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Design Across The Curriculum: An Evaluation Of Design Instruction in a New Mechanical Engineering Program.

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Introduction

Engineering design is a critical learning outcome for a mechanical engineering curriculum. The Accreditation Board for Engineering and Technology (ABET) requires accredited mechanical engineering programs to demonstrate that graduating students have "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." [1] Design has also been identified as a curricular pillar for modern engineering programs in recent reports such as in the "MIT Engineering Department Initiative on New Engineering Education Transformation Report".[2]

A recently created Mechanical Engineering program has emphasized the engineering design process in its curriculum. Currently, students are introduced to the design process in their first-year engineering course. This course challenges students to learn and apply the design process to a semester-long design project. Design is also reinforced in several courses during the students' sophomore and junior years with emphasis on different aspects of the design process. For example, in a course on Machine Design, students are given a design challenge where the focus is to apply analysis techniques for calculating the stress and identifying failure modes and choosing appropriate failure theories to analyze and to create a part that can endure the loads anticipated during use. In their senior year, students take a full-year Capstone design course sequence which serves as a culminating experience in engineering design and requires students to apply all of the knowledge and skills acquired during their studies to complete a sponsored design project.

This study has two main purposes: 1) to evaluate the effectiveness of the curriculum of a new Mechanical Engineering program in helping students to learn and apply the design process and 2) to investigate and propose a curricular strategy for improving design instruction across the curriculum. A survey of current students in all four years of the program is presented and discussed to assess the current state of design instruction and its effectiveness in student comprehension of the design process. Based on the survey assessment, a model for how to include and better reinforce the design process across the curriculum is proposed. This model will be implemented and evaluated in future works.

Program Description

This study focuses on evaluating how design is taught in a new mechanical engineering program. The program was created at Utah Valley University (UVU), a state institution that serves a unique dual-mission role in the state system as both a community college and four-year university. Under this dual mission, an associate of pre-engineering has been offered for several decades. The engineering offerings were expanded in 2018 with three new bachelor's degrees in mechanical, civil and electrical engineering. The curriculum of the mechanical engineering

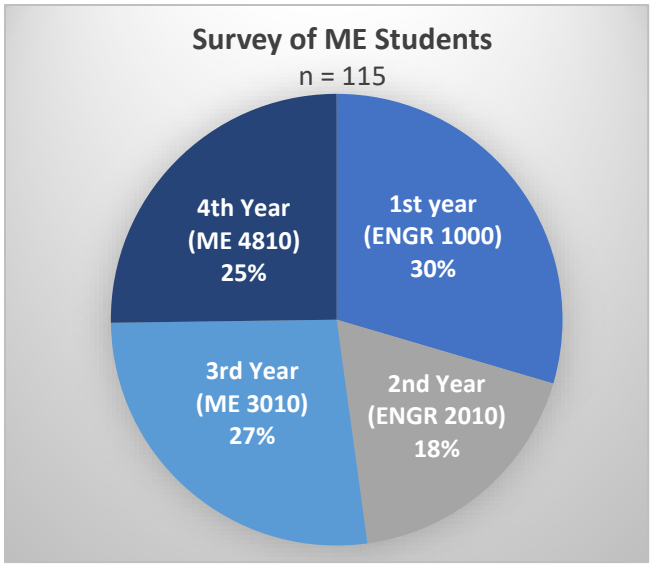

Figure 1: Summary of students surveyed

degree was initially created as a traditional program with the majority of the classes being 3 credit hours and requiring a total of 126 credits to complete the bachelor of Science in mechanical engineering. In the four-year program, 9 courses (27 credits) are lower-division engineering courses and 15 (41 credits) are upper-division with the remaining courses being math, science, and general education requirements. The design process is directly taught currently in the first year Introduction to Engineering course and the fourth year ME Capstone design class. Design is also taught through student projects in Engineering Programming, Machine Design, Automatic Controls, Computer Aided Engineering and in elective courses such as Kinematics and Compliant Mechanisms.

Design Process Survey

A survey was delivered to mechanical engineering students from each of the four years of the program. One course from each year of the program was selected to deliver the survey. These courses were Introduction to Engineering (1st year), Engineering Statics (2nd year), Linear Systems (3rd year), and ME Capstone (4th year). A total of 115 students completed the survey and were split evenly across all four courses as shown in Figure 1. Most of the survey questions asked students to respond using a 5-point Likert scale (strongly agree, agree, neutral, disagree, strongly disagree). The purpose of the survey questions was to evaluate students' perception of how well the design process was presented in their courses and if the design process was applied or used in their course. Also, one question asked students to simply write the steps of the engineering design process. The survey questions are included in the appendix.

Discussion of Survey Results

To better analyze and understand the collected data, the responses were separated out by program year and combined into positive, neutral, or negative responses to each question. Charts illustrating the collected data are shown in Figures 2-5 and will be discussed further in this section.

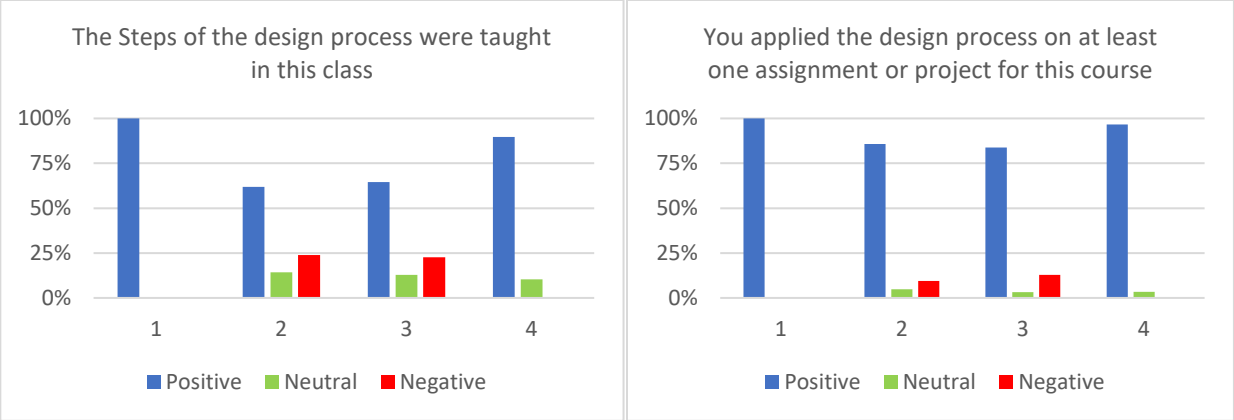

Figure 2: Survey questions related to the course content

Two of the survey questions directly asked the students about the course content. As expected, for the 1st and 4th year courses (Intro to Engineering and Capstone respectively), the vast majority of students stated the design process was taught and they applied the design process in that course. More surprisingly, a majority of students from Statics and Linear Systems also stated that the design process was formally taught in the course despite both courses focusing solely on modeling and analysis. Additionally, the Statics and Linear Systems students also started that they had applied the design process on at least one assignment or project. In Statics, no formal design problem or assignment was given, and in Linear Systems a group design project was given to the students, but did not require the students to complete the entire engineering design process.

Figure 3 presents the summary data from the question related to when the students had been taught the engineering design process. It was expected that the positive response rate would start out very low and increase for each year. While all students in the 2nd year should have responded in the affirmative, if the student had transferred from another school they would not have yet been exposed to the design process at UVU. This is fairly well matched by the data except for the 1st year responses. Half of the 1st year students stated that they had been taught the

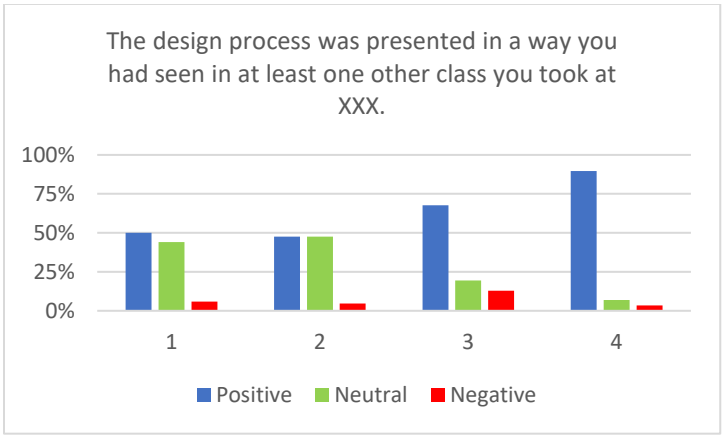

Figure 3: Student perceptions of when they had been taught the design process

design process previously, despite that course occurring in the first semester of the curriculum and is the only engineering course they would have taken at the university.

The students were also asked if the instructor explained the design process in a new way, and if they thought that new way was helpful to their learning (Figure 4). It was expected that the vast majority of 1st year and majority of 2nd year students would respond in the affirmative, which was how the students in those years responded. It was surprising to see over half of the seniors state that the design process was explained differently, especially when compared with Figure 3 where 90% of seniors stated the design process was taught in a manner which they had seen in a previous course.

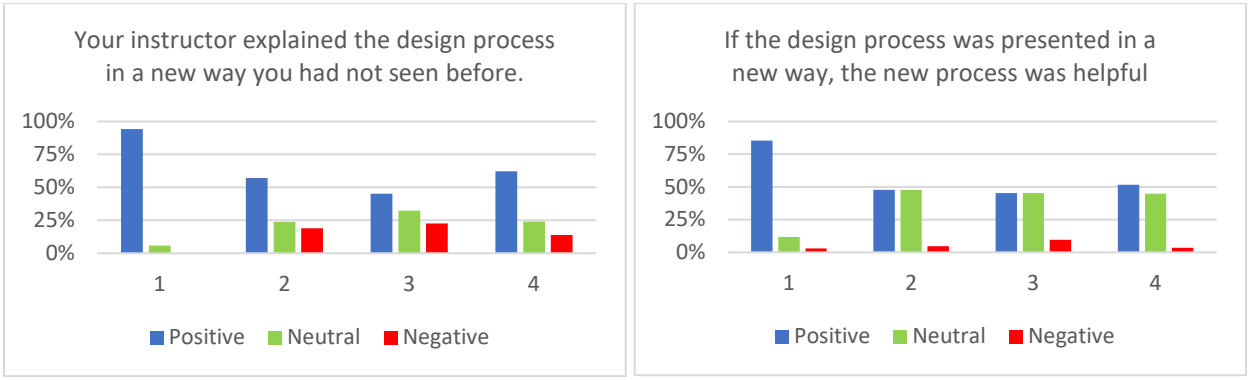

Figure 4: Student responses related to how the design process was taught

Lastly, the authors wanted to better understand the students' perceptions of their ability to apply the design process, in hopes that each year students would feel better prepared (Figure 5). However, the student responses would indicate that they do not feel any more or less prepared to apply the design process. Despite this confusion, the students did feel as though the design process was properly covered in their course.

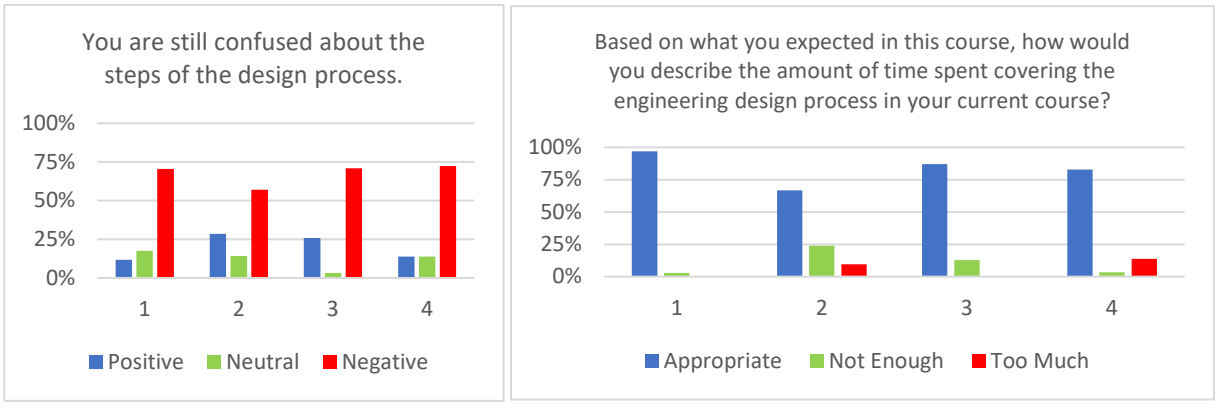

Figure 5: Students perceptions on their ability to apply the design process and if they were adequately prepared to do so

Proposed Curricular Strategy

From the survey results, it was observed that more could be done to provide better and more consistent instruction on the engineering design process. The goal is to identify or develop a standard design process that will be taught and applied across the mechanical engineering curriculum. As instructors teach engineering principles and assign students projects, they can tie these learning activities to this standard process. This will reinforce, not only the students' recall of the steps of the process, but also provide them with deeper understanding by applying the process and synthesizing problem solutions using this process.

Several definitions of the processes will be considered in developing or adopting a standard design process. The design process is taught in many different forms at every level of education. While the general method of the process is fairly consistent, sources will use different wording in describing the steps of the process and use varying levels of detail in explaining the process using as few as three steps or more than 10. For example, the National Aeronautics and Space Administration (NASA) has a simple, six step process that is provided as a resource for elementary or secondary educations students [3]. Some engineering programs have defined their own processes as part of an engineering design course [4] and [5]. The Design School of Stanford University (D.School) popularized the six-step, hexagonal design process shown in Figure 6 [6]. It is important to note that the D.School has since moved away from defining design in terms of steps or processes, and rather approaches design in terms of "8 core abilities" [7].

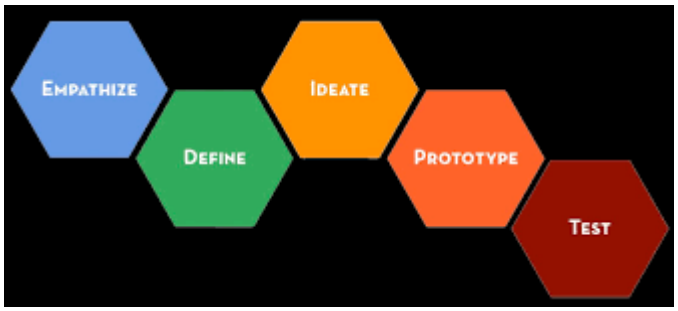

Figure 6: D.School six-step design process.

Another key component of the effort to improve engineering design instruction across the mechanical engineering curriculum is to identify and coordinate the design projects that students will complete throughout the program. Currently, the design process is taught in the 1st year, Introduction to Engineering class and in the 4th year ME Capstone Design course. Additionally, students complete design projects in courses such as Machine Design, Linear Systems and several technical elective courses. Department faculty will identify the projects they currently assign in their courses and how they relate to design. With this information, a determination will be made about which steps or aspects of the standard design process would be emphasized on that project. A chart can then be constructed to determine and assess where curricular improvements should be made.

Conclusion and Next Steps

This study presented the results of a student survey on the design process and explored how the results of this survey will inform future steps in improving the curriculum of a new mechanical engineering program with respect to design instruction. From the survey the following conclusions were drawn: 1) Students reported learning the design process in classes in which there was no formal instruction. This may indicate a lack of understanding on the part of students as to the meaning of design as a formal process. 2) Students reported learning different design processes in their courses than they had previously seen. This shows a lack of continuity and consistency in how the design process in taught across the curriculum. These conclusions will inform the exploration of curricular changes. Several examples of the design process were identified to be considered in developing or adopting a standard design process for inclusion in the program curriculum. Additionally, steps were outlined that will be taken to collect information from faculty in order to identify where and how design is currently taught in courses across the curriculum. This information will allow for evaluation and planning of curricular changes to improve the design instruction across the curriculum. A future study will report on the specific curricular changes made as a result of these efforts.

References

[1] "Criteria for Accrediting Engineering Programs, 2019 – 2020 | ABET." https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2019-2020/ (accessed Jan. 27, 2021).

[2] R. Graham, "Global state of the art in engineering education - March 2018," p. 170.

[3] S. May, "Engineering Design Process," *NASA*, Jul. 17, 2017. http://www.nasa.gov/audience/foreducators/best/edp.html (accessed Mar. 05, 2021).

[4] "MITESD_051JF12_Lec02.pdf." Accessed: Mar. 05, 2021. [Online]. Available: https://ocw.mit.edu/courses/engineering-systems-division/esd-051j-engineering-innovation-and-design-fall-2012/lecture-notes-and-videos/MITESD_051JF12_Lec02.pdf.

[5] "me-basic-design-process-r1-4-pdf.pdf." Accessed: Mar. 05, 2021. [Online]. Available: https://www.me.byu.edu/00000173-91ad-df84-a573-dffd43be0000/me-basic-design-process-r1-4-pdf.

[6] "The Design Thinking Process | Redesigning Theater." http://web.stanford.edu/group/cilab/cgi-bin/redesigningtheater/the-design-thinking-process/ (accessed Mar. 05, 2021).

[7] C. Carter, "Let's stop talking about THE design process," *Medium*, Oct. 11, 2016. https://medium.com/stanford-d-school/lets-stop-talking-about-the-design-process-7446e52c13e8 (accessed Mar. 05, 2021).

Appendix

Engineering Design Survey (Delivered via Google Forms)

Help us better understand your expereince with learning the engineering design process at UVU.

1. What is your major?
    a. Mechanical Engineering
    b. Civil Engineering
    c. Other…
2. Which year of the ME program are you currently in?
    a. 1st year (ENGR 1000)
    b. 2nd Year (ENGR 2010)
    c. 3rd Year (ME 3010)
    d. 4th Year (ME 4810)
3. Which of the following classes have you already taken **at UVU?**
    a. ENGR 1000 - Introduction to Engineering
    b. ENGR 2010 - Statics
    c. ME 3010 – Linear Systems
4. Had you learned the engineering design process prior to taking classes at UVU? If yes, where?
    a. Yes
    b. No
    c. Other…
5. List as many of the steps in the engineering design process that you can.
6. For the course you are currently in, how much do you agree with the following? (Likert)
    a. The steps of the design process were taught in this class.
    b. The design process was presented in a way you had seen in at least one other class you took at UVU.
    c. You applied the design process on at least one assignment or project for this course.
    d. Your instructor explained the design process in a new way you had not seen before.
    e. If the design process was presented in a new way, the new process was helpful.
    f. This class improved your understanding of the design process.
    g. You are still confused about the steps of the design process.
7. Based on what you expected in this course, how would you describe the amount of time spent covering the engineering design process in your current course?
    a. Not enough
    b. Appropriate amount
    c. Too much
8. True or False – I am better at utilizing the engineering design process after having taken this course?