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Board 136: Design-Thinking Abilities in Undergraduate Mechanical Engineering Students

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Design Thinking Abilities in Undergraduate Mechanical Engineering Students

INTRODUCTION

The typical engineering classroom utilizes lecture based lessons to transfer technical knowledge to students [1, 2]. A linear classroom approach such as this leads students down the same repeated path each time they approach a problem. Inside of the classroom this makes for an easy teaching plan and a step by step problem solving guide for students to follow [3]. Outside of the classroom however, this becomes an issue as engineering students have significant experience with the mathematical and scientific side of problem solving and little to no experience developing critical design thinking skills that can be applied to any range of problems. This lack of experience in design thinking can lead students to doubt their abilities and professional place in their industry [4, 5].

The problems presented to engineers in industry often cannot be solved using the familiar path taught in lecture. Thus, recently graduated engineering students who have learned solely through lecture based courses are underprepared for a career in engineering that utilizes creative design thinking on a day to day basis [4]. This study was founded on the strong disconnect between the implementation of engineering in a classroom and the design thinking skills demanded by industry from recent graduates. Though students may be underserved with the current implementation of lecture-based teaching tactics utilized in engineering classrooms across the country, identifying this issue is only half the battle. Engineering skills such as creativity, innovation, and design thinking are difficult to teach due to the lack of subject tangibility [6]. While the difficulty of teaching these skills is a large barrier [3], the goal of this project was to investigate what differences exist in the ways students of different class levels approach design problems. The focus of this study was on students' technical approach to design problems and what the participants perceive their own design abilities to be.

BACKGROUND

Research has shown that while freshmen and seniors in engineering programs understand both engineering knowledge and engineering as a profession, they struggle to understand how the two are connected [7]. Part of that disconnect is due to the lecture methodology implemented in engineering education, also commonly known as "chalk talk." Research has shown that this traditional lecture style of teaching is not as effective as student-centric learning, however it is still widely implemented [8].

Lecture based teaching has been considered the norm in STEM education, while liberal arts adopted the student-centric approach much earlier, allowing students to focus on 'understanding' the content rather than just 'knowing' the content [8]. The difference being that lecture based teaching tends to focus on theory and strict processes, limiting students to finding one particular 'right' answer. Active learning methods, such as flipped-classrooms, think-pair-share activities, and case study reflections, push students to defy their normal cognitive boundaries of what engineering "is" [9, 10]. This education method can ease the often frustrating transition that seniors experience -during capstone design courses where students are expected to translate isolated concepts learned in classrooms to suddenly very technically complex projects [11]. The frustration that students experience during these courses can have a negative impact on their self-perceived ability to be successful as engineers [5]. When students feel unprepared while problem solving it can cause them to doubt their abilities and ultimately not pursue an engineering career [11].

Research has shown that 96% of educators believe their students are ready for the workforce while only 11% of employers would agree [12]. Furthermore, a Kern Entrepreneurial Engineering Network (KEEN) partnered study cited that upon entering the workforce, students struggle with professional skills such as problem solving, critical thinking, and interpersonal skills [13]. To address this national narrative surrounding the employer, teacher, student disconnect, the American Society of Mechanical Engineers (ASME) created an action agenda focusing on creating a better future for mechanical engineering education through means of increased technical course depth, enriched practice-based experiences, and a deeper focus on improving professional skills before graduating [14]. Despite this amazing work, the best implementation and education strategies for properly preparing students for industry work are still unknown, leaving college educators at a teaching disadvantage, regardless of industry experience. The only thing that is certain is that students are unprepared [12].

Design experiences offer a solution to students' level of preparedness and have been proven to be effective in solidifying both student knowledge and preparedness for careers post graduation. Design experiences also offer students opportunities to prove their engineering competency and develop their passion. Despite these advantages that design courses offer, typically present in senior capstone courses, students can find these courses incredibly frustrating when their prior coursework leaves them feeling underprepared [4, 11].

Knowledge gaps such as those between industry leaders and educators were the driving forces for this study, where research was conducted to identify the knowledge that students are missing, preventing them from being career ready. This study tackled two overall research questions that aim to understand the design thinking ability of focus group populations: RQ1. What differences exist in the self-reported design thinking ability between freshman and senior mechanical engineering students? RQ2. What differences exist in the technical design abilities between freshman and senior mechanical engineering students? While it was interesting and valuable to learn what participants report as their own design abilities, the secondary purpose of RQ1 was to compare the self-reported design thinking ability with the results from RQ2, the observed technical design ability. These two research questions allow not only for an observation of the differences between studied populations, as the research questions state, but also insight into whether the participants have an accurate understanding of their own design thinking ability.

When observing the design processes of freshman and senior engineering students, a 1999 study reported the intuitive result of the senior students producing higher quality designs was present [15]. This was to be expected, as the students were able to implement what they have learned over their undergraduate degree. Another 2014 design thinking study focused solely on freshmen engineering students and observed that these freshmen focused primarily on the "making" stage of the design project, along with making sure they had a common understanding [16]. Notably, Swenson's coding scheme was utilized throughout this research.

METHODOLOGY

Study Settings and Participants

This research was approved under IRB #126-SB21-111, all researchers completed CITI Training for Social & Behavioral Researchers. The study had a total of 23 participants, broken down into 6 Freshmen, 7 Sophomores, and 10 Seniors. Each group had 2 or 3 participants, corresponding to 3 freshmen groups, 3 sophomore groups, and 4 senior groups. All participants were recruited through the university's engineering program over the course of two semesters: Fall 2021 and Spring 2022. Participants were recruited by members of the research team speaking during relevant classes and giving a general explanation of the project and expectations upon volunteering to participate. If students were interested, they were asked to sign a consent form either directly in class or via email. The classes that were spoken to were ME 187, Graphical Communication, for freshmen; ME 287, Design I with Lab, for sophomores; and ME 481 and 483, Senior Design I and II, for seniors. Each of these courses were required classes for mechanical engineering students at the university, which was why they were selected for recruitment. Students that chose to participate in the Fall 2021 semester were offered a small amount of extra credit if they participated in this project, with the exact amount of extra credit being determined by the teacher at the end of the semester. Extra credit for the Spring 2022 semester was up to the instructor's discretion.

Table 1: Participant demographics reported by population group

	Freshman	*Sophomore*	*Senior*
Gender: Male	50%	80%	80%
Nationality: Caucasian	83%	100%	100%
Average Age (years)	28.5	20.6	23.5

As reported in Table 1 the participant population was predominantly white males, with average ages relatively consistent with students who attend college immediately following high school. The freshman population was the most diverse of the participant groups in gender, nationality, and age. While the participant population was predominantly Caucasian and male, this was comparable to the approximate department history: 84% male, and 74% Caucasian.

The group design project, conducted via Zoom, lasted no more than 3 hours. Due to the ongoing COVID-19 precautions and campus rules, the projects were chosen to be conducted virtually. Groups were assigned based on each person's availability and consisted of either 2 or 3 participants from the same class standing. Student availability was determined through a Doodle poll, an online scheduling tool, that was distributed via email. Other than the original classroom pitch and the virtually synchronous design project, all communication with participants took place over email.

Data Collection

After completing the consent form, students were asked to respond to a survey and participate in a group design activity. Students were asked to complete the survey on their own time before participating in the group design activity. The 5 minute survey was distributed through Qualtrics XM, and evaluated the participants' self-perceived design thinking ability (Appendix A). This survey was selected as it was already validated [17], and it provided a comparison between students’ self-perceived design thinking ability, and their observed ability. Of the 14 questions on the survey, 9 of them were Likert style and required students to answer on a scale from Strongly Agree to Strongly Disagree. The 5 remaining demographic questions were utilized to understand what each participant pool looked like.

For each groups’ virtual design session, the only people who attended were the 2-3 participants and a researcher. At the start of each session, the researcher welcomed participants and asked for verbal consent to participate in the recorded meeting. After all participants consented, the researcher started the audio and visual recording. The researcher then read aloud an IRB approved script of the design problem statement and emailed students the project handout (Appendix B). The project description reads as follows: “There is a bunch of grapes on the edge of a counter in your kitchen. The grapes need to be moved to an open shelf located across a small gap from the counter. The scenario set up is seen in Fig. 1. Assume the depth out of the page of both the counter and the shelf to be 2 feet. The counter extends 5 feet to the left.”

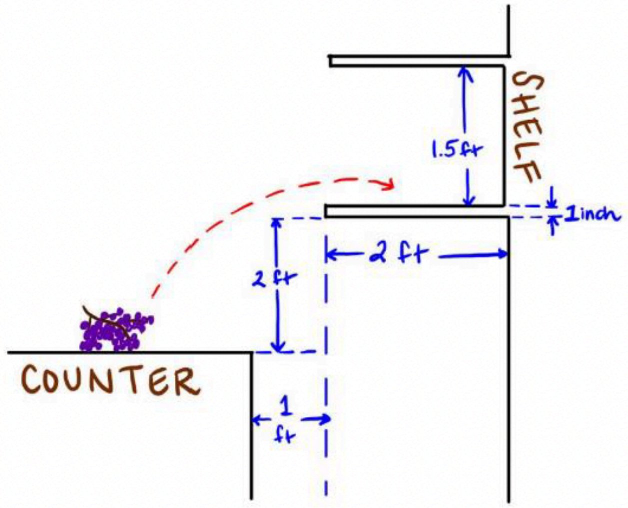

Figure 1: Schematic of problem statement including dimensions

The handout sent to participants included the project description, pictorial as seen in Fig. 1, a recommended budget of $150, and an explanation of their two deliverables. To be considered completed, the project group needed to email the researcher a detailed depiction of their design and a brief 1-page report explaining their design and why they chose it. The report was utilized by the research team to understand students' design solutions and thinking processes when later referring to their work. Participants were given a time limit of three hours, but were only required to stay for as long as it took to finish designing their project. While students were working, the researcher muted their mic and turned off their video and only unmuted when the participants had a direct question. After groups sent in their deliverables and receipt was confirmed, they were free to leave and their participation in the project was complete.

The project itself was developed by the research team and was designed to be a similar level of complexity to other sophomore-based design challenges. The project was intended to have a wide range of solutions so groups could design a solution based on the extent of their technical knowledge. The researchers worked with two design instructors to gauge whether this project would be appropriate for the entire group of participants.

Analysis

The five demographic questions required students to supply their name, relative course, age, gender identity, and nationality. Their name and relative course were utilized to verify that all participants were completing the survey in advance of the synchronous design project. The other demographic questions were used to describe each participant population, as previously stated. The remaining nine Likert-style questions were converted to numerical data points on the following 1-5 scale: Strongly Disagree becoming 1, Neutral becoming 3, and Strongly Agree becoming 5. This transition to numerical data allowed for the use of statistical methods to compare subgroups of the participants and better understand the responses.

The analysis of the synchronous design project meetings was much more complex. These meetings ranged from 1 hour and 22 minutes to 3 hours long, the amount of data transcribed from each of these sessions varied widely. As the recordings were conducted via Zoom, the Zoom software automatically transcribed the entire session and produced a transcript with statements attached to each participants' Zoom name. To ensure anonymity, each students' name was replaced with Student "X", where the X was replaced with numbers for freshmen, Greek letters for sophomores, and English letters for seniors. Pseudonyms were assigned based on when the groups completed their design project.

After obtaining the transcription, every statement was thematically coded based on Swenson's rubric, adapted from Atman and Wendell [16, 18, 19], which contains codes for Design Activities and Design-Related Conversational Moves. Using this list of codes, each statement was categorized into the code most associated with the student statement (Appendix C). The transcript also included timestamps associated with each statement, allowing for the time spent in each design activity to be calculated. The entire data set of transcripts was independently analyzed by two researchers, both using the same spreadsheet format of transcripts and the same thematic coding documentation. The thematic coding results for both researchers were very similar, with single digit differences in their total occurrences of each code per group. Given such small variations between both data sets, they were averaged for use reporting the results.

RESULTS

The data collected from the 9 Likert style survey questions were utilized in investigating Research Question 1 “What differences exist in the self-reported design thinking ability?” As seen in Fig. 2, the student population as a whole answered similarly, with most “Agreeing (4)” that they felt confident in their design thinking abilities. The only statement that had an average below “Neutral (3)” was a negatively phrased statement, meaning that the “Disagreement (2)” with the statement actually indicated confidence in their design thinking abilities. It is important to note that the freshmen participants often reported the most confidence in their design thinking abilities, as demonstrated by scoring the highest on most of the questions.

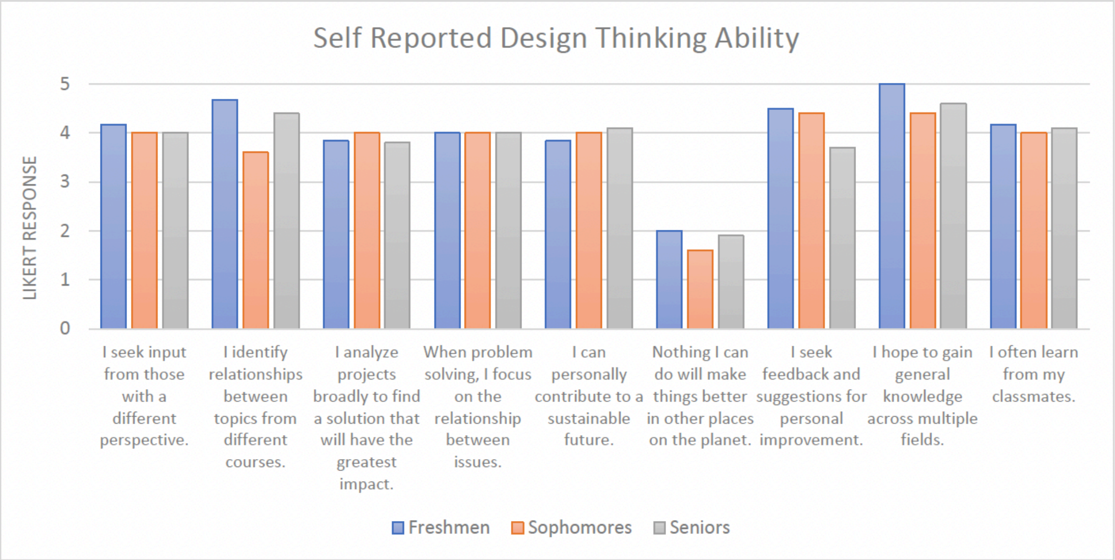

Figure 2: Likert responses of self-reported design thinking ability

The second research question of this study, “What differences exist in the technical design thinking ability?” aimed to investigate the technical or observed difference in the students’ design thinking abilities. This question was analyzed through the thematic coding of each statement made in the Zoom transcripts. There were an average of 689 statements per group session, with each ranging from 1 hour and 22 minutes to 2 hours and 58 minutes.

Figure 3 depicts a breakdown of the communication between group members per class standing. It can be seen that Freshmen spoke the least frequently, with approximately 4.8 statements per minute, and seniors spoke the most frequently, with approximately 5.6 statements per minute. These values were found by finding the average length of Zoom sessions and the average total number of statements for each population group. Each statement was approximately the same average length across groups, meaning that the number of statements can be correlated with the total time spent talking. While the seniors communicated most frequently and there was over an hour and a half in variation in the lengths of each session, the students were observed to still maintain the same ratio of time management.

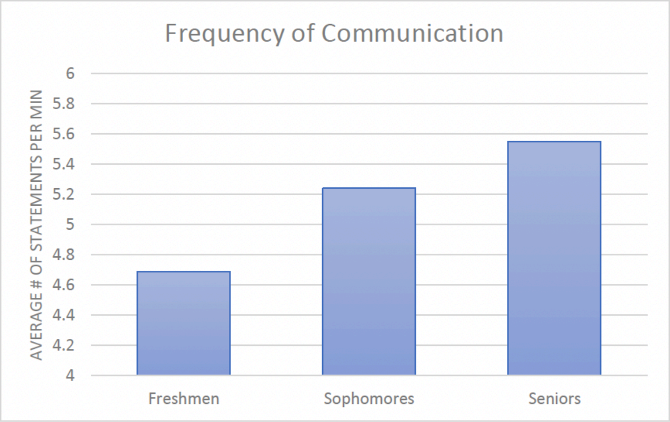

Figure 3: Average statements per minute for each population group

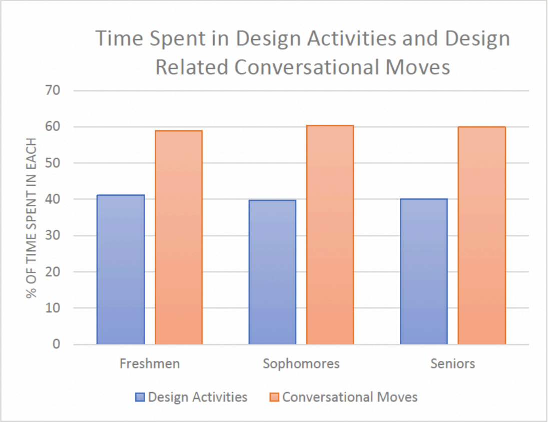

Figure 4: Percentage of time spent in each thematic coding category

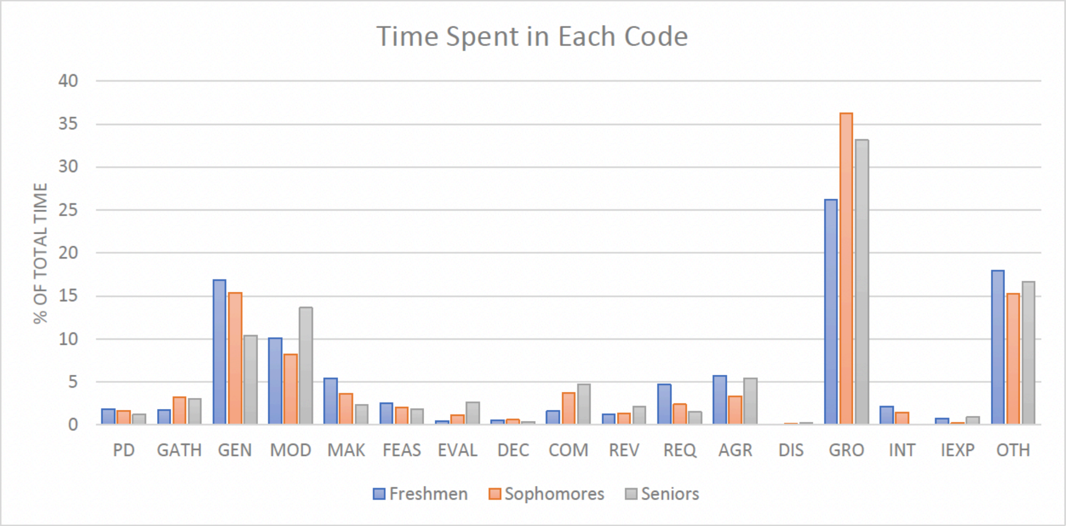

Figure 5: Percentage of time spent in each code

The thematic coding data was analyzed in two different ways: by each individual code and by the two categories of codes. The categories of codes can be seen in Fig. 4 and the individual codes can be seen in Fig. 5. The results from both analysis methods lack variation in each population. In Fig. 4, all three population groups spent approximately the same 40% 60% split regardless of class standing. Figure 5 illustrates that all three populations spent most of their time in three codes: Group Discussion (DR), Generate Ideas (DA), and Other (DR). The code "Other" was generally used to categorize side conversations by the participants that were unrelated to the problem statement, each group spent between 15 and 20% of their time holding outside conversations on topics such as current classes, friends, jobs, and more.

An additional code with significant results is the code Disagree (DR), as neither group spent more than 1% of their statements in that theme. This is to be compared to the code Agree

(DR), where groups spent between 3% and 6% of their statements. It cannot be determined why the participants had little disagreement, as it could be from a multitude of sources including that they were all simply on the same page, they wanted to speed through the assignment, or they feared speaking up to their group members.

While quantitatively there were a lot of similarities between class standings, it is important to also observationally compare the complexity of the submitted projects. Figures 6, 7, and 8 below showcase designs from freshmen, sophomore, and senior groups, respectively. Here, it can be seen that students increase their technical knowledge and written communication ability as they progress through their classes.

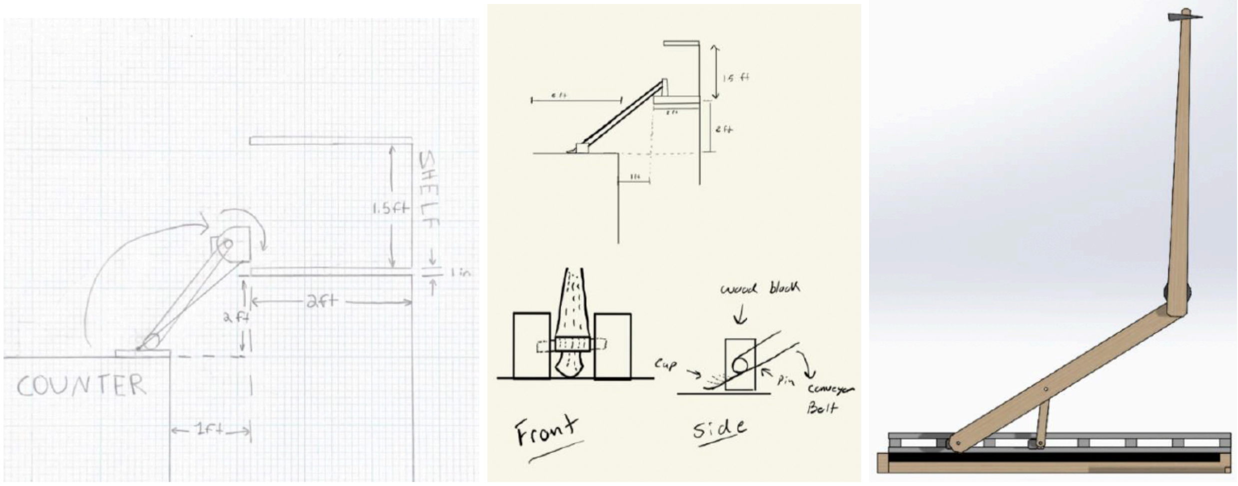

Figure 6 (left), 7 (middle), 8 (right): Designs from freshmen, sophomore, and senior teams.

CONCLUSION

Survey results revealed students' self-perceived design thinking ability was in line with their actual design thinking ability, as students were generally confident in their skills, and all teams submitted designs of some degree of complexity. Their technical knowledge also proved in line with their experience level, as the designs submitted by seniors were more technically advanced and used more complex systems to solve the given problem.

Intuitively it would seem that the seniors would have the most confidence given that they are finishing their degree and moving into the workforce within the current, or following, semester. However, survey results revealed that seniors were less confident than the freshmen, but still more confident than the sophomores. This can be interpreted to mean that students are coming in very confident in their design thinking abilities, losing confidence as they dive deeper into their coursework, and regaining confidence over the remaining years of their degree. This interpretation is consistent with the general stereotype and experience of challenging STEM (Science, Technology, Engineering and Mathematics) degrees, where students come in quite confident and then are drained by higher level courses. By the end of their degree, students often have had internships, research opportunities, and/or project experiences that rebuild their confidence in their skills through real-world applications.

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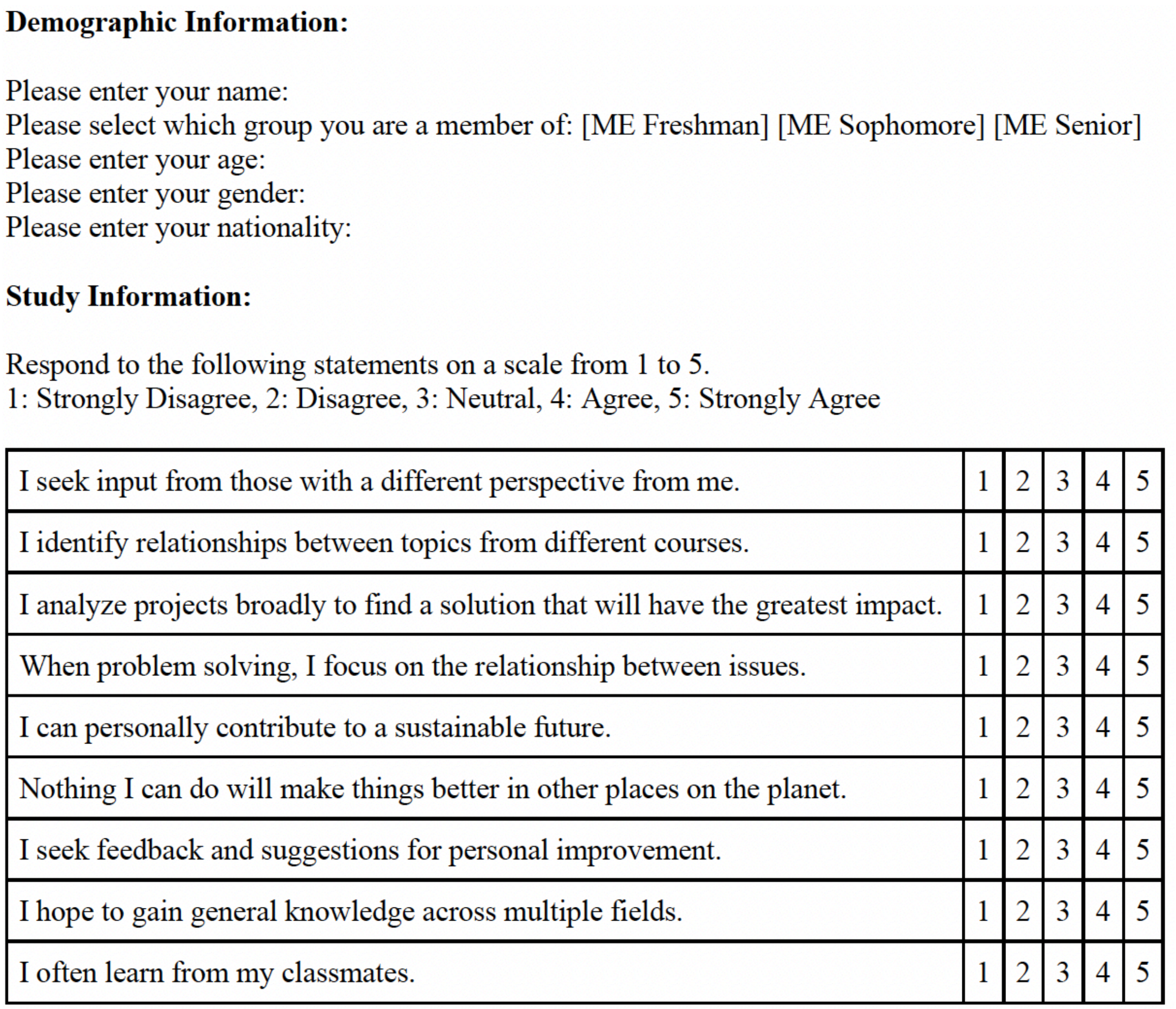
Appendix A

Survey questions drawn from Blizzard (2015). Survey was translated to a Qualtrics survey for ease of use by participants, and a consent to participate was placed at the start.



Demographic Information:

Please enter your name:
Please select which group you are a member of: [ME Freshman] [ME Sophomore] [ME Senior]
Please enter your age:
Please enter your gender:
Please enter your nationality:

Study Information:

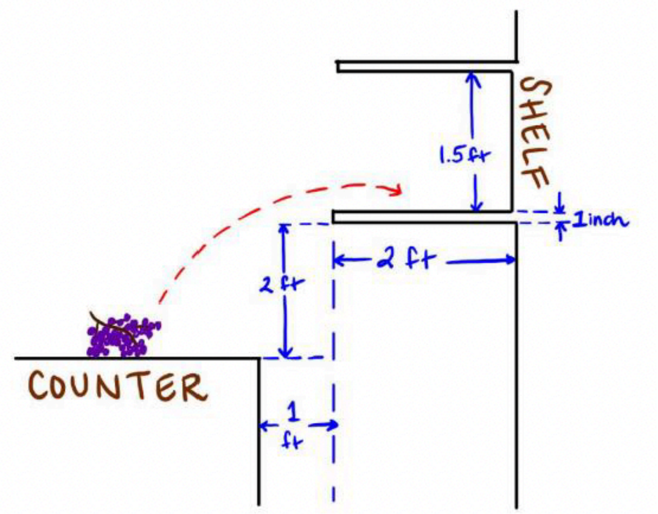
Respond to the following statements on a scale from 1 to 5.
1: Strongly Disagree, 2: Disagree, 3: Neutral, 4: Agree, 5: Strongly Agree

I seek input from those with a different perspective from me.	1	2	3	4	5
I identify relationships between topics from different courses.	1	2	3	4	5
I analyze projects broadly to find a solution that will have the greatest impact.	1	2	3	4	5
When problem solving, I focus on the relationship between issues.	1	2	3	4	5
I can personally contribute to a sustainable future.	1	2	3	4	5
Nothing I can do will make things better in other places on the planet.	1	2	3	4	5
I seek feedback and suggestions for personal improvement.	1	2	3	4	5
I hope to gain general knowledge across multiple fields.	1	2	3	4	5
I often learn from my classmates.	1	2	3	4	5

Appendix B

The following is the entirety of the handout given to participants during synchronous zoom sessions. Students were also given SolidWorks models of both the counter and grapes in case they wished to use them.

PROBLEM SCENARIO: There is a bunch of grapes on the edge of a counter in your kitchen. The grapes need to be moved to an open shelf located across a small gap from the counter. The scenario set up is seen below. Assume the depth out of the page of both the counter and the shelf to be 2 feet. The counter extends 5 feet to the left.



TASK: Your task is to move the grapes onto the shelf without damaging the grapes or dropping any on the floor. You cannot simply pick up the grapes yourself and move them. You can only touch the grapes while they are sitting on the counter, as soon as the grapes are not touching the counter you cannot be touching them.

CONSTRAINTS:

- Budget: Approximately $150.
- Size: Your design has to have a footprint that fits on the counter.

DELIVERABLES - email to samanthaschauer@u.boisestate.edu:

- Submit your **completed design** at the end of 3 hours
  - There are no requirements for what this submission looks like, so long as it is a visual representation of your design and it is clear how your design works. This could be a detailed and annotated sketch, a 3D model, etc.
- Submit a **report (roughly 1 page)** describing how your product works, and why you selected that design.
  - This is meant to be used as a reference for the PI to understand your design and thinking throughout the data analysis process.
  - Please include a list of the materials you know are needed (Bill of Materials).

MATERIALS & TIPS

- No restriction on internet access. However, please do not simply copy a pre-existing solution if you find one.
- You have access to any programs at your disposal, or physical items laying around for prototyping.
  - Students: https://www.boisestate.edu/coen-its/aws-appstream-at-coen/ for virtual access to programs through COEN computer lab.
  - Google files are great for collaboration online. Google Jamboard will allow you to draw freely if you like.

Appendix C

Design Activity Codes

Code	Name	Definition	Example from Prior Report
PD	Problem Definition	Defining what the problem really is by re-stating the problem statement, identifying criteria and constraints, or re-framing the problem.	"Are we even allowed to use this many pieces?"
GATH	Gather Information	Stating the need for, searching for, asking for, or collecting additional information needed to solve the problem.	"I mean, we can test the shade because if we have the, look, if we have the shade. We'll check, we'll test it."
GEN	Generate Ideas	Stating Potential solutions (or parts of potential solutions) to the problem, and playing with and fleshing out those ideas. Involves the use of tentative language and suggestive tone.	"Um, let's see, if we do it this way we can reinforce the top more but it's harder if its over out here, you know."
MOD	Modeling	Detailing how to build the tentative or final solution (or parts of the solution) to the problem. Involves making estimates, calculations, or fitting an element into the overall design. Building or making should be coded MAK.	"Yeah, you need this curved in, not out."
MAK	Making	Discussing making and building without reference to conceptual design ideas. Includes placing and finding pieces while building, or taking and out pieces of code.	"We can use these black pegs."
FEAS	Feasibility Analysis	Passing judement on whether a possible or planned solution to the problem (or parts of the problem) will function and meet the problem's criteria and constraints.	"Actually, I don't know if that's gonna work because sometimes the little pegs like come through."

EVAL	Evaluation	Comparing and contrasting alternative solutions or solution elements, along a particular dimension such as strength or cost. Also, testing a design, making observations about it's performance, and accessing results.	"I think that's just too heavy."
DEC	Decision	Selecting one solution to the problem (or parts of the problem) from among those considered, or eliminating a design option or explicitly changing one's mind about the problem.	"We actually don't even need the backwards loops. So we can actually take that out."
COM	Communication	Communicating to external parties (professors and teaching assistants) the elements of the design via oral discussion or physical presentation, deciding upon design, via sketches, diagrams, lists, or oral or written reports.	To the professor "No, um it's LoggerPro, but we're using LabVIEW for human factors. We have a LabVIEW thing. Ummmm..."

Design Related Conversational Moves

Code	Name	Definition	Example From Prior Report
REV	Revoicing	Restating one's own or other's idea related to the engineering task to affirm or check understanding.	Speaker 1: "FYI, it's not a uniform circle whatsoever." Speaker 2: "Really, it's totally irregular?" Speaier 1: "It's like egg-shaped."
REQ	Request	Requesting further clarification about an idea, model, design detail, or a response from others about an idea; *not used for requests abou instructor's intent.*	"So you want it behind the wheels?"
AGR	Agreement	Without restating, acknowledging understanding of an idea or expressing favorable response. *If favorable response labels a particular discussion of the problem, should be coded EVAL.*	"Yeah, that's true, yeah."

DIS	Disagreement	Expressing disagreement with other's statement or general unfavorable response to an idea, without feasibility analysis.	"Uhh I don't think so…"
GRO	Group Discussion	Conversational moves within the group. Specifically transitions, planning, and asking questions (but not requesting information).	"We will be testing in 2 seconds."
INT	Instructor's Intent	Discussion of the instructional requirements rather than the engineering task; request for clarification about what the instructor has assigned.	"Okay. Let's check. Does anybody have the paper? Oh wait we didn't have instructions."
IEXP	Instructor Explanation	The instructor explaining a concept, their understanding of a design, or any other relevant comments by the instructor.	"Right, right. So somehow you're sending a value to port 3 which is getting driven to this and you're sending to mailbox 2 a new value which is getting driven into this."
OTH	Other	Conversation not relevant to the problem being solved; none of the other codes apply.	"This is gonna be so hard."