"WIP" Introducing Design Thinking in First-Year Engineering Education

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Work in Progress : Introducing Design Thinking in First-Year Engineering Education

Our initial Work in Progress student research suggests today's engineering student sometimes choose engineering as a profession that can make a difference in the world. They see it as providing them an education that will enable them to join a profession that has substantial social purpose which is congruent with their values and goals. This student aspiration conforms to one of the basic tenets of "design thinking" in that it is a methodology that imbues the full spectrum of innovation with a human-centered design ethos.

At our university we have started to infuse the concepts of design thinking in our initial Introduction to Engineering course and then later in our capstone senior design project courses. Between those "course bookends" we are working with our faculty to introduce to them the design thinking concept of "identifying the need" in place of only teaching "transactional" engineering concepts and theories and how to solve engineering problems.

This paper will illustrate how we have introduced design thinking in our first-year introduction to engineering course and then conducted indirect assessment of our students' learning outcomes for the course for the purpose of continuous improvement. The indirect study results were obtained by an anonymous survey given to over several hundred freshman engineering students who are matriculating in a wide range of undergraduate engineering and engineering technology programs.

One of our key findings was that about 82% of students agreed that Design Thinking was a valuable learning experience. Further, 93% of students agreed that having a basic understanding of Design Thinking will be of assistance to them as they pursue their engineering education.

After being informed by students that one of the two design thinking projects had a relatively low value with regard to providing future assistance to them as they pursued their engineering education we substituted that project with a choice of 6 projects that we believe will be more favorably appreciated by the students. At the completion of the modified course we will survey the students again to see if there are further opportunities for continuous improvement of the course.

“WIP” Introducing Design Thinking in First-Year Engineering Education

Introduction

Undergraduate engineering education was focused historically on solving problems (***solutio ligatorum***) in traditional areas depending on the major. For instance, an undergraduate mechanical engineering program would consist of problem-solving courses such as statics, dynamics, mechanics of solids, fluid mechanics, thermodynamics, and heat transfer. The class lectures were focused essentially on learning the engineering principles of these subjects and then solving homework and quiz problems. The problems were clearly defined by the professor and/or textbook. Eventually, engineering students were exposed to ‘pencil and paper” design exercises with predetermined “right” solutions; actual class-related construction work tended to be limited to small test devices, built by the book.

In the 1970’s an assistant professor in the Mechanical Engineering department at MIT, Woodie Flowers, recognized that an innovative approach to engineering education would enhance the students’ education and he developed a hands-on project centered mechanical engineering design class. This freshman course was eventually replicated by many world-wide engineering education programs.[1]

During the late 1990’s Dr. Joseph Bordogna, former National Science Foundation (NSF) Deputy Director and his colleagues began to look for broader possibilities for intervention in engineering education, with a focus on the phrase, “innovation through integration.” Bordogna and colleagues were among those who pointed to <u>quantitative accreditation standards</u> as a significant reason for the stagnation of US engineering curricula. By allowing faculty to focus on delivering specific content, little attention was given to how students integrated and applied this knowledge.[2] As a result, the Engineering Accreditation Commission (EAC) of ABET revised undergraduate engineering education accreditation criteria to include:[3]

(c) an ability to design a system, component, or process to meet **desired needs**

The EAC eventually expanded the criteria to include:[4]

(c) an ability to design a system, component, or process to **meet desired needs within realistic constraints** such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability

For the 2020-2021 accreditation cycle the EAC revised the Student Outcome Assessment criteria to include:[5]

2. 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

Amongst the description for “Engineering Design” the EAC states “Engineering design involves identifying opportunities,….”. Below is a diagram which shows the flow of changes made to EAC student outcome criteria associated with engineering design.

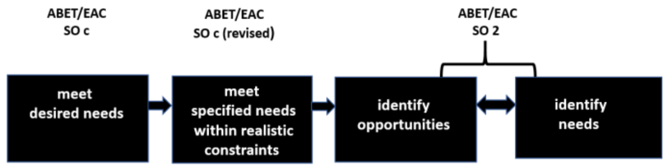

Fig. 1 Flow of Changes Made to ABET/EAC Student Outcome Criteria

In view of the current ABET Student Outcome 2, our institution is beginning to infuse the concept of Design Thinking in many of our undergraduate engineering program curriculum. We are basing this infusion on a concept that has been promulgated by MIT, - 10 Steps to Design Thinking. Blade Kotelly, a senior lecturer at MIT and co-instructor of the MIT Professional Education course "Mastering Innovation & Design Thinking" explains that "design thinking is a framework that helps engineers and designers move through a structured design process. It's a way to frame your strategy, your design approach, and your development around the end-user. Design Thinking starts with identifying needs. This is the most critical and most difficult step. It's about truly understanding the problem and how it intersects with users, technology, businesses, and–most importantly–society." The full list of the 10 steps are:[6]

1. Identify Needs
2. Gather information
3. Stakeholder analysis
4. Operational research
5. Hazard analysis
6. Specification creation
7. Creative design
8. Conceptual design
9. Prototype Design
10. Verification

At our institution we distilled the MIT 10-Step process to 3 overarching steps and explain to students that this is the overall educational philosophy of the design thinking process. These are shown below along with their harmonization to the MIT 10-step process.

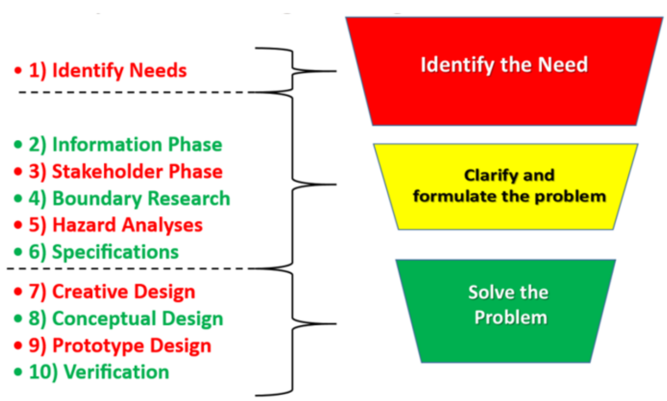

Fig. 2 MIT 10-Step Design Thinking Process

At our institution we recently redesigned our freshman "Introduction to Engineering and Engineering Technology" course so that it is based on the concepts of design thinking and, as such, when our students begin their engineering or engineering technology education after enrolling in this course they are fully acquainted with the basic tenets of design thinking. During the first two-weeks of the 14-week course they are exposed to the concepts of design thinking. Further, they are assigned two group design projects in which they are required to implement design thinking concepts.

After introducing the students to design thinking with lectures, two design projects are given to the students to solidify their understanding and help them apply the design thinking process. For each project, they work in groups and submit a written report. For the second project, they also build a prototype and present their designs to their classmates.

The first project is short in length (two weeks) and consists of a traffic study of an intersection. The process was modified from one developed by the Delaware Department of Transportation.[7] Below is the overview given to the students:

Overview: The level of service is of an intersection is a measure that describes the operational conditions of traffic flow and can be based on service measures such as speed and travel time, freedom to maneuver, traffic interruptions, comfort and convenience.

There has been an increase in the population of Philadelphia by 17% over the last decade. Of those new residents, approximately 80% drive their car more than three times per week. The Philadelphia Traffic Planning Committee has been conducting surveys of drivers and pedestrians to gauge the level of congestion and ability for drivers to navigate the streets. They have approached your team for advice on certain key intersections on our campus in particular. We will use the 10-step design process.

Objective: Your team's objective is to make lane and signal recommendations for the particular intersection you are assigned. This will be accomplished by following the 10-step design process.

At the end of the project you will submit a report which will make recommendations based on your analysis.

The second project is longer in length (seven weeks) and the students' goal is to design a box that could transport a donor human liver. Here is the overview given to the students:

One of your friends, Stacy, recently told you a story about her recent liver transplant. During the follow up appointment, the surgeon made a comment that while there had been enormous leaps and bounds of technology in the operating room, the liver was still being transported in a cooler! Luckily in Stacy's case the organ was delivered undamaged, but this was not so in all cases. Your goal will be to use the 10-Step Innovation Process Based on Design Thinking to develop a working solution to this problem.

Throughout both projects, students follow the MIT 10-step design process. The following table shows how they are instructed to apply each step of the design process to each project.

Design Step	Traffic Study Application	Liver Box Application
1. Identify Needs	Lecture discussion on needs from project overview	Lecture discussion on needs from project overview; Class skimmed research article to identify and discuss need
2. Information Phase	Visited intersection and completed phasing worksheets and traffic volume count	Lecture discussion and manufacturer's website of current product
3. Stakeholder Analysis	Lecture discussion	Lecture discussion
4+5. Boundary Research and Hazard Analysis	Lecture discussion	Lecture discussion
6. Specifications	Student led at the intersection.	Interactive upvoting in class to collaboratively come up with specifications to use as a class
7. Creative Design	Completed critical lane summation	Designed box with given specifications in SolidWorks
8. Conceptual Design	Interpreted results and recommend changes to intersection.	Performed heat modelling in SolidWorks to confirm correct heating specifications; Calculated correct length of a heating wire to output wattage from SolidWorks and maintain desired temperature
9. Prototype Design	Could not implement design since it was a real intersection.	Laser cut designs out of three different materials; Designed control system for heating wire with Arduino and temperature sensor
10. Verification	Same as #9	Compared SolidWorks model with prototype

As with many design projects in engineering education, more time was spent on steps 6-10 and more thought will be given in future iterations of how to put more emphasis on the earlier steps.

Students' Indirect Assessment of Design Thinking in the Revised Course

At the end of the Fall 2019 semester, 260 students were surveyed anonymously using an on-line survey. Approximately 50% of the enrolled students responded. Students were first asked to identify their undergraduate engineering or engineering technology current major. They were then asked a series of questions wherein they could rate their responses on a (5)-(1) Likert Scale: (5)-Strongly Agree, (4)-Agree, (3)-Neither Agree or Disagree (neutral), (2)-Disagree, (1)-Strongly Disagree. We decided to group ratings in our proceeding analysis with (5) and (4) together since they are positive and (2) and (1) together since they are negative. Below are the data from each of the seven questions related to Design Thinking.

Survey Question 1. "The section on "Design Thinking and Innovation" was a valuable learning experience."

Strongly Agree/Agree	Neutral	Disagree/Strongly Disagree
82.1%	15.4%	2.4%

Survey Question 2. "I anticipate that having a basic understanding of "Design Thinking" will be of assistance to me as I pursue my entire engineering or engineering technology education."

Strongly Agree/Agree	Neutral	Disagree/Strongly Disagree
93.1%	6.0%	0.9%

Survey Question 3. "The initial section of the course that focused on "Design Thinking" was helpful when I participated in the Design Projects."

Strongly Agree/Agree	Neutral	Disagree/Strongly Disagree
71.9%	19.5%	8.6%

Survey Question 4. "Design Project #1 (traffic study) was a valuable learning experience."

Strongly Agree/Agree	Neutral	Disagree/Strongly Disagree
52.1%	25.6%	22.3%

Question 5. "I believe that the experience I had doing the Design Project #1 (traffic study) will be of great assistance to me as I continue my engineering or engineering technology education."

Strongly Agree/Agree	Neutral	Disagree/Strongly Disagree
38.6%	26.3%	35.1%

Question 6. "Design Project #2 (liver incubator) was a valuable learning experience."

Strongly Agree/Agree	Neutral	Disagree/Strongly Disagree
74.2%	9.3%	16.4%

Question 7. "I believe that the experience I had doing the Design Project #2 (liver incubator) will be of great assistance to me as I continue my engineering or engineering technology education."

Strongly Agree/Agree	Neutral	Disagree/Strongly Disagree
73.5%	11.5%	15.0%

Course Modification Including Improvement

The original intent of having two design projects in the course was to have a short project that would let the students practice the design thinking approach and allow an opportunity for formative assessment before applying it to the liver box project. However, both the students and instructors concluded that the first design project did not lead to learning the design thinking process. This could be due to the fact that students were not able to implement their designs, but there were also several flaws in the methodology that led students to calculate traffic metrics that did not match what they observed at the intersections. The other overall observation from the faculty was that the course focused more on steps 6-10 even though we wanted to stress steps 1-5 in this course.

In order to address these concerns, we implemented the following revisions in the course. First, we have eliminated the traffic project. Second, we have decided to ask students to go through one formative and one summative application of the first five steps of the design thinking process in the following way. While the students are being introduced to the steps of design thinking, we introduced the prompt for the liver transport box problem and we give them two assignments based on steps 1-5 of the design process with detailed rubrics in order to give them formative feedback on the process. We also dedicated a class to using the information they have gathered to inform specification creation (step 6). For the final design project (seven weeks total), we asked them to pick from one of the following final problem prompts with their group and then, using a very similar rubric and similar process, we ask them to go through the same design process for steps 1-6 that they have already done for the liver box. This is handed in and formative assessment is given on it before the next phase of the project begins.

Design Thinking Problem #1

You are hired by a green building materials supply company whose customers create green buildings through the LEED standard.[8] *Your manager asks you to certify your material as low-emitting. You must design a testing method.*

Design Thinking Problem #2

You are hired by a company that installs remote weather stations powered by photovoltaics. The company has many installations in New England, but they have recently been hired by Arizona to install weather stations there. You are given the task to investigate weather (including at least temperature) effects of photovoltaic output.

Design Thinking Problem #3

You work for a highway company. You were recently hired to produce this project in Houston, Texas by the Texas coastline. Your manager approaches you and tells you to figure out what the implications of this location might be on the materials of highways in this region.

Design Thinking Problem #4

You are a concerned student who came across this article titled "Your 3D printer is trying to kill you". You are asked to visit our college's new Innovation, Design and Applied Sciences (IDEAS) Hub and observe multiple 3D printers. Come up with a way to test your concern and then determine if this concern is reasonable.

Design Thinking Problem #5

You are a new engineer hired by Boeing. The avionics department wants to use a new environmental sensor package and needs you to verify that it functions accurate under various conditions. Design a platform to produce such testing.

Design Thinking Problem #6

You have been hired by SpaceX to design a cell culture device that can fit in a 3U CubeSat.

The last step in the course is for the students to go through the rest of the 10-step design process (7-10). It may not seem that the six final problems are related, but they were carefully selected so that each would require an environmentally controlled enclosure just like what was designed in the previous semester for the liver transport box. Therefore, for the rest of the course, we limit their design to this aspect and they go through the exact same 7-10 steps described for the liver box. The only difference being is that their size and temperature specifications may be different depending on the final problem they choose and lead to different design choices for their box design. The course will end with a summative direct assessment in which the student groups write a report and give a short oral presentation of their findings.

At the completion of the course the students will be surveyed again using an updated version of the survey that former students completed and the results will be analyzed to determine if the course was improved.

Conclusions

The revised (2020-2021) EAC Student Outcome Criterion 2 now requires 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." Further, EAC defines "engineering design" as being able "to identify opportunities". As such, at our institution we are beginning to have many of our engineering courses address "identifying opportunities" as an important and critical portion of each course's content. Toward this end we modified our initial freshman engineering course (Introduction to Engineering and Engineering Technology) to focus on design thinking. We accomplished this by first offering a two-week module dealing with the basic concepts of design thinking. This is then followed up by two design projects that require implementation of the design thinking process.

Our student indirect assessment results clearly demonstrate that students overwhelmingly agree that design thinking education is 1) a valuable learning experience and 2) it will be of assistance to them as they pursue their further engineering education. However, while about 75% of the students thought design thinking was helpful to them as they completed their two design projects they were not as positive with regard to the first project involving a "traffic study project". As a result, we are removing that project from the curriculum and have added replacement projects. We are sharing our findings to the entire college engineering faculty to further reinforce the need to include design thinking in all subsequent engineering courses.

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