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Design-learning Preferences of First-year Electrical and Computer Engineering Students

Dr. Christopher D. Schmitz, University of Illinois at Urbana Champaign

Christopher D. Schmitz was born in Pana, Illinois in 1969. An Electrical Engineer, he received his BS with University Honors in 1993 and his MS in the area of algorithmic fault-tolerant adaptive systems in 1996 from the University of Illinois. He completed his Ph.D. in the area of multi-user cellular communication in 2002 from the University of Illinois.

He worked for TRW Space and Electronics Group from 1995 until 1997 and at the University of Illinois from 2002 to present. His research interests are in adaptive digital signal processing, digital communications, and education pedagogy. He currently serves the ECE department of the University of Illinois as a Teaching Associate Professor and an undergraduate advisor and is working to improve undergraduate education as an Education Innovation Fellow (EIF) in the Grainger College of Engineering.

Mr. Jake Fava, Siebel Center for Design

Jake is a Design Strategist at the University of Illinois at Urbana-Champaign's Siebel Center for Design, working to integrate human-centered design education into curricula across campus.

Ms. Sneha Subramanian, Siebel Center for Design

Sneha Subramanian is a Design Fellow at the Siebel Center for Design. Her work is primarily focused on design strategy and research.

Design Learning Preferences of First-Year Electrical and Computer Engineering Students - Work in Progress

Purpose

The individuals that apply to and attend engineering post-secondary institutions are a part of a rapidly changing and highly-diverse group. If we develop a deeper understanding of today's engineering students - what motivates them, what interests them, and what's important to them - we can use that knowledge to help inform their experiences. Engineering programs certainly have specific objectives and requirements to fulfill - these should remain their primary focus. Understanding student desires could instead be applied towards guiding students to seek out opportunities that align with their goals, as well as providing personalized experiences (wherever possible) to maximize student learning and growth.

The goal of this research is to begin to construct a profile of the different types of engineering students in regards to engineering design experiences. Through a combination of qualitative and quantitative methods, this research seeks to identify key attitudes and beliefs that separate one type of student from another. Additionally, the research team hopes to identify where and how (if at all) human-centered design methodologies could be integrated into curricular design experiences and which students would benefit most from them.

Background

This research is being conducted in partnership between Dr. Christopher D. Schmitz, a professor in the electrical and computer engineering department at the University of Illinois at Urbana-Champaign, and the Siebel Center for Design, a new design center focused on bringing human-centered design to UIUC. Dr. Schmitz teaches an introductory electrical engineering course ("ECE 110 - Introduction to Electronics") that is required for students in the department (often taken within the first year in the program) and for a select few outside of it. The course serves as a basic introduction to simple electronic circuits and how to build them.

In addition to three hour-long lectures each week, students in ECE 110 attend a weekly three-hour lab session, where they work on a series of guided projects exploring topics they're learning in lecture using components in a personal required lab kit. In past semesters, the final project of the course has been an open-ended design project where students are encouraged to create something using the concepts learned throughout the course. However, curricular limitations as a result of the ongoing COVID-19 pandemic have forced the final project to be more narrow in scope the past two semesters. ECE 110 was selected for this study since it is one of the only courses in the curriculum that (normally) contains an open-ended design project, and also because a large portion of the students in the course are first-year students within the

department. Analyzing this group will give the research team a better idea of the attitudes and beliefs students are coming into the program with.

Design Projects and Creativity in Engineering Curriculum

Striking a balance between teaching the technical fundamentals and allowing engineering students to explore creative projects is a constant struggle for many institutions. One study analyzed a massive sample of syllabi from electrical engineering classes and concluded that the curricula did not support students' creativity and innovation [1]. Design experiences are often delayed until later in the curriculum, with the belief that students need more time to develop a foundational understanding of the science before moving on to design [2].

Despite this, the literature suggests that many engineering students have a desire to explore these creative design experiences. Multiple studies indicate students wish they could spend more time working on projects instead of preparing for and taking exams [2][3]. Students are often under a large amount of pressure to succeed - this compounded with professor attitudes around assessment and project expectations can lead students to be especially risk-averse, stifling their creativity [4]. This lack of opportunity for creative expression can have measurable effects on retention of students, as one study showed that students who considered themselves having high creativity were more likely to drop out of their engineering programs before graduating [5].

Students themselves also have their own attitudes and perceptions of design in engineering. Studies have explored the different ways students identify what an engineer does, and how much students see themselves as belonging to that group [3]. Studies indicate creative design projects are often highly-associated with what students believe engineers "really do" [4].

In the cases where creativity is involved, divergent thinking is often emphasized over convergent thinking [6] even though both types of thinking are an important part of creativity and human-centered design. Incorporating human-centered design has been shown to help engineering students learn to co-construct prototypes and understand viewpoints other than their own [7]. Certain engineering students who are very motivated to help people and are interested in practicing human-centered design, but they do not often get the chance to work on projects where they can interact directly with their intended user groups [8]. Some students pursue an engineering degree because they want to help others by working on positive social impact projects. Introducing human-centered design to these engineering students will give them a skillset that can help them achieve their goals.

Research Questions

As a result of reviewing existing literature, the following research questions were developed to guide the study.

- What motivates students to pursue a degree in electrical or computer engineering?
- What expectations do students come into the program with, and how are those expectations formed?
- Are the current curricular offerings meeting those expectations?
- What are the most important aspects of a design experience to ECE students?
- How can human-centered design be incorporated into the curriculum so that it benefits students and develops skills needed after graduating from college?

Methods

- Data Collection

This study uses both qualitative and quantitative methods to collect data.

For the qualitative component of this study, students majoring in electrical engineering or computer engineering were interviewed by the research team. These students were recruited to participate in this study from the introductory electrical engineering class and the electrical and computer engineering department as a whole. Each interview consisted of an hour-long, in-depth virtual conversation with two members of the research team. These conversations were guided by a series of open-ended, neutral questions related to their attitudes around and experiences with engineering design. A copy of the interview guide is attached in the appendix.

A message and video was disseminated in both the introductory class (during lab sessions) and to the student body as whole containing information about the study and how to participate. Students who self-selected to participate signed up for an interview slot that worked with their schedule.

The first round of interviews was conducted in the Fall of 2020. 5 students were interviewed - 3 from the introductory electronics course, and 2 from the rest of the engineering student body. The second round of interviews \were conducted in the Spring of 2021. For this round, the recruitment strategy was updated to include a $10 gift card incentive for students participating in the interviews. The research team has interviewed 7 additional students this Spring.

For the quantitative component of this study, students in the introductory electrical engineering class of the Spring semester of 2021 were administered a survey at the beginning of the class about their attitudes and experiences with various aspects of engineering design. The survey consists primarily of validated items from several published papers in addition to a few

questions designed by the research team. Survey questions include a few qualitative short answer questions and quantitative questions that have students rank their attitudes and abilities A complete list of survey items and references is included in the appendix. This survey was not required for students to complete, but they did receive extra credit in the course for completing it. Students who completed the survey were then asked to consent to have their responses released to the research team. Students who consented have had their responses anonymized, and no one on the course staff for the introductory electrical engineering course will know who consented and who didn't. The survey data will be analyzed over Summer 2021.

Throughout the semester, students in the course completed a series of modules related to various aspects of human-centered design. At the end of the semester, students completed the same survey to see if their experiences in the class led to any sort of shift in their responses.

- Data Analysis

Interview data is currently being analyzed through a multi-step qualitative analysis process. During the interview, one or both research team members took highly-detailed and extensive notes, doing their best to capture as many direct quotes as possible. After each interview, a debrief process is conducted, where research team members recount the interview together and document their notes in a collaborative virtual whiteboard space, writing one thought or quote on each post-it.

Once notes have been transferred to the board, thematic analysis is next. Research team members categorized post-its based on trends and patterns that are appearing across multiple interviews. These emergent groupings become themes, and the team looks at these areas more closely - what commonalities have been observed? What key differences? To what extent do we know why these similarities and differences exist?

The final step is the abstract analysis, where frameworks are developed to visually display findings in an easily digestible format. An early framework is contained below in the preliminary findings section.

Survey data has not yet been analyzed, on account of the post-survey data being collected right at the end of the semester and needing more time to complete a full statistical analysis. However, once data is available for analysis from the surveys, it’s function will be two-fold: first, looking at the pre-survey alone to see if we notice any particular trends across the responses of students coming into the course, and next, comparing responses across the pre- and the post- surveys to see if student attitudes and beliefs change after their experiences in the course.

This iteration of the survey was developed before the interview analysis was as far along as it is now, so the categories on the survey don't necessarily match up 1:1 to the categories identified in the preliminary findings, but the questions asked will still give us insight into students' attitudes and desires.

Preliminary Findings

This section will include an early analysis of the 5 interviews that were conducted in the Fall of 2020 as well as the 7 interviews conducted in the Spring of 2021. Those interviewees and their pseudonyms are detailed below.

TABLE I
FALL 2020 INTERVIEWEES

Pseudonym	**Profile**
Aang	Female, third-year computer engineering student from the US west coast
Zuko	Female, third-year computer engineering student from the US midwest
Katara	Male, first-year electrical engineering student from the US midwest
Toph	Male, first-year electrical engineering student originally from country in Asia; completed high school in US northeast
Momo	Female, first-year electrical engineering student from country in Asia

TABLE II
SPRING 2021 INTERVIEWEES

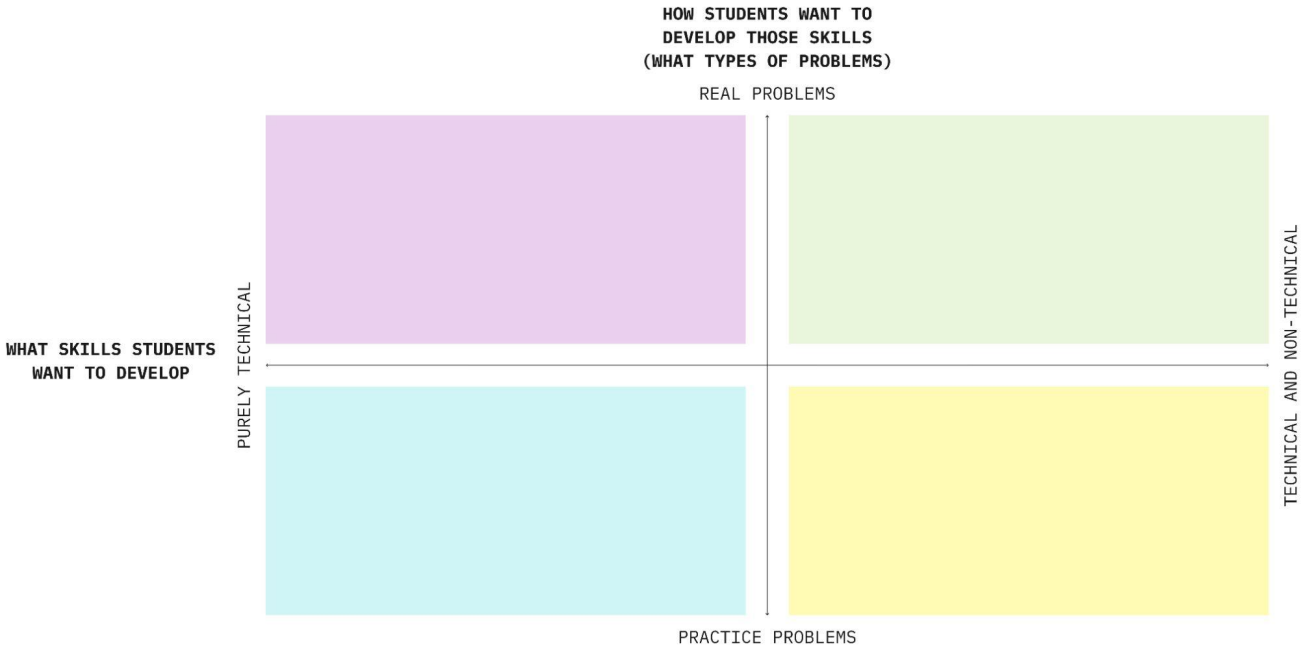
Pseudonym	**Profile**

Roku	Female, first-year electrical engineering student from the US west coast
Azula	Male, first-year computer engineering student from the US midwest
Haru	Female, first-year computer engineering student from the US midwest
Jet	Male, first-year computer engineering student from the US south
Sozin	Male, first-year computer engineering student from the US south
Ozai	Male, first-year undeclared engineering student originally from a country in South America ; completed high school in US midwest
Suki	Male, first-year computer engineering student from the US northeast

As this research continues, the team is searching for ways to represent their evolving understanding using visual frameworks. An early concept for one such framework that seeks to capture student learning preferences is explored below.

FIGURE I

ENGINEERING STUDENT LEARNING PREFERENCE MATRIX



This matrix captures two key ways attitudes differ between students, identified through the interviews conducted thus far. One differentiator (captured above on the x-axis) has to do with ***what*** skills students hope to develop during their time in the program, while the other (captured on the y-axis) has to do with ***how*** students prefer to be developing those skills.

- The "What" - Student Skill Development Priorities

One clear divide in the attitudes of students we interviewed had to do with what skills they wanted to prioritize developing during their time in the program. All the students we spoke with acknowledged that the primary purpose of engineering education is to develop technical skills and knowledge, but many students also saw a lot of value in developing non-technical, "soft" skills (such as presentation and collaboration skills), and even expressed the desire to have more of this skill development integrated into their curricular experiences.

TABLE III
NON-TECHNICAL SKILLS QUOTES (MATRIX RIGHT HEMISPHERE)

Pseudonym	**Quote**
Jet	*"I do definitely feel like it's important to explore non-technical stuff like teamwork, division of [labor] within projects… the courses I've taken so far haven't been super effective in doing that."*
Zuko	*"How is it acceptable for us to not communicate with each other? ...when we go into industry, it's a very collaborative process"*
Aang	*"Being able to talk about technical achievements to a non-technical audience… [that] would be a good thing to sneakily put into the curriculum… I hate working with people that only know technical things... it's such a drag"*
Katara	*"One of the greatest things an engineer can do is convincing people."*
Sozin	*"Empathy is very important for engineers to have… communication is another big one… Just in general, being willing to think from a perspective that doesn't match your own."*

Students interested in developing non-technical skills through class experiences are those who

see these skills as integral to their success in their future endeavors. Some students are interested in entrepreneurship, or at least being able to develop and pursue self-selected creative projects, and see presentation ability as a vital skill for communicating and getting support for their ideas. These students also identify non-technical skills as being key to both getting a job in industry and being successful on that job.

One interesting note - a few students expressed disappointment or frustration with classmates that they perceived to be less interested in developing non-technical skills. We heard about experiences with this "uncooperative engineering student" - someone who prefers to work on their own so much so that it makes collaboration on group projects extremely difficult - from multiple students.

On the flip-side, we also heard the opposite perspective from some students. These individuals tend to recognize the importance of non-technical skill development, but see it as something that happens naturally as a result of life experience, and not something that needs to be prioritized in curricular experiences.

TABLE IV
PURELY-TECHNICAL SKILLS QUOTES (MATRIX LEFT HEMISPHERE)

Pseudonym	**Quote**
Roku	*"It's easier to develop soft skills… not every class needs to focus on collaboration because that is something we learned on our own as children."*
Ozai	*"In theory, [learning presentation skills in class] sounds like a great thing, but I don't think that's an effective way of teaching people… you have to learn by doing that sort of thing."*
Toph	*"Non-technical skills are important… [but] I think having a lot of technical classes is necessary and required… [electrical engineering] is kind of a new field."*

Some of these students emphasize that they see the role of the engineer in the design process being confined to the technical aspects, so it makes sense that technical ability is their top priority. Others acknowledge the importance of non-technical skills, but would rather focus on technical skills right now, and worry about other skills later on.

- The "How" - Student Learning Experience Preferences

The other axis of the matrix above attempts to capture another key distinction between students - how they prefer design experiences to be framed in order to maximize their interest levels and learning retention. Many students express a strong desire to work on projects that they consider to be closer to what "real-world" projects look like - open-ended prompts around complex and meaningful problems.

TABLE V
REAL PROBLEMS QUOTES (MATRIX UPPER HEMISPHERE)

Pseudonym	**Quote**
Aang	*"I like doing things that weren't exercises and projects that were given to me… I prefer figuring things out on my own… I like things like the [introductory electronics course] open-ended final project."*
Katara	*"I wish we had more opportunity to design our own thing... you build something they tell you what to build… You can't really design something for a problem that doesn't exist."*
Toph	*"If I'm not creative, I'm just like another person on the production line… a good engineer has to be creative and come up with new ways to solve a problem"*
Jet	*"Having more open space in the project for how you could approach it would be more useful… it's really easy to be given a project with one answer and a bunch of steps to get to that answer…. But I do understand the professor's reasoning with starting small - I'm just hungry for the real world [problems]."*
Sozin	*"I want class projects challenging enough to push us to break out of the boundaries of what we've learned in the class…. You can have creativity and still have guidelines to help students get comfortable with what they're learning."*

These students often consider themselves highly creative, and are likely motivated (at least in part) to pursue engineering out of a desire to create a positive impact in the world.

Interesting to note, however, is that the students on the opposite end of this spectrum that we spoke with also universally expressed interest in making a positive impact, and some of them even mentioned a preference for open-ended problems. However, these students felt that their current skills were inadequate to pursue this type of project in class at this time. Instead, these students expressed a desire to pursue these opportunities later on in or beyond their

college careers.

TABLE VI
PRACTICE PROBLEMS QUOTES (MATRIX LOWER HEMISPHERE)

Pseudonym	**Quote**
Momo	*"I'd like it if I had more choice into the projects I want to work on… but it is important to give students the option of choice to a certain limit - it might be unfair to students if it was totally open"*
Azula	*"I really like what Solar Car does - giving students free reign to work on the problem… but in classes, initially I wouldn't want to get a very broad problem and figure it out, especially in intro courses."*
Haru	*"So far we've just been doing the lab procedures… for now, I'm completely fine with just doing lab stuff… eventually [I'll be ready], just not right now."*
Suki	*"To be honest, don't think that in the first few years of college, any project you do as a final project for a class is going to be super innovative and applicable to the real world."*

Reasons for this attitude are varied - one student (Haru) had very little exposure to circuit design before college, and they explained that completing the procedural labs in the introductory course was already difficult enough; attempting an open-ended project appeared to be a daunting challenge to them. Another student (Suki) told us that they viewed their college years as training, and that working on open-ended, real-world problems is something reserved for post-college. While another student (Roku) also viewed real-world problems as being reserved for post-college, their reasoning had to do with a concern for responsibility of the potential impact.

Other students expressed a general fear that these types of problems could be too challenging for them or other students in an introductory course to approach. The vast amount of uncertainty surrounding the scoping, implementation, and assessment of such a project can make students resistant to wanting to explore these challenges.

Preliminary Discussion

As the qualitative understanding develops, the research team hopes to identify other key differentiating factors between engineering students that might be useful for guiding recommendations and personalizing experiences. Expanding on the ***what*** and ***how*** captured in

the above matrix, other spectra or segmentations could exist around ***why*** students choose to pursue degrees in engineering, as well as what skills students currently have and how confident they are in their own skills.

The end goal of the qualitative analysis is to find ways to use the categorizations and differentiators identified in the research to provide more personalized experiences to students. At a basic level, this could include providing recommendations for courses and extracurricular experiences that align with student interests and desires (for example, steering students interested in working on real problems towards relevant student organizations, or helping students interested in developing non-technical skills select elective courses that teach them). At a deeper level, this understanding could be used to provide personalized experiences within a course (in the form of optional tracks/modules) or even to help guide the evolution of curricular priorities and offerings based on overarching student desires.

The quantitative component of the research, once completed and analyzed, will hopefully offer valuable insight into the prevalence of these different attitudes. What fractions of electrical and computer engineering students represent the different types of students we characterized here? The pre- and post-surveys administered in the introductory electrical engineering class will give us a glimpse into what attitudes students have coming into the course as well as how those attitudes change (if at all) in response to the human-centered design modules being introduced this semester.

The ultimate goal for the insights gathered from synthesizing both the qualitative and quantitative data from this study is to understand the gaps that exist between engineering student desires and existing curricular offerings, and how human-centered design can be best integrated to help fill some of those gaps (if at all). The research should help us identify who would benefit most from this integration (what type(s) of students) and when in the 4-year curriculum it would benefit them most.

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Appendix A

INTERVIEW GUIDE

- Introductions
  - Ourselves
  - This project
- Get-to-know-you
  - What year in school are you?
  - Where are you from?
  - What factors contributed to you coming to UIUC?
  - Why did you choose ECE?
    - What do you hope to do with your degree after you graduate?
    - What experiences do you plan to take advantage of during your time here to help move you towards that goal?
- Design
  - In your own words, what is "design" as it relates to engineering?
  - In your opinion, what should the role of an engineer be in the design process?
  -
  - In your opinion, is it important for an engineer to interface directly with a person they're designing something for? Why or why not?
  - In your opinion, is it important for engineering courses to explore topics that aren't just technical? Why or why not?
    - If so, what topics or concepts come to mind?
  - What's important for you to have in a class project?
    - Creativity/freedom to explore?
      - Freedom of choice?
    - Connection to a real-world problem?
    - Working in multidisciplinary teams?
- Remote Learning
  - What has been the most unexpected part of remote learning this semester?
  - What's the biggest challenge of remote learning that you're experiencing?
- ECE

110 Lab

- What has your experience been with ECE 110 labs so far?
- Do you feel like the remote lab experience is meeting your needs?
  - If not, how do you wish it were improved?

○ Future Career

- What do you hope to do with your degree after you graduate? ■ How do you stay connected with your motivation/purpose for choosing engineering?
- From your perspective, what do you think is most important to recruiters looking to hire engineering students or graduates?
- Is there anything you wish your program did differently to help prepare you for life after your degree?

Appendix B

SURVEY QUESTIONS

Demographics

a. Name
b. Semester in School
c. Age (optional)
d. Gender

Section I: Understanding of Human-Centered Design
Please answer the following questions in 1-3 sentences.

Survey questions created by the research team

a. What definition would you give for "Human-Centered Design"?
b. Do you have any past experiences with the concept of Human-Centered Design? i. If you have past experiences with Human-Centered Design, describe processes or practices you have implemented during these experiences.
c. How do you see human-centered design (as you understand it) playing a role, if any, in engineering projects?

Section II: HCD taxonomy

Survey questions created by research team

#	**Item**	Very Poor (don't know)	Poor	Fair	Good	Excellent
1	When working on a project I am comfortable documenting my biases, assumptions, and predictions.	1	2	3	4	5
2	As I work on a project, I actively reflect on my biases, assumptions, and predictions.	1	2	3	4	5
3	I am comfortable generating potential solutions to a problem.	1	2	3	4	5
4	In design, I know how to generate multiple alternative solutions.	1	2	3	4	5
5	I know how to develop a plan of action that outlines next steps and possible challenges.	1	2	3	4	5
6	I know how to create a prototype.	1	2	3	4	5
7	I know how to communicate the details of a completed design project.	1	2	3	4	5

Section III: HCD outcomes/mindsets

Survey questions taken from [9]

When working in groups, I tend to	Never	Not Very Often	Sometimes	Quite Often	Always
1. Provide emotional support to my group members	1	2	3	4	5
2. Remind the group how important it is to stick to schedules	1	2	3	4	5
3. Be sensitive to the feelings of people	1	2	3	4	5
4. Show that I care about my group members	1	2	3	4	5
5. Be open and supportive when communicating with others	1	2	3	4	5

Section IV: Communicative Mindset

Survey questions taken from [10]

	Very easy for me	Somewhat easy for me	Did not do this/not applicable to my project	Somewhat challenging for me	Very challenging for me
1. Effectively presenting a design orally (ex. clear, audible, well-paced, natural)	1	2	3	4	5
2. Finishing a technical report or oral presentation within an allotted	1	2	3	4	5

time.					
3. Presenting information in a logical and organized way	1	2	3	4	5
4. Tailoring technical reports/presentations to the target audience.	1	2	3	4	5

Section V:
For each of the following items, rate how much you agree with each statement,

Survey questions taken from [11]

	Strongly Disagree	Somewhat Disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
1. Creativity is important to the engineering process	1	2	3	4	5
2. The role of engineers is limited to technical problem solving	1	2	3	4	5
3. Collaboration and teamwork are essential components of the engineering process.	1	2	3	4	5
4. Ethical problem solving is an important part of engineering design.	1	2	3	4	5

Section VI:
For each of the following items, rate how much you agree with each statement

Survey questions taken from [12]

	Strongly Disagree	Somewhat Strongly Disagree	Somewhat disagree	Somewhat agree	Somewhat Strongly agree	Strongly Agree
1. Solving a challenging engineering problem is rewarding	1	2	3	4	5	6
2. I like engineering design projects	1	2	3	4	5	6
3. I would like to design new products to make peoples' lives more convenient	1	2	3	4	5	6
4. I would like to play a role in advanced technology development in the future.	1	2	3	4	5	6
5. I would like to have a career involving innovative engineering products design.	1	2	3	4	5	6