationalartsstandards.org, 2014. https://www.nationalartsstandards.org/

[18] Virginia Braun & Victoria Clarke (2006) Using thematic analysis in psychology, Qualitative Research in Psychology, 3:2, 77-101, DOI: 10.1191/1478088706qp063oa

[19] Corden, A., & Sainsbury, R. (2006). Using verbatim quotations in reporting qualitative social research: researchers' views (pp. 11-14). York: University of York.

[20] "Criteria for Accrediting Engineering Programs, 2021 – 2022 | ABET." https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2021-2022/

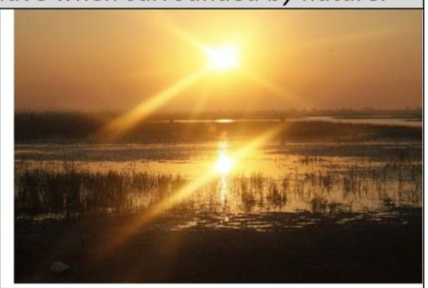
Appendix A

Photovoice Reflection

Directions: Replace all yellow highlighted text with information specified.

Part 0 - Photovoice Reflection Example

Directions: Please respond to the photovoice reflection prompts using three pictures or photos, and writing a narrative (i.e. voice). The narrative with a minimum of 200 words for the entire response should reference the pictures and their relationship with respect to your response. Be sure to check for spelling and grammar prior to submission. **Next, an example response is presented to demonstrate expectations:**

*Photovoice Reflection Prompt (**Example**): Describe the feelings you have when surrounded by nature.*		
		
Springtime with trees in bloom	House plants	Sunset over a lake
A wonderful serenity has taken possession of my entire soul, like these sweet mornings of spring (Figure 1) which I enjoy with my whole heart. I am alone, and feel the charm of existence in this spot, which was created for the bliss of souls like mine. I am so happy, my dear friend, so absorbed in the exquisite sense of mere tranquil existence, that I neglect my talents. I should be incapable of drawing a single stroke at the present moment; and yet I feel that I never was a greater artist than now. When, while the lovely valley teems with vapour around me, and the meridian sun (Figure 3) strikes the upper surface of the impenetrable foliage of my trees, and but a few stray gleams steal into the inner sanctuary, I throw myself down among the tall grass by the trickling stream; and, as I lie close to the earth, a thousand unknown plants (Figure 2) are noticed by me: when I hear the buzz of the little world among the stalks, and grow familiar with the countless indescribable forms of the insects and flies, then I feel the presence of the Almighty, who formed us in his own image.		

Part 1 - Photovoice Reflection Prompt

*Photovoice Reflection Prompt A (**Entrepreneurial Mindset**): The entrepreneurial mindset is defined as "the inclination to discover, evaluate, and cultivate opportunities." Explain how participating in the project incorporated the entrepreneurial mindset, and lessons learned relevant to the entrepreneurial mindset.*

<table>
<tr><td><Insert Picture 1></td><td><Insert Picture 2></td><td><Insert Picture 3></td></tr>
<tr><td><Insert Caption 1></td><td><Insert Caption 1></td><td><Insert Caption 1></td></tr>
<tr><td colspan="3"><Insert Narrative (200 word minimum)></td></tr>
</table>

<table>
<tr><td colspan="3">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 back into engineering. Art can be incorporated through pieces, process, and movements. Explain how participating in the project incorporated STEAM (specifically, the arts), and lessons learned relevant to STEAM (specifically, the arts).</td></tr>
<tr><td><Insert Picture 1></td><td><Insert Picture 2></td><td><Insert Picture 3></td></tr>
<tr><td><Insert Caption 1></td><td><Insert Caption 1></td><td><Insert Caption 1></td></tr>
<tr><td colspan="3"><Insert Narrative (200 word minimum)></td></tr>
</table>

<table>
<tr><td colspan="3">Photovoice Reflection Prompt C (Bio-Inspired Design): Bio-inspired design uses the nature-focused context of life, sustainability, security, or biomedicine and health outcomes to motivate analogical thinking and improve the engineering design. Explain how participating in the project incorporated bio-inspired design and lessons learned relevant to bio-inspired design.</td></tr>
<tr><td><Insert Picture 1></td><td><Insert Picture 2></td><td><Insert Picture 3></td></tr>
<tr><td><Insert Caption 1></td><td><Insert Caption 1></td><td><Insert Caption 1></td></tr>
</table>

<Insert Narrative (200 word minimum)>

Part 2 - Open-Ended Reflection Questions

Direction: Please respond to the open-ended reflection questions with a minimum of 200 words per question. Be sure to check for spelling and grammar prior to submission.

*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 project?*
<Insert Narrative (200 word minimum)>

*Open-Ended Reflection Question B (**Debrief**): What went well? What didn't go so well? What will you do differently next time?*
<Insert Narrative (200 word minimum)>

*Open-Ended Reflection Question C (**Connect to Real World**): What skills did you learn? Please consider both professional skills (e.g., communication, collaboration, critical thinking) and context specific skills (e.g., dynamics and kinematics). Why are these skills important for engineers in the real world?*
<Insert Narrative (200 word minimum)>

Appendix B

Project Requirements

I. Introduction and Need Statement: In the introduction you should introduce the purpose of your project. Describe for what need or requirements you are designing your linkage. To establish your need, find something in your everyday life (or someone else's) that could be improved using a linkage mechanism. Truly, you have an open slate of what you would like to design ranging from basic necessities to luxuries and everything in between. So you can be very creative about that. While this freedom may be challenging at first, it matches the beginning of most engineering projects and is among the most challenging parts. One of the major goals of this course project is to take you through the design process in a manner that you might experience once you graduate.
The requirements for your need statement are:

I.A. Description of Need: You must be able to meet your needs through the design of a mechanism. This means you must meet your need through creating a complex motion of a coupler (a combination of rotation and translation). The input motion can be generated either by a human interaction or through the use of a motor.

I.B. Bio-Inspiration: Engineering systems are always integrated with life and you are required to bring this aspect of your design explicitly into your work through one of the following two options:
i. Your need statement must address health and biomedicine outcomes, for example:

3. directly, by working on athletic or therapeutic systems
4. indirectly, by working on systems addressing safety and efficiency of human- machine interface.

ii. Alternatively your need statement can be based on harnessing the natural rules of biological life to translate solutions from one area into another.

I.C. Aesthetic Objective: All engineering products are ultimately designed for sentient beings. How we freely take a position toward things, the way we find and feel them to be, in short, the way we develop a "taste" becomes the court of adjudication over entities. This sensual position we always have toward objects and experiences define our Aesthetic State. In your project, you must define and operationalize aesthetic or artistic factors of your system (at least two factors) and use elements such as

- sound,
- color,
- motion
- packaging,
- finished surface components

to fulfill your definition of aesthetic dimensions, i.e. sensual relation of human and machine.

II. Design Thinking Section: Engineering projects are embedded in markets and entrepreneurial contexts. We will eventually implement the full cycle of Design Thinking as follows:

II.A. Empathize: identify the need through documented observations or written self-reflection.

II.B. Define: define specifications and constraints that explicate the success of your design.

II.C. Ideate: synthesize low fidelity solutions and determine the grounds for your top selection.

II.D. Prototype: fully simulate and analyze the kinematics, dynamics and CAD assembly of your selected solution (or 3D-print for extra credit).

II.E. Test: give evidence of how your solution compares to your defined specifications and constraints.

For part one of our project we only require Sections II.A to II.D. The only caveat is that in the ideate section (II.C) you must propose at least two alternatives based on your research on current state-of-the-art, available products, patents, etc.

III. Position Synthesis of the First Prototype: Initially, your mechanism must be simplified as a 2-dimensional fourbar linkage or sixbar. As we explore these linkages and their benefits and limitations, you may add other components to improve upon this original design, but let’s start simple. The simplest design is often the best! For your position synthesis section you will be tasked with providing at least two prototypes of a fourbar linkage to meet your need above. To generate the two designs you will be using the 3-position synthesis technique. This means you first need to determine the 3 most critical positions which your linkage must hit. Once you have your 3 positions, go through the following procedure.

III.A. First Prototype: Without regard to any limitation on where your fixed pivots can be, conduct a 3-position synthesis. This will be your first design. Please provide a sketch of your design and all link lengths. Be sure to include all work either in your document body or a document appendix.

III.B. Second Prototype: Identify the constraints on the position of your fixed pivots, and first determine their location. Then conduct a 3-position synthesis with specified moving pivots. Finally, add a dyad driver if desired. This will be your second design. Please provide a sketch of your design and all link lengths. Be sure to include all work either in your document body or a document appendix.

III.C. CAD Design: Model your designs in Solidworks and generate the coupler curves of them using Solidworks Motion Analysis. (5% extra credit)

III.D. Coupler Curve Analysis: By conducting a coupler curve analysis you can check references to see if someone has created a design that already meets your desired linkage output. To do this you will need to read section 3.6 of Norton's textbook and research on different mechanisms that have been already created for your needs. You will need to find a mechanism that you think serves your purpose and you can use it in your design. (5% extra credit)

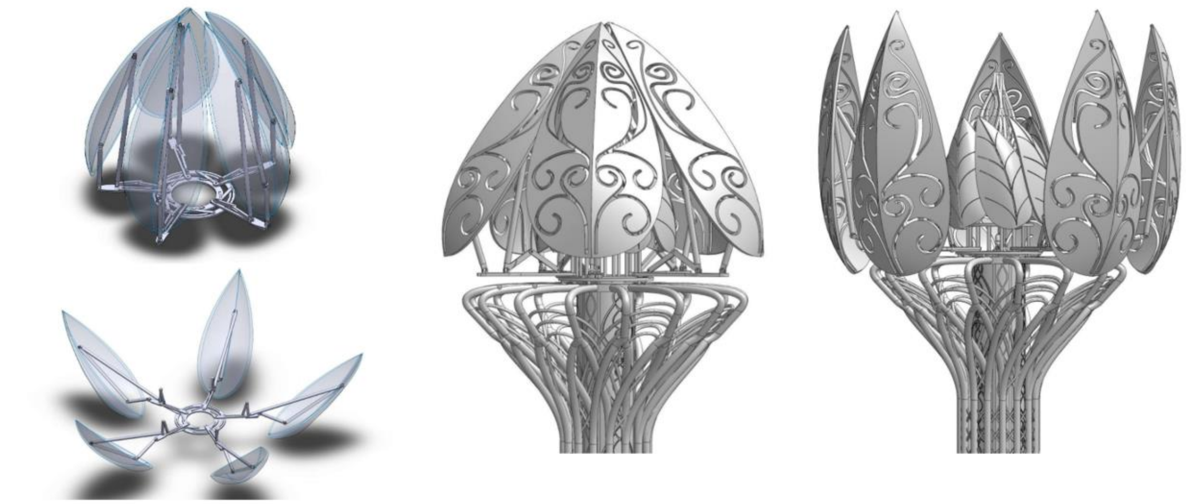
IV. Photovoice Reflection: This serves as your conclusion section to reflect on your own activities and their outcomes. Please refer to the template given in the last pages of this document (appendices).

V. Appendix: In your appendix you should include any calculations or designs that are too burdensome for the general body of the report, but that you think will provide good insight into your design process.

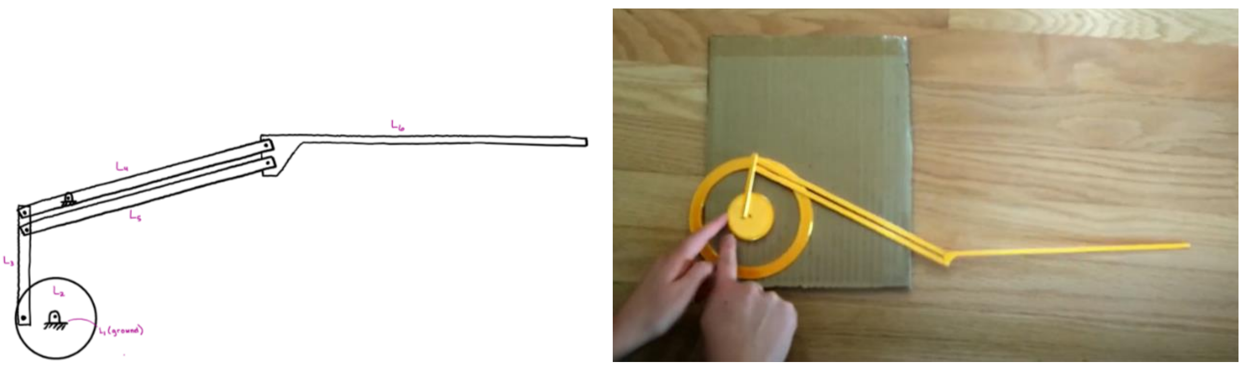
Appendix C

Samples of students' work

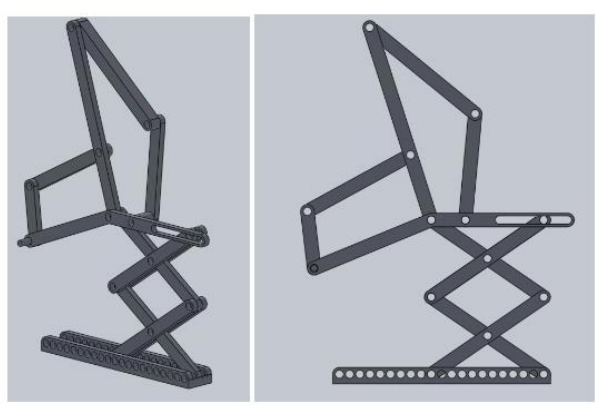
Sample 1: Prosthetic finger design using three fourbar linkages in series.



Sample 2: Sunrise alarm clock to gradually light up the room, operating with fourbar linkages combined with slider joints. Inspired by the unsuspecting time scale of plant movements.



Sample 3: Ornithopter kite design, inspired by flapping motion of wings to generate lift.



Sample 4: Plant watering mechanism (sixbar linkage) with adjustable height to accommodate and track the plan growth.