Engineering Educators Bringing the World Together
2025 ASEE Annual Conference & Exposition
Palais des congrès de Montréal, Montréal, QC • June 22–25, 2025
Paper ID #48323

BOARD # 49: Defining Design: How Undergraduate Civil Engineering Students Think of Design

Aja Rachel Bettencourt-Mccarthy, University of Cincinnati

Aja Bettencourt-McCarthy is the Science & Engineering Global Services Librarian at the University of Cincinnati. Prior to joining the faculty at the University of Cincinnati, Aja was the STEM Instruction Librarian at the University of Kentucky Libraries and the Head of Public Services at the Oregon Institute of Technology Library. Aja earned an MLIS degree from the University of Washington and a Bachelor of Arts & Sciences in French and Community and Regional Development from UC Davis.

Dr. Matthew Sleep, University of Cincinnati

Matthew Sleep is an Associate Professor Educator at the University of Cincinnati in the Civil and Architectural Engineering and Construction Management Department.

Work in Progress Defining Design: How Undergraduate Civil Engineering Students Think of Design

Engineering design is a critical element of undergraduate engineering programs and is an integral criterion in ABET assessment. Despite being a foundational element of engineering instruction, there is no single definition of design in engineering and the definitions of engineering design have shifted over time. In addition, while scholars and accrediting bodies have worked to define engineering design, the extent to which these definitions reflect the students' understanding of engineering design is less clear. This paper aims to provide insight into student perceptions of design by discussing the results of a survey that asked both first year and capstone undergraduate civil engineering students to identify the components of several design and engineering design definitions that resonated most strongly with their experience and understanding of engineering as a profession. In addition to sharing the results of this study, we review the literature on ways to expand student understanding of engineering design and provide recommendations, along with areas for future research, for civil engineering.

Introduction

Design is a core component of engineering practice and education. Scholars [1], [2], [3], accrediting bodies [4], and professional associations all highlight the centrality of design to engineering. In addition, ASCE whose *Civil Engineering Body of Knowledge* lists design as one of the core aspects of the profession and further states that design is the "essence" of civil engineering practice [5]. In 1985 the Engineering Directorate at the National Science Foundation (NSF) launched a program with the aim of developing a theoretical foundation and generalizable principles for engineering design [6]. Since then, and despite evidence of maturity in engineering design theory and methods [7], [8], there remains a lack of consensus around a singular, lasting definition of engineering design for the field as a whole [9]. Instead, there continues to be variation in approaches to engineering design that reflect different philosophies [10], [11] with organizations and researchers having developed their own definitions and typologies. Many of these are summarized by Erbuomwan, Sivaloganathan, and Jebb [10] and Howard, Culley, and Dekoninck [12] who focus on the range of engineering design processes.

In addition to the absence of a field-wide consensus on the definition of engineering design, engineering students' understanding of engineering design has been understudied. Past engineering education research has sought to better understand students' perceptions of engineering and engineering work [13], [14]. These studies consistently show that students believe design to be a core component of engineering practice [7], [13], [15] across a range of engineering disciplines and educational experience. Yet they fail to specifically address the ways in which students understand the concept. More information about students' understanding of design is crucial because, as Walker and King [1] note, mis-conceptualizations of design or the design process could negatively impact students' workplace performance. In addition, including student perspectives in the discussion of a definition of engineering design is necessary if the aim is to create a shared understanding [15].

Methodology

A survey was used to gather data to help answer the question of how students in the first and fifth years of a civil engineering program view the importance of engineering design and their perceptions of the concept. A survey was selected for its ability to collect a range of data from a large sample of students in a relatively compressed time frame.

Study Design

Students were given the opportunity to participate in the short survey during class time. The IRB-approved survey drew from past research on student definitions of engineering concepts by including an open-ended question that asked students to define engineering design in their own words [7], [15], [16]. To augment this qualitative data, students were also asked about their educational and co-op experience, to assess their familiarity with engineering design on a scale of zero to one hundred, and to rank the extent to which they felt design was valuable in engineering using a Likert scale. Students then ranked thirteen engineering design concepts developed from the definition of engineering design used by ABET [4] (Table 1).

Table 1. Components of engineering design as summarized in the survey

Iteration	Idea Generation
Disciplinary Knowledge	Testing
Creativity	Empathy
Problem Definition	Optimization
Prototyping	Problem Selection
Communication	Requirements Development
Stakeholder Input	

The ABET definition was selected as the basis for the development of the survey given its role in guiding undergraduate curriculum development and program accreditation. In addition, this definition was written to apply across a wide range of institutions and engineering programs and reflects concepts from other commonly used educational resources [17]. The authors used terms pulled directly from the definition as well as those that summarized additional core concepts referenced in the paragraph-long statement. For example, the terms ‘empathy’ and ‘communication’ are listed to summarize the user-centered components of the engineering design implicit throughout the definition from “meet desired needs” to “obtaining a high-quality solution under the given circumstances” [4].

Data Collection

The survey was shared with a required civil engineering first-year seminar course and a required civil engineering senior capstone course during the 2024-25 academic year. Across both classes, 101 students participated in the survey with slightly more participants at the capstone level (Table 2).

Table 2. Survey participation by time in college

	Total Class Size	# of Survey Respondents	Participation Rate	Year at the University of Cincinnati						
				1st	2nd	3rd	4th	5th	6th	No Response
First Year Class	98	49	50%	45	0	0	0	0	0	4
Capstone Class	56	52	92.86%	0	0	0	2	47	1	2

Surveyed students were either in their first year of study at the University of Cincinnati or in their fifth year with a small minority of students in the capstone class in their fourth and sixth years. The capstone course distribution is expected. Since multiple experiential co-op experiences are a requirement at the University of Cincinnati, the curriculum is designed for students to complete the program in 5 years rather than the more typical 4-year engineering program.

Data Analysis

Data from the survey were first separated by course and analyzed separately. After the initial analysis, a comparative analysis was conducted to determine if there were any differences between students' perception of engineering design between their first year and capstone course.

The results of the open-ended question, "In your own words, what is engineering design?" were analyzed using word counts and word clouds. The data was cleaned by removing prepositions, conjunctions, etc. as well as the terms 'design' and 'engineering.' In addition, correlational analysis was conducted to connect the responses to knowledge of engineering design to the ranking of the thirteen terms associated with engineering design.

In addition, statistical analysis was used to analyze the results of the qualitative survey data and to make comparisons between first- and fifth-year students' responses. Responses to two questions, "On a scale of 0- 100 with 0 being not at all and 100 being very knowledgeable, how would you describe your knowledge of engineering design?" and "How important do you think design is for Civil Engineers?" were analyzed. To test for normality, a Shapiro-Wilk normality test [18] was conducted. This test indicated that the first-year student data was not normally distributed. Thus, to compare means of the data sets, a Mann-Whitney U test [19] was conducted to determine whether there were meaningful differences in the means of the two data sets.

Results

The results of the survey include findings about both first year and capstone students as well as interesting information gained from comparing the responses between groups.

Open-Ended Responses

The word clouds presented in Figure 1 were created using words with frequencies greater than one.

1st Year Students' Response Capstone Students' Response

Figure 1. Students' response to, "In your own words, what is engineering design?"

The word clouds and frequencies (Table 3), demonstrate that both student groups believe that engineering design addresses 'problems' with 'solutions/solving.' Both also see engineering design as a 'process'.

Table 3. Word Counts of Figure 1

1st Year Course (CVE 1100)		Capstone Course (CVE 5002)	
Word	**Frequency**	**Word**	**Frequency**
process	9	solution	8
creating	7	problem	8
something	6	process	8
problem	6	creating	6
solve	4	problems	5

Interestingly, the word clouds show that fifth year students used the term 'need' in their descriptions of engineering design while this term was absent from any first-year student responses.

First year responses

In response to the questions about knowledge and importance of engineering design, first-year students gave themselves an average score of 51.5 out of 100 (Figure 2) on their knowledge of engineering design and most indicated it was 'very important' to civil engineering.

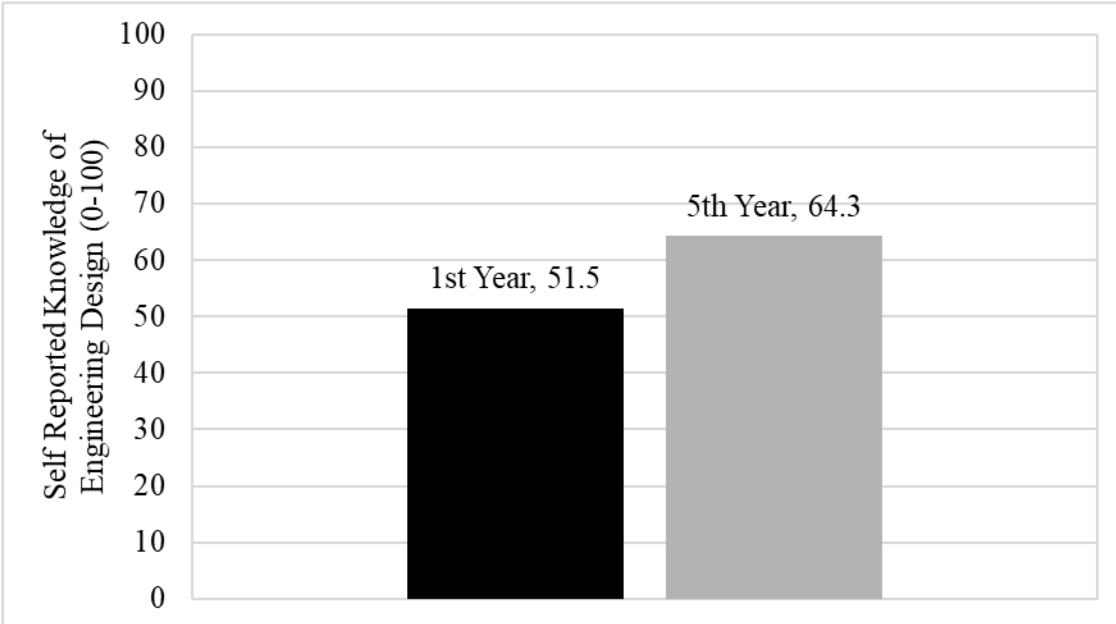

Figure 2. Self-Reported knowledge of engineering design of 1st and 5th year (capstone) civil engineering students

They also ranked 'disciplinary knowledge' highest and 'iteration' lowest among the engineering terms provided. For first-year students, relatively mild positive correlations were found (coefficients of 0.20 and 0.17) between student knowledge of engineering design and the terms 'testing' and 'problem selection.' More significant were the negative correlations (coefficients of -0.30 and -0.28) between perceived knowledge of engineering design and the terms 'optimization' and 'prototyping', respectively. In other words, if a student reported higher knowledge of engineering design, they found 'testing' and 'problem selection' to be the most important terms and were less likely to find the terms 'optimization' and 'prototyping' as relevant. Testing of designs is necessary for optimization so the large difference between a positive correlation for testing and a negative correlation of optimization might be a result of 1st year students' inexperience with engineering design.

Capstone responses

On average, capstone students gave themselves a 64.3 (Figure 2) score out of 100 on their knowledge of engineering design and most indicated it was 'very important' to civil engineering. When ranking engineering design terms in order of their importance, on average the most highly ranked term was 'problem definition' and lowest ranked term was 'prototyping.' For capstone students, relatively mild positive correlations were found (coefficients of 0.15 and 0.14) between their knowledge of engineering design and the terms 'testing' and 'idea generation.' More significant were the negative correlations (coefficients of -0.24 and -0.17) between perceived knowledge of engineering design and the terms 'prototyping' and 'communication', respectively. In other words, if a student reported higher knowledge of engineering design, they found ‘testing’ and ‘idea generation’ to be the most important terms and were less likely to find the terms ‘communication’ and ‘prototyping’ as relevant. It is notable that capstone students with higher perceived knowledge of engineering design had a positive correlation to testing but a negative correlation to prototyping which is similar to the positive correlation of testing and negative correlation to prototyping found with first-year students. One explanation for the persistence of this correlation might be the difference between the civil engineering curriculum and that of other engineering disciplines which, given the smaller scale of many of their designs, place more emphasis on prototyping.

Importance and Knowledge Comparisons

With a p value of 0.011 ($p<0.05$), the fifth-year responses of self-reported knowledge of engineering design are meaningfully different than the first-year responses. First year students reported an average value of 51.5 while 5th year students reported an average value of 64.3 indicating that students had a higher perception of their knowledge of engineering design as they progress through the civil engineering program.

A similar test was conducted on the responses to the question, “How important do you think design is for Civil Engineers?” The result of a Mann-Whitney U test was a p value of 0.174 ($p>0.05$) indicating that there is no statistically significant difference between first- and fifth-year student responses to the question at the 95% confidence level. So, while students reported an increase in perceived knowledge of engineering design as they progress in the curriculum, there was not a statistically significant difference in their reported perception of the importance of engineering design (Table 4).

Table 4. Comparison of 1st year and capstone student responses to importance and knowledge of engineering design in Civil Engineering

	"How important do you think design is for Civil Engineers?"	“On a scale of 0- 100 with 0 being not at all and 100 being very knowledgeable, how would you describe your knowledge of engineering design?”
1st Year vs. Capstone	Statistically **same** response	Statistically **different** response

Term Ranking Comparisons

Comparing the ranking of engineering design terms between first year and capstone students shows that there are differences between the relative importance that each group assigns to these terms. Table 5 shows the rankings of the thirteen terms associated with engineering design and described by ABET [4] for both the first- and fifth-year students.

Table 5. Results of 1st and capstone civil engineering students' rankings of engineering design terms from ABET

1st Year	
Rank	Term
1	Disciplinary Knowledge
2	Creativity
3	Idea Generation
4	Problem Definition
5	Communication
6	Prototyping
7	Requirements Development
8	Problem Selection
9	Testing
10	Optimization
11	Stakeholder Input
12	Empathy
13	Iteration

Capstone	
Rank	Term
1	Problem Definition
2	Communication
3	Stakeholder Input
4	Disciplinary Knowledge
5	Problem Selection
6	Idea Generation
7	Requirements Development
8	Optimization
9	Testing
10	Creativity
11	Iteration
12	Empathy
13	Prototyping

In addition, Figure 3 shows the difference in ranking position between each of the terms. A bar to the left indicates that the term was more important (ranked higher) for first-year students and a bar to the right indicates the term was less important (ranked lower) for fifth-year students. For example, 'creativity' was ranked 8 positions higher among first-year students as opposed to fifth-year students. The same can be said for 'stakeholder input' which ranked 8 positions higher for fifth-year students as opposed to first-year students.

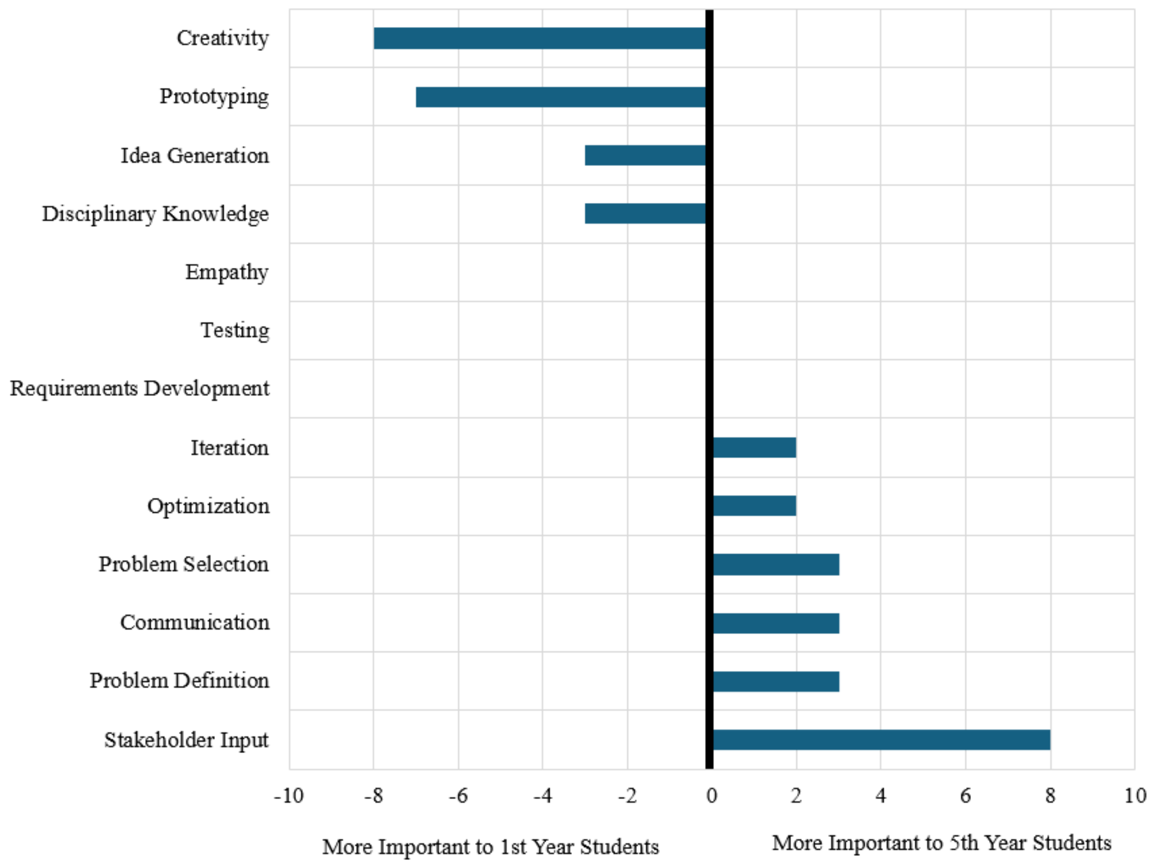

Figure 3. The differences in term ranking for engineering design between 1st and 5th year (capstone) students

These differences indicate that students' perception of engineering design might change as they progress through a civil engineering program. For example, first-year students have what may be considered a more object-oriented view of engineering design based on the higher ranking they gave to the terms creativity and prototyping. Capstone students, on the other hand, ranked stakeholder input and problem definition significantly higher than first-year students raising the question of whether student progress through the civil engineering curriculum changes their design focus to become more human-centered.

Conclusions and Discussion

The data collected and analyzed as a part of this study attempt to answer the question: How do students in the first and fifth years of a civil engineering program self-analyze the importance of design in engineering and what are their perceptions of engineering design as a concept? In addition, when analyzing the data we discovered significant differences between the responses from first year and capstone students.

Students' level of perceived knowledge of engineering design was significantly higher among students in the capstone course which is expected given that these students have received more instruction on engineering design than those in their first year. Interestingly, there was no statistically significant difference between the way the two student groups viewed the importance of engineering design to civil engineering. Both groups indicated that they perceive engineering design as 'very important' which is consistent with previous research on student definitions of design [7], [13], [15] and indicates that challenges students face with engineering design are unlikely to be due to a perceived lack of relevance to the field.

When asked to rank the importance of terms associated with engineering design, first-year students rated 'disciplinary knowledge', 'creativity, and 'idea generation' as most important while fifth-year students rated 'problem definition', 'communication', and 'stakeholder input' as most important. Another area of discrepancy between the way first and fifth year students ranked concepts associated with engineering design was higher rating, among first year students of 'creativity' and 'prototyping'. Capstone students, meanwhile, rated 'stakeholder input' and 'problem identification' more highly. While there was a lack of overlap between these selections, when students were asked to define engineering design in their own words, both first year and capstone students focused on 'problems,' solutions,' and 'process'. Capstone students' free-text responses did differ from those of first year students, however, in that they described more instances of 'need.' These results highlight the similarities and differences in responses between these two groups and raises the question of whether students' understanding of engineering design changes as they progress through an undergraduate civil engineering program.

The authors hypothesize that difference in responses between these two groups may be the result of civil engineering students at the University of Cincinnati having a required college-wide first year engineering course experience that may highlight individual components of the design process while capstone students are exposed to human-centered design during their capstone design sequence where they are required to conduct a stakeholder analysis. In addition, capstone civil engineering students at the University of Cincinnati have gained experience from 4-5 semesters of co-op experiential learning by the time they're enrolled in the capstone sequence and therefore might be more aware that engineering design work for civil engineers is primarily focused on large, infrastructure projects as opposed to traditional prototyping and the development of models. Additional research is required to better understand why 'creativity' is perceived so differently between these two groups of students, though these results align with previous research that highlights that there is room for additional skill development around creativity in engineering [3] and that in some cases, divergent thinking and creativity stagnate rather than grow in engineering programs [20].

Limitations & Future Research

The primary limitation of this study was the small sample size which provides a necessarily limited snapshot of the students' understanding of the definition of engineering design. In addition, all data were collected from a single institution so results may not be generalizable to civil engineering students more broadly. Future research in this area could help to further refine our understanding of civil engineering students' perceptions of engineering design. Conducting longitudinal studies or similar studies of midcareer students would provide a more detailed picture of the ways in which definitions of design change across a students' course career. Doing so with additional attention dedicated to past and concurrent course work as well as co-op and internship experience might help to surface and solidify connections between student responses and educational and work experiences. Finally, the definition of engineering design in the ABET criteria is one of several that civil engineering students might encounter. Expanding this research to include students' reactions to a variety of different definitions might provide additional insight into student understanding of engineering design.

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