Definitions of Design: A shifting narrative from first to final year in a civil engineering program

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Design is a significant component of undergraduate engineering programs as evidenced by the central role it plays in both curricula and ABET assessment. While scholars and organizations have proposed a range of definitions, there remains a lack of consensus around a single, universally understood, definition of engineering design. The ways in which engineering students conceptualize design have also not been fully explored. This paper aims to fill this gap by summarizing two years of survey data where students were asked to explore their perceptions of engineering design. The data from first year and capstone civil engineering undergraduate students indicates that students' understanding of engineering design undergoes a predictable shift over the course of the undergraduate experience. Specifically, first year engineering students emphasized creativity and prototyping while capstone students tended to highlight human-centered components including problem definition and stakeholder input.

Introduction

Design is consistently emphasized as a central component to both engineering practice and engineering education. Multiple authorities including scholars [1], [2], [3], accrediting bodies – including ABET [4] in the United States and CEAB [5] in Canada - and professional associations highlight the importance of design to engineering. For example, the American Society of Civil Engineering (ASCE) places design as one of the core components of the profession and states that it is the "essence" of the practice of civil engineering [6].

Despite its importance, engineering design continues to lack a uniform definition [7]. In 1985 the Engineering Directorate at the National Science Foundation (NSF) undertook an effort to develop a unified theoretical foundation and principles for engineering design [8] but these efforts fell short of yielding widely accepted results. While theory and methods around engineering design have evolved and matured [9], [10], various approaches and definitions persist reflecting a range of philosophies [11], [12] and approaches. Erbuomwan, Sivaloganathan, and Jebb [11] and Howard, Culley and Dekoninck [13] summarize some of these while Chong et. al. [5] highlight the ways that even engineering textbooks vary in their presentation of engineering design concepts.

It is also unclear how these different definitions of engineering design impact students' understanding of the concept. Studies of student perceptions of engineering and engineering work [14], [15] regularly demonstrate that students across a range of disciplines and educational experience see engineering design as a core aspect of the field [9], [14], [16] . Missing from these studies is a deeper look into the ways in which students conceptualize engineering design.

This study aims to elucidate the ways in which civil engineering students think about engineering design and to better understand whether their perspectives change over the course of their undergraduate educational career.

Methodology

Surveys were used to gather data from civil engineering students in both first year and capstone courses over the course of two academic years. A mixed methods survey was selected to facilitate the collection of rich data from many students in a short period of time.

Study Context

Study participants were students enrolled in required first year and capstone civil engineering courses at large, R-1 university. Students in the first year course did not receive any formal introduction to civil engineering design as part of the course prior to the survey but were simultaneously enrolled in a first year engineering course sequence common to all engineering students at the University of Cincinnati which includes design as one of many curricular components. Students in the capstone course were actively engaged in a team design project at the time of the survey. In addition, most students were in their fifth year of a five-year program which includes four semesters of engineering co-op work experience.

Study Design

Surveys were designed to gather qualitative and quantitative data related to students' definitions of engineering design. After initial questions about educational and co-op experience, students were asked to rate both their familiarity with engineering design and the extent to which they consider engineering design to be an important part of engineering. Then, drawing on past research into student perceptions of engineering concepts [9], [16], [17], students were asked to define engineering design in their own words. Finally, the survey prompted students to rank thirteen engineering design concepts (Table 1). These concepts were synthesized by the authors from the longer and broad definition of engineering design developed by ABET [4].

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 [4] was selected from the range of engineering design definitions discussed above due to its role in guiding curriculum development and education across American undergraduate engineering programs and because it reflects many of the concepts commonly present in other definitions [18]. When developing the survey, the authors used terms pulled directly from ABET as well as some that exemplified core concepts [19].

Data Collection

Surveys were shared with two required civil engineering courses during the 2024-25 and 2025-26 academic year. Across the study period, 127 first-year students and 97 fifth-year students responded to the survey with slightly higher participation rates among capstone students (Table 2).

Table 1. 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
2024 1st Year Class	98	49	50%	45	0	0	0	0	0	4
2024 Capstone Class	56	52	93%	0	0	0	2	47	1	2
2025 1st Year Class	106	78	74%	76	1	1	0	0	0	0
2025 Capstone Class	52	45	87%	0	0	0	4	35	6	0

Survey participants were either in their first year 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. This distribution of years of study was expected amongst the capstone respondents given the undergraduate engineering program co-op requirements that make a 5-year completion the norm.

Data Analysis

Qualitative data from the free-text portion of the survey was analyzed using word clouds to surface the most used words across all the entries for each year and class. The data was also coded using a mix of deductive a-priori categories and inductive codes developed using open coding based on the data [20]. A priori codes included the components of the ABET definition of engineering design discussed earlier while inductive codes were generated directly from the data. A full list of both types of codes can be seen in Table 3.

Table 3. Initial list of codes from qualitative data analysis

A Priori Codes	Inductive Codes from Data
Communication	Attention to Detail
Creativity	Cost
Disciplinary Knowledge	Creation/Building Something
Empathy	Customer/User
Idea Generation	Drawing
Iteration	Innovation
Optimization	Other
Problem Definition	Problem Solving
Problem Selection	Product
Prototyping	Safety
Requirements Development	Teamwork
Stakeholder Input	Thought Process/Way of Thinking
Testing	Value

Next like codes were grouped into broad categories to facilitate analysis (Table 4). The educational constructs category groups codes that address the ways in which engineers approach work in the discipline while the standard process of solution category groups problem and solution focused codes. The people and creativity categories are relatively self-explanatory and group codes that refer to interaction with others – either clients or collaborators – and to the process of developing new ideas, respectively. Finally, the product-oriented codes have a focus on the product being created or the process of product creation while the value engineering process category groups codes that highlight attributes required of the completed product. Neither the other nor drawing codes were included in this categorization as they fell outside of any of the major themes.

Table 4. Qualitative codes by category

Category	Codes
Educational Constructs	• Attention to Detail • Disciplinary Knowledge • Optimization • Thought Process/Way of Thinking
Standard Process of Solution	• Problem Definition • Problem Selection • Problem Solving
People	• Communication • Empathy • Customer/User • Teamwork • Stakeholder Input
Creativity	• Creativity • Idea Generation • Innovation • Iteration
Product Oriented	• Creation/Building Something • Product • Prototyping • Testing
Value Engineering Process	• Cost • Safety • Requirements Development • Value

Quantitative data were analyzed using a range of statistical techniques. Welch's t-tests were used to compare mean responses to the question that asked students to rank their knowledge of engineering which used a Likert scale. The Welch's t-test was selected for this analysis because of the comparison between two independent groups with what were assumed to be unequal variances [21].

Students were also asked to rank the importance of design in civil engineering on a Likert-style scale with 1 (least important) to 5 (most important). Unlike the self-reported knowledge data, this scale is ordinal rather than continuous and does not meet normality assumptions as required for parametric tests. Therefore, to compare the data we used the Mann-Whitney U test [22].

To compare student ranking of engineering design terms, data was initially analyzed individually for first year and capstone students across both survey dates. An evaluation was made to determine consistency between the years evaluated. To accomplish this the Spearman rank-order correlation [23] was computed. This method first computes the mean rank of each term for the two cohorts and then compares the order. After analyzing each set of results independently, we then compared the first year and capstone student rankings to determine whether shifts occurred as students progressed through the engineering curriculum. In addition, an analysis was conducted to determine shifts in rankings from the first year to capstone. First, the difference in rankings between the first year and capstone students in the 2024 cohort was determined and was then repeated for the 2025 cohort. To determine consistency, the difference in rankings was compared between 2024 and 2025.

Results

Results from both the initial 2024 survey and the second 2025 survey are discussed below.

Definitions of Design

Word clouds summarizing first year and capstone students' written definitions of engineering design for the 2024 and 2025 cohorts (Figure 1) show that across both years, first year responses tend to emphasize terms related to creation and tangible outcomes (e.g., *creating, things, structure, bridges*) while capstone responses consistently highlight terms associated with formal problem solving and professional practice (e.g., *problem, process, solution, calculations, value, clients*).

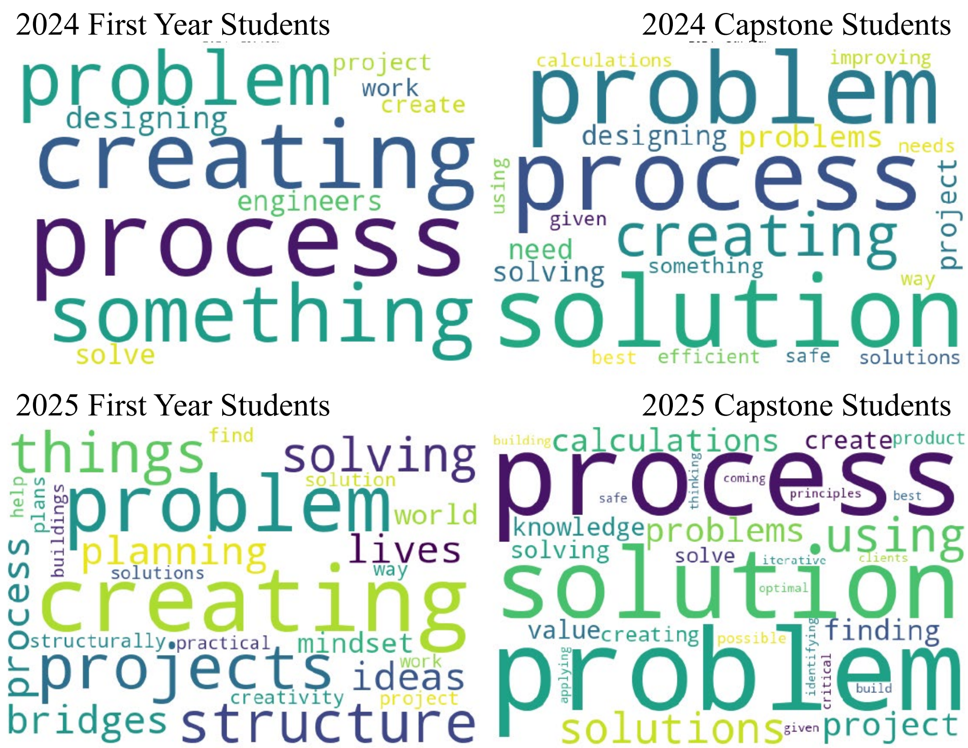

Figure 1. Students' response to, "In your own words, what is engineering design?"

Additional qualitative analysis of the students' free-text responses revealed interesting differences across groups while also exposed areas of agreement (Table 5). Since each survey had a different number of responses and among those, some students chose not to write their own definition, the percentage of responses including each of the codes was calculated excluding blank responses from the total number of responses that included some text. The result of this analysis is a marked increase across both years in the frequency with which capstone students refer to concepts related to the value engineering process and to educational constructs. There was also a noticeable decline across both years in student use of product orientation concepts.

Table 5. Code category percentage per cohort

	2024 First Year	2025 First Year	2024 Capstone	2025 Capstone
Educational Constructs	24%	29%	35%	56%
Standard Process of Solution	24%	38%	39%	49%
People	16%	25%	29%	29%
Creativity	16%	30%	20%	24%
Product Oriented	46%	48%	20%	20%
Value Engineering Process	3%	6%	31%	29%

Students' self-reported knowledge of engineering design was assessed with a 0-100 Likert-type scale for both first year and capstone students in the 2024 and 2025 cohorts (Figure 2). Results indicate a consistent increase in perceived knowledge from the first year to the capstone for both cohorts.

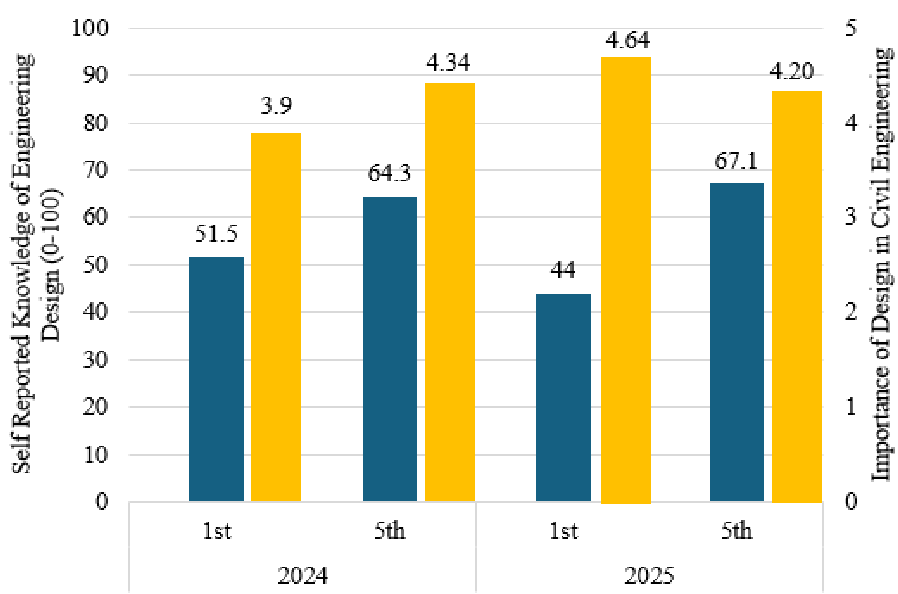

Figure 2. Self-Reported knowledge of engineering design of first year and capstone civil engineering students

Comparing the means self-reported knowledge scores between first year and capstone students reveals statistically significant increases in perceived knowledge of engineering design between the first year and the capstone for both 2024 and 2025 cohorts with differences ($p = 0.004$ and $p < 0.001$ respectively). There is also a significant increase ($p<0.001$) of self-reported engineering importance between the 2024 and 2025 cohorts of first year students while there was no significant difference in capstone student ranking of the importance of design in civil engineering between 2024 and 2025 ($p=0.33$).

Ranking of Engineering Design Concepts

A Spearman rank-order correlation of the ranking of 13 engineering design terms between the two first year cohorts was calculated as $r = 0.48$ (Figure 3). A value of $r = 1$ would indicate identical rank ordering, 0 would be no relationship and -1 would indicate complete opposite ordering. The calculated value indicates moderate agreement in ranking. This analysis was conducted to provide an understanding on the similarity and consistency of student cohort responses. This moderate level of agreement between 2024 and 2025 first year students increases the confidence that first year students have similar rankings for the engineering design terms. In addition, these data indicate that first year students generally rank Creativity highly (ranked 2nd and 1st between 2024 and 2025) with little difference in position and provide consistently lower rankings to Optimization, Stakeholder Input, Empathy, and Iteration.

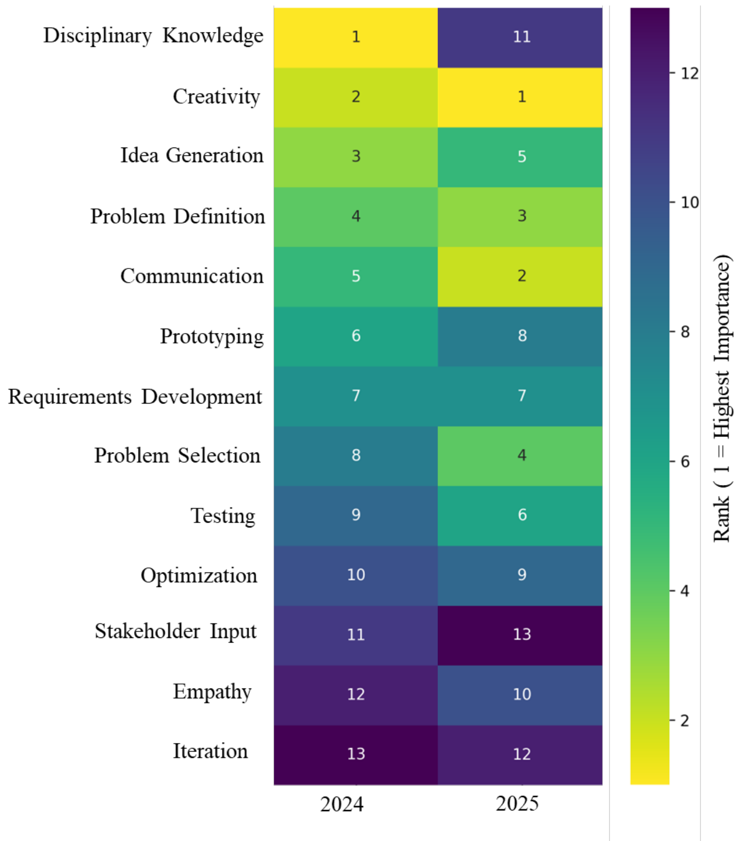

Figure 3. Comparison of term rankings for first year students

A similar comparison was made between the 2024 and 2025 cohorts of capstone students (Figure 4). The Spearman rank-order correlation coefficient was computed again for these two groups of students and found to be r = 0.88. This value indicates strong agreement in how capstone students ranked the importance of engineering design terms. This suggests that the relative ordering of design priorities among near-graduating students is highly stable year-to year, in contrast to the first year students (r = 0.48). Again, this longitudinal analysis supports a level of confidence of student's rankings. Among capstone students, Problem Definition, Communication, and Stakeholder Input are consistently ranked highly while Prototyping, Empathy, and Iteration are ranked as less important.

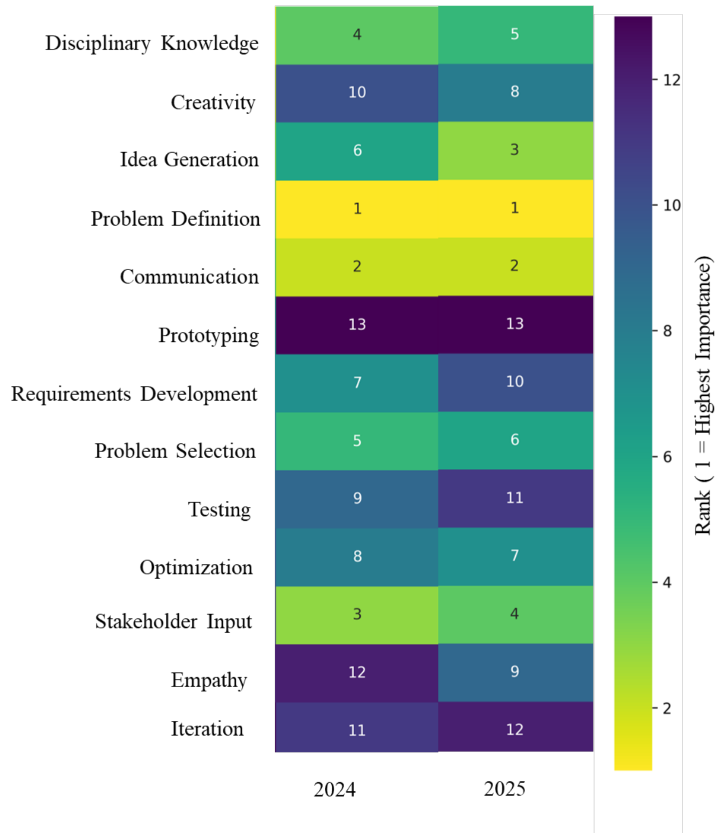

Figure 4. Comparison of term rankings for capstone students

As described, there is consistency between the first year and capstone students, across two years of data collection, in what they rank as most important and less important in engineering design. We also note, through the Spearman rank-order correlation, that more consistency exists among the capstone student rankings indicating a convergence on design mindset.

We then compared the first year student rankings to those of the capstone students to determine if a shift occurs as student progress through the engineering curriculum. An analysis was conducted to determine shifts in rankings from the first year to the capstone students. First, the difference in rankings between the first year and capstone students in the 2024 cohort was determined and was then repeated for the 2025 cohort. To determine consistency, the difference in rankings was compared between 2024 and 2025. A large difference between the first year and capstone students (Δ_2024 1st →5th and Δ_2025 1st →5th) shows a shift in importance. A small difference in the magnitude of this shift (Δ_2024 – Δ_2025) comparing 2024 and 2025 cohorts indicates consistency between the two study years (Table 3). When this value is small, we have more confidence that the result is not just a one-time occurrence and is valid across the longitudinal study.

Table 6. Comparison of Engineering Design importance rankings between first year and capstone students across both the 2024 and 2025 cohorts

Engineering Design Term	2024 Cohort		2025 Cohort		Importance Change		Consistency of Change (Δ_2024-Δ_2025)
	1st Year	5th Year	1st Year	5th Year	Δ_2024 (1st→5th)	Δ_2025 (1st→5th)	
Disciplinary Knowledge	1	4	11	5	-3	6	9
Creativity	2	10	1	8	-8	-7	1
Idea Generation	3	6	5	3	-3	2	5
Problem Definition	4	1	3	1	3	2	1
Communication	5	2	2	2	3	0	3
Prototyping	6	13	8	13	-7	-5	2
Requirements Development	7	7	7	10	0	-3	3
Problem Selection	8	5	4	6	3	-2	5
Testing	9	9	6	11	0	-5	5
Optimization	10	8	9	7	2	2	0
Stakeholder Input	11	3	13	4	8	9	1
Empathy	12	12	10	9	0	1	1
Iteration	13	11	12	12	2	0	2

Analysis of ranking data revealed consistent differences between first year and capstone students across both cohorts. First year students tended to prioritize Creativity and artifact related terms (Prototyping and Idea Generation) while placing lower importance on Stakeholder Input and Iteration. A low value of the consistency of change values between 2024 and 2025 gives the authors more confidence that these changes in rankings are real and not just an occurrence from a single year of collected data.In contrast, capstone students consistently ranked Problem Definition as the most important design activity, followed by Communication and Stakeholder Input. Rank-shift analysis showed that terms associated with professional practice and systems thinking particularly Problem Definition, Communication, and Stakeholder Input, increased in importance from the first year to the capstone year, while Creativity and Prototyping declined. Again, a low value of the consistency of change values between 2024 and 2025 indicates consistency across the two-year study. The stability of capstone rankings across both years suggests convergence toward a shared professional understanding of engineering design (Figure 5). This is supported by the calculated Spearman rank-order correlation of r=0.88 indicated a nearly identical ranking of the terms from a 2024 capstone class and a 2025 capstone class.

It is more difficult to interpret a few of the significant shifts in rankings when they occur only across a single year. For example, Disciplinary Knowledge was ranked highly for both first year and capstone students in 2024, but had a dramatic decrease in importance for first year students in 2025. The authors chose to focus conclusions from the data that were consistent from the longitudinal study across both years.

When rankings were aggregated by class standing (all first year students from 2024/2025 and all capstone students from 2024/2025), the Spearman rank-order correlation was low ($\rho = 0.30$) further indicating that students' perceptions of design priorities shift substantially over the course of the curriculum.

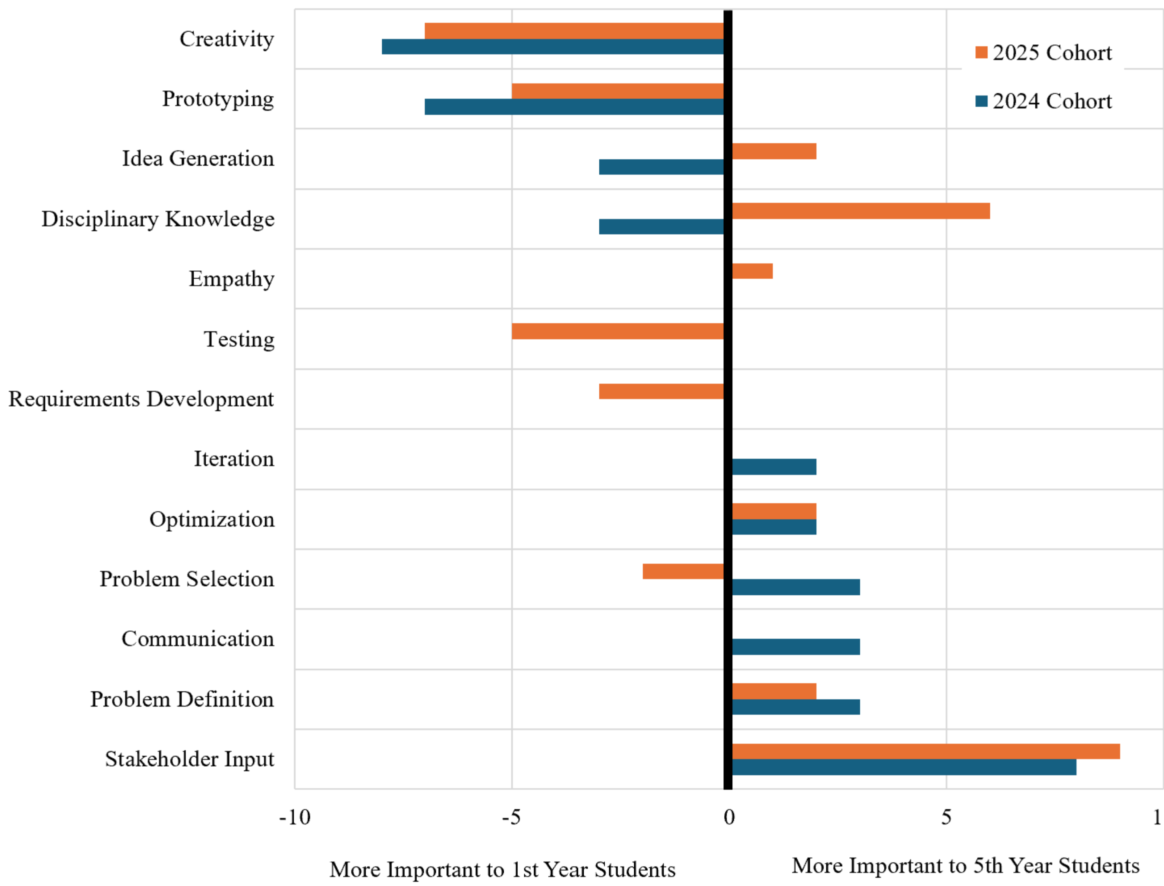

Figure 5. The differences in term ranking for engineering design between first year and capstone students (Cohorts 2024 and 2025)

Discussion

The data from this multi-year study point to consistent changes in the ways in which civil engineering students view and understand engineering design.

Coherence of Definition

The reported increase in knowledge of engineering design between the first year and capstone students is expected due to students' exposure to engineering design as part of their engineering coursework and co-op experiences. This shift may also help to explain the increased consistency with which capstone students emphasized the importance of engineering design. As students gain experience, the data indicates that they develop more uniformity around self-reported knowledge of engineering design and impressions of its importance to the field.

When students were asked to rank engineering design terms, first year cohorts exhibited moderate consistency in design term rankings between 2024 and 2025 ($\rho = 0.48$) while capstone cohorts showed strong stability in their rankings ($\rho = 0.88$), suggesting that students' perceptions of design priorities converge as they progress through the curriculum. The stability of capstone student rankings across both years suggests along with the consistency with which they ranked the importance of engineering design indicates that students begin to formulate a common conceptual idea of design in engineering as they progress through their undergraduate degree

Change in Definition

There were also clear differences between the ways in which first year and capstone students approached engineering design. In both the free-text and term ranking, first year students consistently highlighted the importance of Creativity, Prototyping, and Idea Generation while using language that spoke to making and building as core to the engineering design process. Capstone students emphasized the importance of Problem Definition, Communication, and Stakeholder Input and used language that demonstrated a more integrated view of engineering incorporating analysis, optimization, stakeholder considerations, and safety. These trends are consistent across both cohorts with a low Spearman rank-order correlation ($\rho = 0.30$) between aggregated first year and capstone student ranking results across cohorts indicating valid shifts in design priorities over the course of the curriculum. Aspects of this shift align with existing research into the decline in creativity among engineering students as they progress through undergraduate programs [24], [25]. Previous research also indicates that while creativity may decline as students move through their engineering education, other facets of engineering including understanding of social responsibility [26] and clarity around future careers [27] tend to increase. These findings echo the trend we see toward more nuanced, stakeholder focused, and professionally grounded definitions of engineering design among capstone students.

Limitations and Future Research

This study found evidence of consistency across the two cohorts of students surveyed, particularly in the capstone course. However, the findings are limited to students at a single institution in a particular program across two years (2024 and 2025). Further research is required to determine whether these findings are unique to students from the University of Cincinnati or whether they can be extended to civil engineering programs more generally. Similarly, studying students at two distinct points in their educational career provides a snapshot of changes to their perceptions of engineering design but falls short of providing insights into the factors that prompted these shifts. Additional research that examines students' perceptions at multiple points throughout their academic career might help to isolate whether specific courses, extra-curricular activities, or co-op experiences make an impact on shifting design definitions. Finally, more research is needed to determine whether these findings apply to civil engineering students specifically or if there are parallels with engineering students across disciplines.

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