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Fostering Early-Stage Design Thinking: A Hands-On Design Exercise for Freshman Engineering Students

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Abstract

A strong understanding of the engineering design process (EDP) is essential for engineering students, as it provides a framework to develop and apply critical thinking and problem-solving skills. In engineering, senior design courses focus on the use of the EDP to develop solutions to complex problems. However, students frequently overlook the importance of the early stages of the EDP, eager to jump directly into product implementation.

This paper describes an EDP exercise implemented with freshman electrical and computer engineering students, aimed at emphasizing the value of the early stages of the EDP, as well as teamwork and communication skills. The primary objective was for students to collaborate in teams and apply the EDP to address a real-world problem. The exercise spanned two weeks: the first week focused on familiarizing students with EDP concepts, defining the problem and those affected by it, identifying constraints, analyzing the market, and proposing a solution. In the second week, students implemented their proposed solutions by building mock prototypes, using craft materials, and presenting their results.

As a result, students engaged deeply with the design process, concentrating on the early stages and bringing their solution to "life" through the construction of mock prototypes. This paper includes objectives, required tools, instructions, a timeline of the design process, and sample student work. Student reflections collected using a "classroom critical incident questionnaire" revealed high levels of engagement throughout the exercise, from problem identification to prototype presentation.

Introduction

A key part of the journey of any engineering student is their engagement in the engineering design process (EDP). Recognized as essential for students to develop their critical thinking and problem-solving skills, the EDP equips students with tools to identify needs and conceptualize solutions. The accreditation board for engineering and technology, ABET, defines EDP as the process of "devising a system to meet desired needs and specifications within constraints" [1]. All students in ABET accredited programs are required to engage in a "major engineering design experience that 1) incorporates appropriate engineering standards and multiple constraints, and 2) is based on the knowledge and skills acquired in earlier course work" [1]. Typically, senior undergraduate engineering students engage in a one-semester or two-semester design experience where they need to follow the engineering design process to find the solution to a given or found problem.

While senior design courses in engineering programs emphasize these processes, students often neglect critical early stages, such as market analysis and stakeholder's desires, favoring immediate implementation of possible solutions. To address these educational challenges in the early years of their engineering journey and ensure students fully engage in the early stages of

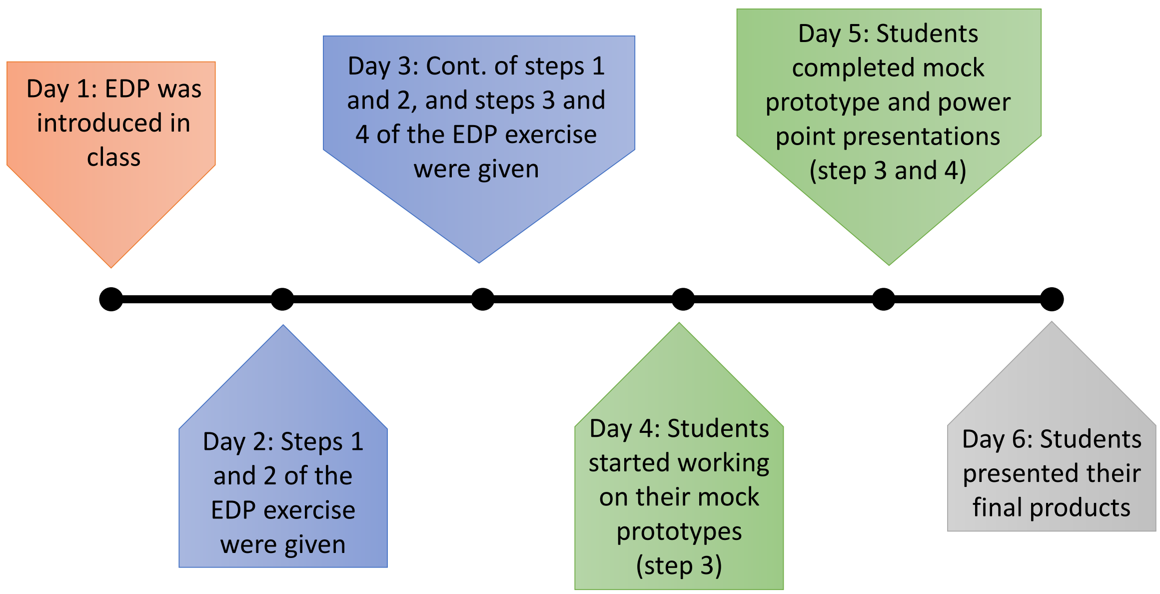

Figure 1. Timeline of the EDP exercise.

the EDP, an engineering design exercise was introduced into a Fundamentals of Engineering class. This class is taken by first-year engineering students and covers a variety of topics, from the basics of what is involved in the engineering profession to the fundamentals of electrical theory.

This paper delves into the implementation of the EDP exercise, aimed at emphasizing the value of the early stages of the EDP, as well as teamwork and communication skills. The primary objective was for students to collaborate in teams and apply the EDP to address a real-world problem. As a result, students engaged deeply with the design process, concentrating on the early stages and bringing their solution to "life" through the construction of mock prototypes. The following sections will describe the EDP activity instructions, the timeline of the EDP exercise, and sample student work. Student reflections collected using a "classroom critical incident questionnaire (CCIQ)" revealed high levels of engagement throughout the exercise, from problem identification to prototype presentation.

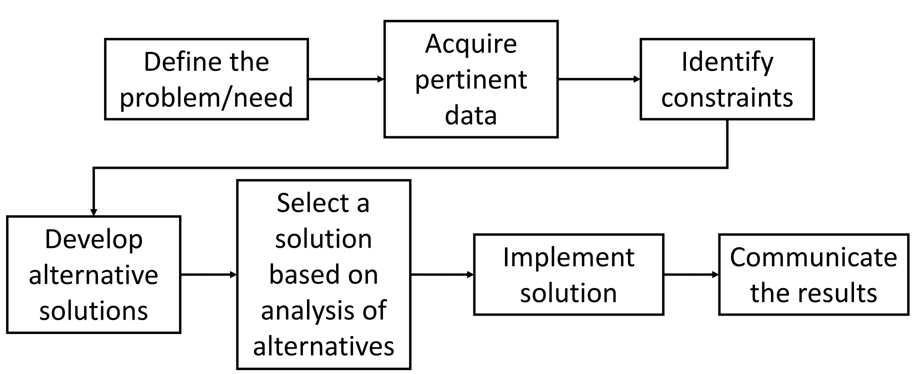

Figure 2. Engineering design process as described by [2].

EDP Exercise Description

The exercise spanned six classes (two weeks), as shown in Fig. 1. The first class focused on familiarizing students with EDP concepts. Students were introduced to the design process using the diagram in Fig. 2. The introductory class to the design process had a special emphasis on the importance of understanding the problem and the customer, as well as communicating with those involved in the design of a product, such as marketing personnel, economists, and project managers. The second and the third class focused on providing students with a real-world problem, provided by a professor in the Nursing department for a Capstone class, and requesting

Table I. EDP exercise guiding questions.

Step 1: Brainstorming and Problem Definition	1) *Define the problem:* a. Are there any questions that you should ask the customer for clarification? 2) *Acquire pertinent data:* a. Identify at least two challenges visually impaired individuals face when trying to communicate. (You are allowed to use the internet.) 3) Define a one-sentence problem statement based on the data and challenges identified in parts 1 and 2 of this step. Your problem statement should start with "Design a…"
Step 2: Propose Solutions	4) *Identify constraints and criteria:* a. Are there questions that you should ask of your teammates / supervisor / customer? b. Research existing assistive technologies and solutions related to the defined problem. c. Highlight promising ideas, "must have's," or technologies you have discovered. 5) *Develop solutions:* a. Are there multiple ways to solve this problem? Provide examples of at least two different ways. b. Generate initial concepts for a solution. You are encouraged to think creatively and consider different approaches.
Step 3: Solution Design	6) Select a solution from alternatives: a. Amongst the different solutions, what are the pros and cons? b. Select one concept from your group's proposed solutions phase. 7) Solution Development: a. Using materials provided by your professor, develop a preliminary design for your solution. (Consider aspects like usability, affordability, and accessibility.)
Step 4: Communicate Results	8) Prepare a brief presentation (5-7 minutes) of your proposed solution. Use your mock-ups prepared under Step 3, part 7 to illustrate your ideas.

that they use the EDP to propose a design that could provide a solution to the given problem. The class was divided into groups of three students so that they could experience the teamwork aspect of the EDP.

The provided problem/situation read as follows:

An assistive technologies company hires you to provide a solution to the following situation: As the push to focus on community/population health increases, as does the age of the "baby-boomer population", healthcare finds itself needing to increase access to items that increase their ability to function in day-to-day life. Visually impaired individuals, attempting to read, whether in their native language or in a non-native language, need to be able to communicate as part of their day-to-day life.

The second and third classes were divided into students completing a brainstorming section and the definition of the problem (step 1), proposal of different solutions (step 2), and design of a chosen solution (step 3). Students were also instructed to communicate their results (step 4); however, they did not get to complete step 4 until day 6 of this exercise. For each step, students were provided with related guiding questions, as shown in Table I. The class professor acted as the customer to provide the students with requested input during steps 1 and 2. For step 3, students were provided with craft materials (such as construction paper, popsicle sticks, chenille stems, plasticine, cardboard, tape, scissors, and glue) that they used to create a mock prototype of their designs.

During the design process, students were asked to fill out the CCIQs [3][4] to collect information about how engaged they were during this exercise. Students filled out this questionnaire, containing five questions (listed in Table II), once a week.

Results

At the end of the two weeks, students had presented their designs based on their problem definition and the particular need they wanted to solve. Samples of the mock prototypes created

Table II. Questions from the Classroom Critical Incident Questionnaire (CCIQ) [3][4].

Questions
At what moment in class this week did you feel most engaged with what was happening?
At what moment in class this week were you most distanced from what was happening?
What action that anyone (instructor or student) took this week did you find most affirming or helpful?
What action that anyone (instructor or student) took this week did you find most puzzling or confusing?
What about the class this week surprised you the most? (This could be about your own reactions to what went on, something that someone did, or anything else that occurs)

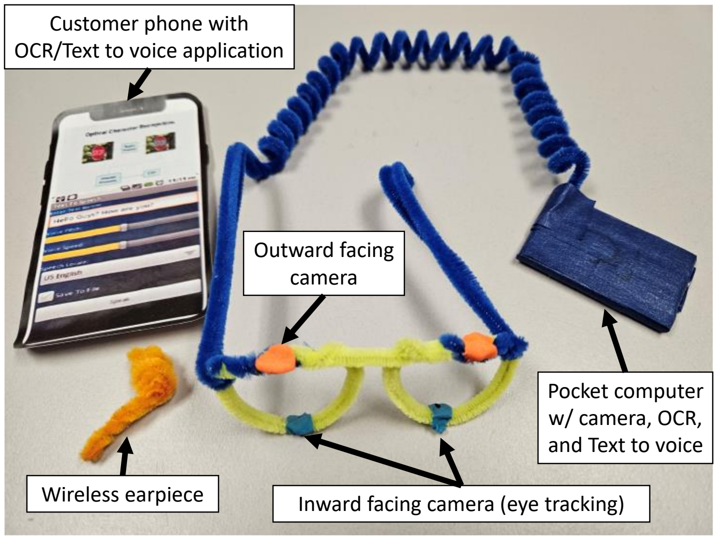

Figure 3. Mock prototype of group A, which they called “Assistive recognition kit.”

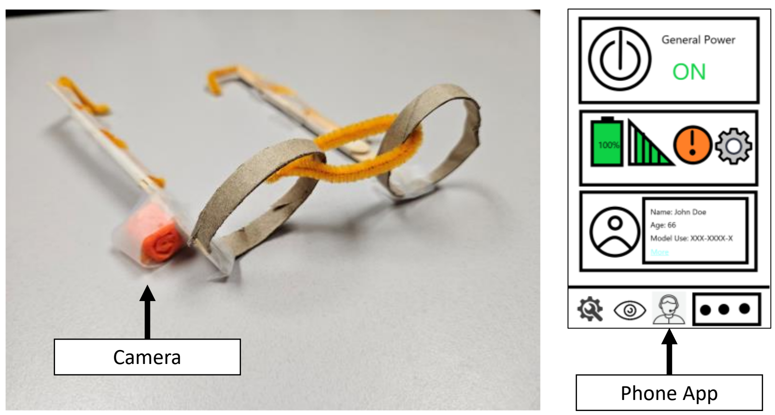

Figure 4. Mock prototype of group B, which they called “FreeVision.”

by the students can be appreciated in Fig. 3 and Fig. 4. In Fig. 3, we can observe the prototype created by Group A. As described by the students, the “assistive recognition kit” is a wearable device that has eye tracking technology and outward facing cameras that will translate the text user is looking at to an earpiece for auditory assistance. Group A’s problem statement was “Design a wearable/application with optical character recognition and text to voice.” As part of step 1, Group A developed a set of questions for the customer (listed in Table III) and identified two main challenges visually impaired individuals face when trying to communicate: (1) Day to day personal reading and (2) environmental reading (menus, street signs, etc.). As part of step 2, they developed a set of questions that helped them define constraints, as listed in Table III.

In Fig. 4, we can observe the prototype created by Group B. As described by the students, the “FreeVision” is a facial recognizing system attached to glasses, it has the ability to detect anyone around in users’ vicinity that are displaying facial expressions and cues. Along with this it has an app that is where all the data from the facial recognition system is sent to. Group B’s problem statement was “Design a product that assists in the ability to recognize visual cues such as mood or emotion.” As part of step 1, Group B developed a set of questions for the customer (listed in Table III) and identified the following challenge visually impaired individuals face when trying to communicate in addition to having reading difficulties: “lack of ability to interpret the other person’s facial effects and expressions as a visually impaired person may not be able to tell if someone is being sarcastic or rolling their eyes.” As part of step 2, they also developed a set of questions that helped them define constraints. For Group B, Table III presents a selected list of their questions.

As observed, two groups that were given the same initial situation ended up with two different problem statements and solutions based on their research of the customer’s needs and challenges. Customer input was given by the class professor, but it was limited to the type of questions that were developed by the students. As each group presented their results, students understood that their final design can vary depending on their findings during steps 1 and 2, the types of questions they ask, and how often they go back to the customer and other stakeholders for feedback. However, it is recommended that students get additional reinforcement of these early-stage concepts in subsequent courses before their senior design experience.

A sample of the students’ responses to the CCIQ for the first and second weeks of the activity are shown below:

- Students responded that they felt most engaged…:
    - “During the group work regarding our designs.”
    - “Working as a team to develop a solution.”
    - “Working in a team to create/plan a technological design.”
    - “Working on a design and slide deck with a team.”
    - “Giving and listening to presentations.”

Table III. Questions developed by Group A and Group B for the customer and other stakeholders.

	Group A	**Group B**
Questions for the customer	“What devices do you have access to?” “What would be your cost limit?” “Do you have an opposition to wearing glasses?”	“What things are you doing day to day?” “How much are you willing to spend monthly?” “What are some products that you’re reading daily?” Do you have any other disability that would affect the use of the product?
Questions for the customer and other stakeholders	“What languages are needed?” “Network availability?” “Cost limitations for the project?” “Timeline/deadline?”	“What are you looking to get out of the visual aid?” “What is the time frame for project completion?” “What is the budget?”

- Students responded that they felt most distanced…:
  - "Brainstorming idea for product."
  - On day 5, after they were done preparing their prototypes and presentations.
  - More than 50% of the students never felt distanced.
- Students felt that the action that was most affirming or helpful was…
  - "Answering questions regarding the design."
  - "Researching for Design Process."
  - "My teammates helped on the project."
  - "Bouncing ideas for the design with my team, and suggestions from the instructor on better model designs."
  - "Presentations, further explaining their designs."
  - "Classmates working together outside of class."
  - "When speaking with the instructor on certain solutions and ideas, which helped kickstart my teams' ideas for our design project."
- Students felt that the action that was most puzzling or confusing was…
  - One student answered: "Process of making product."
  - All other students did not find anything puzzling or confusing
- Students were surprised the most by…
  - "That we got to work on a mock design."
  - "I learned that the designing process is more complex than I thought."
  - "Being told I'm having the chance to create a prototype for our design assignment."
  - "The different ideas we had for the project."
  - "That we were building a model of our invention."
  - "All the groups having the same sort of idea with glasses as a baseline."
  - "Perhaps seeing how every team created a similar design but for different purposes."

Conclusion

In conclusion, the EDP exercise provided an engaging and educational experience for electrical and computer freshman engineering students, effectively introducing them to the fundamentals of problem-solving, critical thinking, teamwork, and creativity. Over the course of two weeks, students demonstrated their ability to define problems by understanding their customers, conduct research, and develop innovative solutions tailored to the identified needs. The outcome of this exercise demonstrates the diversity of approaches to the same initial situation, as evidenced by the sample prototypes presented from Group A and Group B. These designs highlighted the importance of customer-centered design thinking.

Student feedback further validated the success of this exercise. Most students reported feeling highly engaged during collaborative tasks, particularly in designing and presenting their solutions. The majority of the class never felt distanced from the EDP exercise. The exercise also helped students gain valuable insights into the complexities of design and prototype development, leaving many pleasantly surprised by the hands-on nature of the activity and the variety of ideas generated. This exercise serves as a model for fostering active participation, critical thinking, and innovation in an introductory engineering curriculum.

Acknowledgement

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