Students' Self-Efficacy of Human-Centered Design and Engineering Student Entrepreneurial Mindset in a Two-Semester Materials Science and Engineering Capstone Course

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Abstract

Successful design experiences require students to engage in both divergent and convergent thinking throughout the design process. However, student experience and competency with navigating ambiguity, especially in the divergent thinking domain, is often lacking, leading to student frustration and poor design experience. Expanding upon our previously reported work, one solution described here is to restructure the Materials Science and Engineering capstone course into a two-semester sequence and to incorporate design frameworks that emphasize different thinking domains. In the two-semester sequence, the students are introduced to the Human-Centered Design (HCD) framework that provides a scaffold for design thinking in alternating convergent and divergent domains. Throughout the sequence, students are also explicitly introduced to, and engage in, the Engineering Student Entrepreneurial Mindset. This mindset drives innovation by focusing on Curiosity, Connections, and Creating Value (the 3 C’s).

Reported here are the results of survey data taken at the beginning, midpoint, and end of the capstone sequence for academic year 2024-25 (i.e., August, December, and May). This survey examines the students’ perceptions and self-efficacy of HCD and includes the Engineering Student Entrepreneurial Mindset Assessment (ESEMA) that examines the students’ mindsets centered around the 3 C’s. The 2024-25 survey had 43/57 respondents (~75%); the survey was also administered in AY 2023-24 with 25/60 respondents (~43%). While the AY 2023-24 survey results showed a plateau between the midpoint and end of the capstone sequence, the new 2024-25 survey results show a clear increase in the students’ self-efficacy in all five HCD spaces from beginning to midpoint to end of the capstone sequence. We can correlate these results with classroom activities and interventions that were designed to explicitly target HCD spaces stemming from the previous results.

In the ESEMA survey, AY 2023-24 had nuanced results, with some categories peaking in the midpoint surveys. In 2024-25, the results show clearer trends (positive, negative, and constant) that can be attributed to classroom interventions and explicitly engaging the students in the Entrepreneurial Mindset. These analyses provide insight and feedback on the courses’ content, activities, and structure, allowing for evidence-based course modifications.

Introduction

Capstone courses in engineering are tasked with developing students’ design knowledge while allowing students to apply their obtained technical knowledge through real-world challenges and design problems [1-3]. To be successful in design, practitioners need to engage in both divergent and convergent thinking [4]; however, unless explicitly delineated in the overall curriculum, students rarely obtain practice in divergent thinking. Thus, the overall role of design courses is the opportunity for students to engage and practice both convergent and divergent thinking.

Additionally, design courses need a framework to build the fundamental development of the design processes that the student will engage in; this framework provides scaffolding for the students to explore the complexity of design challenges. Having said framework and scaffolding can lead to more innovative, creative, and inclusive designs, with the added benefit of increasing the teams' productivity, improve the overall quality of the design, and minimization of errors throughout the design process [5]. One design framework that emphasizes divergent and convergent thinking is the Human-Centered Design (HCD) approach. Integrating HCD into existing engineering courses is challenging, with research indicating the uptake of HCD processes by engineering students is complex. As such, implementing the HCD framework in an engineering design course requires careful development of course materials and strategic implementation of instructional interventions materials [6, 7].

Previous work showcased HCD introduction through a case study approach, piloted in AY 2022-23 [8], with AY 2023-24 interventions captured through self-reported ability and self-efficacy of the entire class through the use of survey responses [9]. The underlying interventions were the introduction of the HCD framework to formalize the design process and the introduction of the Engineering Student Entrepreneurial Mindset. This mindset is used to foster innovation as it ties to curiosity, connections, and creating value (3 C's).

This work expands upon the previous through targeted interventions; interventions that were developed based on the previous year's results. This is the second consecutive year the survey tool was utilized, with the results supporting the earlier findings.

Background/Theoretical Perspectives

Capstone courses in engineering

Capstone courses are crucial in the engineering curriculum to provide students with the opportunity to solve design problems utilizing their accumulated knowledge of their chosen field. These design problems allow students to practice and gain mastery of the design principles prior to graduation. Oftentimes these design problems and challenges incorporate real-world objectives and constraints, requiring students to balance competing objectives [1, 2]. Further considerations are given beyond the technical feasibility of the projects: business feasibility, environmental, social, political, and ethical implications, as well as manufacturability.

The design projects provide a structured, collaborative learning environment where students can engage in the design framework [3, 10]. However, design learning must accompany the design project and experience to have a meaningful impact on student learning, and the teaching of design remains challenging [4]. One successful methodology is through project-based learning and has been shown to successfully motivate and engage students in design learning [11-14].

As mentioned, design requires the use of convergent and divergent thinking and thus design learning must have the students engage with both [4]. As described in Dym, et al., convergent thinking has the questioner converging on "facts" or verifiable knowledge. Divergent thinking has the questioner looking toward solution possibilities; one is not yet concerned about the verifiability of the solution [4]. The vast majority of courses in a typical engineering curriculum rely on convergent thinking; in these, there is one verifiable truth that is expected for a given problem: given a set of parameters, there is a solution as to what will happen. This thinking is critical to understanding an engineering system; however, it is not the only type that is necessary to create or design the engineering system. Design thinking requires divergent thinking; instead of collapsing down onto one solution, many possible solutions can exist simultaneously. Divergent thinking, in the concept domain, focuses on solution possibilities rather than verified solutions. Convergent thinking, alternatively, is in the knowledge domain. Both of these domains and types of thinking are necessary for a successful design solution. While students routinely have experience with convergent thinking, divergent thinking often is challenging due to requiring students to accept ambiguity through the design process.

This ambiguity can be a significant challenge if a design framework is not present. It has been shown that, when tasked to “solve” or “innovate”, teams of learners often have no prior experience nor a framework to guide them to solving the design challenge, leading to poor a poor design experience [1, 4, 5, 15]. One solution to both the lack of framework and requirement of both convergent and divergent thinking is the introduction of HCD into the engineering curriculum. Given explicit instruction on HCD, its spaces, processes, and role in engineering, students are then able to utilize the framework as a scaffold to a successful design completion [16].

Integrating HCD in capstone courses

HCD is a problem-solving approach utilizing design thinking methods and tools, focusing on the underlying design challenges through understanding the unmet needs of a population. This framework provides scaffolding for teams to collaboratively and iteratively create design solutions. HCD is composed of 5 spaces: Understand, Synthesize, Ideate, Prototype, and Implement with four design processes in each space. The spaces alternate between convergent and divergent thinking, allowing teams to engage in the different domains while providing a path to design completion [16, 17]. A key component of HCD is empathizing with stakeholders; this prompts teams to design solutions that consider deeper implications in terms of the economy, society, or environment, with the resulting design solution often meaningful and relevant [18]. A key challenge by student teams is conflicting information they may receive during the design process. HCD expects this conflicting information and has processes and a framework that design teams can effectively use to collapse the information to relevant content. Additionally, the HCD framework has been shown to facilitate students’ growth in soft skills such as communication and collaboration [19]. The HCD framework provides the scaffold and processes for creation of meaningful, impactful solutions, with HCD integration into engineering courses being supported by higher education institutions [8, 19-21].

Several research studies have shown the integration of HCD into existing engineering courses [8, 9, 20, 21]. In these, HCD was incorporated into the engineering design process, focusing on the 5 spaces of HCD and the 4 processes of each space. Processes include understanding the challenge, building knowledge, weighing options and making decisions, generating ideas, prototyping, reflecting, and revising/iterating. The task of learning about the HCD framework and utilizing said framework in a design challenge in a single semester is challenging due to the minimal engagement of the teams in each process and space [6-8].

The purpose of the study

Previous work [8] using a case study approach [22] inferred, and subsequent investigation highlighted [9], that incorporating and teaching a design framework, notably human-centered design, prior to the capstone experience enhances the capstone project and improves students' self-efficacy. This was the second year after the curriculum was formally changed to have all seniors take the fall and spring sequence. The previous year utilized three surveys throughout the two-semester sequence, notably at the beginning (August), middle point (December), and end (May). These surveys investigated students' self-efficacy in HCD and incorporated the Engineering Student Entrepreneurial Mindset Assessment (ESEMA) [23]. This work continues with these surveys, used to support the previous data collection, and, as such, this is the second consecutive year the surveys were implemented. By having a two-semester sequence, and the surveys given at the beginning, midyear, and end of the sequence, the results from the surveys can be correlated to course activities during each semester and can be used for feedback on course interventions and improvements.

Building upon earlier work, course elements included explicit instruction on HCD, its use in engineering as a tool to approach design [16], as well as the Kern Entrepreneurial Engineering Network (KEEN) mindset. Capstone projects are sourced from real clients, a mix of external to the university and internal, posing real-world challenges. Reflection prompts and weekly progress reports are submitted to document progress, HCD processes, and the Engineering Student Entrepreneurial Mindset, with final deliverables of a poster session and written portfolio.

Methods

Course Structure and Design Elements

A restructuring of the materials science and engineering capstone experience was formalized in academic year 2023-24 where the historical 1-semester, 3-credit course was divided into a 2-semester sequence: a fall, 1-credit course to learn design principles and a spring, 2-credit course to complete a capstone project. This sequence is required of all seniors, with exceptions granted for the fall course given to those away from campus (e.g., internship, study abroad). In these cases, students away in the fall take a 1-credit independent study course in the spring to fulfill their graduation requirement.

In the course structure, the HCD spaces and processes provide the framework for *how* to perform design, while the Engineering Student Entrepreneurial Mindset explains *why* design happens, highlighting the motivations, values, and drivers behind design choices. The HCD framework and the 3 C's mindset are thus complimentary in the overall design process. The mapping of HCD spaces to the KEEN mindset of Opportunity, Design, and Impact and the 3 C's is shown in Table 1.

Table 1. Mapping of HCD taxonomy to KEEN's Opportunity, Design, and Impact and the 3 C's through engineering design activities.

HCD Taxonomy	**Example Engineering Design Activities**	**KEEN Opportunity, Design, Impact**	**Connection to KEEN 3 C's**
Understand	Understand the Challenge, frame the problem, implement empathic techniques	Opportunity	Curiosity
	Build Knowledge	Opportunity	Curiosity, Connections
Synthesize	Weigh Options and Make Decisions	Design, Opportunity	Connections
Ideate	Generate Ideas	Design	Connections, Create Value
Prototype	Represent Ideas	Design	Create Value
	Experiment	Design, Impact	Create Value
	Troubleshoot	Design, Opportunity	Connections, Create Value
Implement	Revise/Iterate	Design	Create Value
	Reflect on Process	Impact	Curiosity, Connections, Create Value

The course has a 50-minute, once a week class time in the fall semester that was spent outlining a design topic, typically an HCD space and processes, with small-group, in-class activities to emphasize the topic. A mini-project was given approximately a third into the fall semester so students could practice the HCD processes, and use the Engineering Student Entrepreneurial Mindset, in a low-stakes environment. Shortly thereafter, capstone project teams were created, maximizing student preference. Final deliverables in the fall semester included a literature review, a work plan presentation and document, as well as a budget with ordering information. This is a change from the previous academic year 2023-24, where the fall deliverable was solely the literature review.

The spring semester, the 2-credit course utilized a 50-minute class once a week to highlight design topics, including team dynamics, engineering standards, and communication skills. HCD spaces were highlighted, showing teams where they should ideally be in the design framework. Important to note, explicit class discussion was held on the HCD framework having both divergent and convergent processes and that the overall design process is not linear. For detailed discussion on their individual projects, teams met with the instructional staff for 30 minutes each week, using the submitted progress reports as a meeting agenda. As in the previous year, the major milestones of the spring semester included an oral midterm presentation to the class peers, a final poster session, and a final written portfolio.

In previous course iterations, explicit care was taken to delineate the HCD processes; however, the Engineering Student Entrepreneurial Mindset was not discussed to the same extent [9]. In academic year 2024-25, specific interventions were made to enhance the interactions students had with the Engineering Student Entrepreneurial Mindset. The weekly progress reports had reflection questions that prompted the team to decide what actions promoted curiosity, connections, or creating value. Of important note, these progress reports, and thus reflections on the mindset, were only conducted in the spring semester. Additionally, reflection prompts on the major deliverables explicitly asked how the team engaged in the Engineering Student Entrepreneurial Mindset. Major deliverables had rubrics explicitly asking what HCD spaces and processes the teams were currently engaging with and how those processes affected the overall design experience. Key course interventions are outlined in Table 2.

Table 2. Key course interventions and implementation to engage students in HCD thinking and the 3 C's mindset.

Intervention	Description of Intervention	Course Implementation
Lecture discussions on HCD and 3 C's mindset	Lecture time was devoted to discussion of how the mindset drives the design process.	Weekly lecture discussions, fall and spring semesters.
Mini-design project	Out-of-class project where groups design a playhouse using stand-in stakeholders to give student groups conflicting information (parents, child, HOA). Adapted from [24].	Mid-October, fall semester. Small group presentation in class, online slide deck submission, post-assignment reflection.
Capstone Work Plan Presentation & Reflection	Final deliverable of fall semester is the capstone work plan, outlining steps for project completion in the spring semester. Rubric emphasizes HCD processes. Reflection prompt asks how and where the 3 C's were utilized in creating the work plan.	December, fall semester. Team submission.
Creation of Structured Problem Statement	Systematic framework of defining a problem [25]. Bridges the HCD synthesize space with Creating Value.	Team submission, early February, spring semester.
3 C's reflection prompts	Weekly progress reports ask what actions promoted curiosity, connections, or creating value.	Weekly team assignments in spring semester. Online PDF submission.
Midterm and poster presentations, final portfolio	Rubrics for major deliverables emphasized HCD spaces and the 3 C's mindset. Teams were to present their work using these frameworks to obtain full points.	Spring semester: midterm presentation in March, poster presentation in April, final portfolio in early May.

Design

The described study, following the design-based project approach [26], was conducted at a large midwestern university as part of the broader department initiative to revise the materials science and engineering capstone experience. To evaluate the students' self-efficacy based on curriculum and course changes, a Qualtrics survey was conducted. As in the previous year [8], the survey was executed at three different times during the 2-semester capstone sequence: a pre-survey (August), mid-survey (December), and post-survey (May). The survey investigated the students' reported self-efficacy of HCD aligned tasks [27] and the ESEMA [23]. An exploratory factor analysis was previously conducted to ensure internal consistency between the questions for each of the HCD spaces [28]. The HCD aligned questions and ESEMA questions were used as previously published. The HCD aligned questions used a multiple-choice numerical scale (0, 10, … 90, 100), asking participants their confidence in performing the described tasks. The 17 HCD aligned questions aggregate to the 5 HCD spaces of Understanding, Synthesize, Ideate, Prototype, and Implement. The ESEMA used a Likert scale from 1-5, indicating how true the statement was of the participant, ranging from "never or only rarely true" to "always or almost always true" [9, 23]. The 34 questions aggregate to the factors of Altruism, Empathy, Help Seeking, Ideation, Interest, and Open Mindedness.

Participants and Data Collection

Participants were materials science and engineering students in their senior capstone sequence (fall-spring) in academic year 2024-25. Total enrollment for the course sequence was 57 students, with 43 students (75.4%) completing all three surveys. The surveys were conducted during class time, where the instructor and teaching assistants removed themselves from the classroom. Submissions were tracked with unique identifiers for each student.

Data Analysis Procedures

Individual survey items were averaged to form the HCD, ESEMA, and 3 C's self-efficacy scales. Since measurements were repeated within subjects, changes across time were analyzed using a one-way repeated-measures ANOVA. Sphericity was evaluated using Mauchly's test, and Huynh-Feldt adjusted degrees of freedom were applied when this assumption was violated. Pairwise comparisons were conducted using paired-samples t-tests with Holm-Bonferroni correction to control the familywise error rate. Statistical significance was set at $\alpha = 0.05$. All self-efficacy scales were analyzed independently. All statistical analyses were performed in OriginPro 2025.

Results

Figure 1 shows the students' self-reported self-efficacy (mean ± standard error of the mean (SEM)) for the HCD spaces across the three survey administrations. All HCD-aligned scales displayed a positive upward trend from the pre-survey to the mid-survey and subsequently to the post-survey. Statistical significance results are summarized in Table 3. Four HCD spaces, Understand, Ideate, Prototype, and Implement, showed statistically significant increases for all pairwise comparisons. The Synthesize space showed a statistically significant increase only from the pre- to the post-survey; the pre-mid comparison was not significant, and therefore the mid-post comparison was not tested under the Holm-Bonferroni step-down procedure. Full pairwise comparison details are provided in the Appendix.

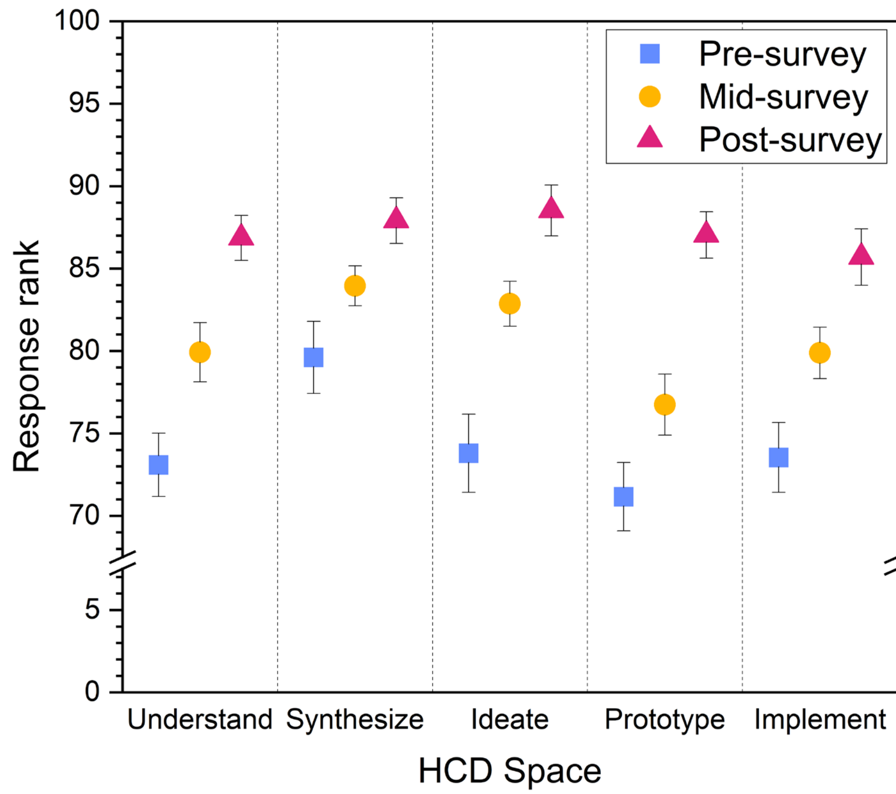

Figure 1. Survey results of students' reported self-efficacy of HCD aligned questions aggregated into their respective HCD Space. Plotted is the mean ± SEM.

Table 3. Statistical significance of pairwise differences in means for HCD Spaces, using Holm-Bonferroni correction (α = 0.05).
Key: ✓ significant, ✕ not significant, — not tested (Holm step down rule).

HCD Space	Pre-Mid	Mid-Post	Pre-Post	Note
Understand	✓	✓	✓	
Synthesize	✕	—	✓	Holm stopped after Pre-Mid failed; Mid-Post not tested.
Ideate	✓	✓	✓	
Prototype	✓	✓	✓	
Implement	✓	✓	✓	

Survey results corresponding to the ESEMA factors are shown in Figure 2 with the statistical significance summarized in Table 4. Altruism was relatively constant over the year-long design sequence. In comparison, four other factors (Empathy, Help Seeking, Ideation, and Interest) had a significant increase in the spring semester (i.e., pre-/mid- to post-survey). Interestingly, Open

Mindedness had a negative correlation over the length of the capstone sequence, with statistically significant decreases in the pre- to mid-surveys and pre- to post-surveys.

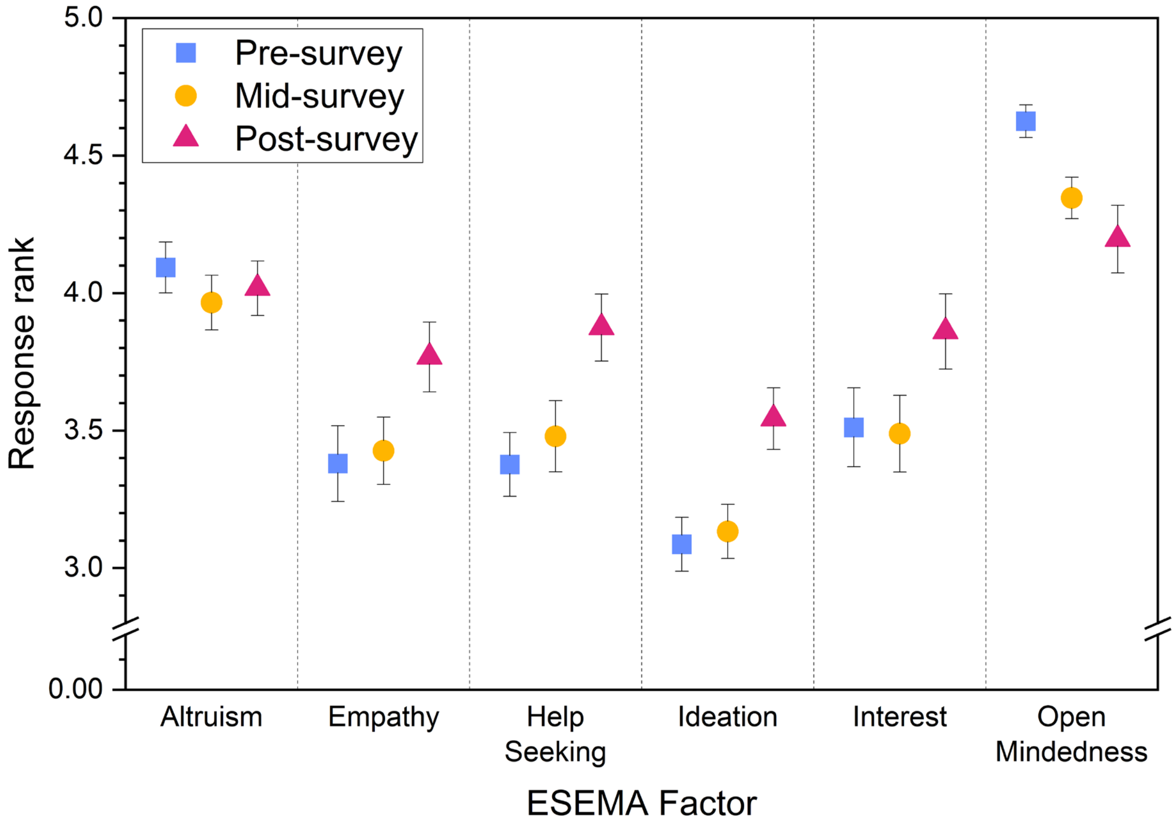

Figure 2. Survey responses corresponding to the ESEMA factor. Plotted is the mean ± SEM.

Table 4. Statistical significance of pairwise differences in means for ESEMA Factors, using Holm-Bonferroni correction (α = 0.05).
Key: ✓ significant, ✕ not significant, — not tested (Holm step down rule).

ESEMA Factor	Pre-Mid	Mid-Post	Pre-Post	Note
Altruism	✕	—	—	Holm stopped after Pre-Mid failed; Mid-Post & Pre-Post not tested.
Empathy	✕	✓	✓	
Help Seeking	✕	✓	✓	
Ideation	✕	✓	✓	
Interest	✕	✓	✓	
Open Mindedness	✓	✕	✓	

The ESEMA categories map to the Kern Entrepreneurial Engineering Network (KEEN) 3 C's of Curiosity, Connections, and Creating Value [9, 23]; the results are shown in Figure 3 and statistical significance shown in Table 5. Curiosity and Creating increased significantly after the spring semester, with the post-survey results showing statistically significant increases over the pre- and mid-survey results. Reported students' self-efficacy in Connections was relatively high and constant through all three surveys, and its Holm-Bonferroni sequence halted after a nonsignificant mid-post comparison.

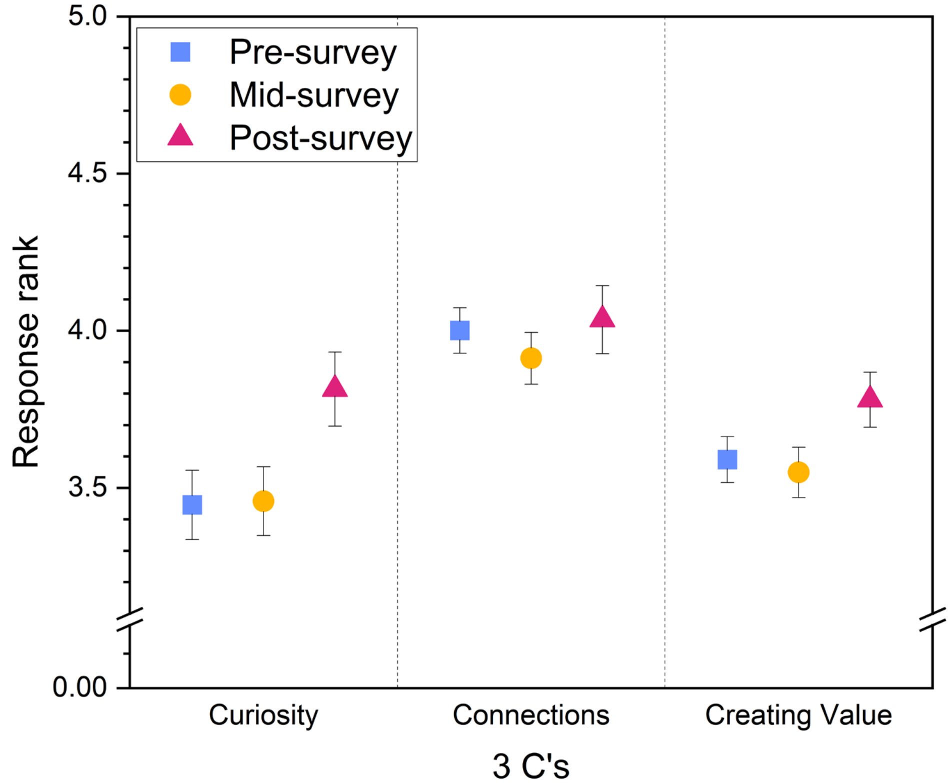

Figure 3. ESEMA survey questions aggregated to the 3 C's. Plotted is the mean ± SEM.

Table 5. Statistical significance of pairwise differences in means for 3 C's Mindset, using Holm-Bonferroni correction ($\alpha = 0.05$).
Key: ✓ significant, ✕ not significant, — not tested (Holm step down rule).

ESEMA Factor	Pre-Mid	Mid-Post	Pre-Post	Note
Curiosity	✕	✓	✓	
Connections	—	✕	—	Holm stopped after Mid-Post failed; Pre-Mid & Pre-Post not tested.
Creating Value	✕	✓	✓	

Discussion

The purpose of this study was to support and build off previous findings, showing that learning about the design framework prior to the capstone project improves student self-efficacy and benefits the capstone project. The three surveys provide snapshots of the students' progress and can be correlated to classroom activities and interventions.

Interpretation of Survey Results, HCD aligned questions and Spaces

A clear, positive trend is shown for all the HCD aligned questions (Figure 1), with statistically significant increases in the students' self-reported self-efficacy for all design processes over the two-semester sequence, i.e., pre- to post-survey. There is a correlation with these self-efficacy increases and the students engaging with the HCD processes throughout their capstone experience through lectures, activities, and deliverables with rubrics explicitly targeting HCD elements (e.g., Work Plan Presentation, etc., Table 2). This supports earlier findings that learning about the design process and then engaging in the process can be beneficial to the learners' self-efficacy [8, 9].

An interesting pattern occurs in the Prototype space where there is a moderate significant increase in self-reported self-efficacy between the pre- and mid-surveys followed by a substantial significant increase between the mid- and post-surveys. This is attributed to the fall semester having little to no opportunities for the iterative design process; indeed, the mini-project the students completed had a single submission with no opportunities for revisions. In contrast, the spring semester had groups focusing on their capstone projects, where the teams would prototype their design, solicit feedback from stakeholders, and iterate to create a better prototype.

In contrast to last year's results [9], where the improvement from mid- to post-survey was small and not statistically significant, the results presented here show a positive trend that is statistically significant for every pair-wise correlation (pre- to mid-, pre- to post-, and mid- to post-) in the Understand, Ideate, Prototype, and Implement spaces. The Synthesize space, while only showing significance between the pre- and post-survey, follows this positive trend. By having students engage with the design processes through directed activities, mini-projects, and their capstone project provides extended time for teams to practice the design principles and processes, which in turn could lead to higher self-reported self-efficacy.

Interpretation of Survey Results, ESEMA and 3 C's

Last year's results in the ESEMA were nuanced [9]; there were no unifying trends, and the majority of the pairwise results were not statistically significant. This was attributed to not explicitly discussing the Engineering Student Entrepreneurial Mindset nor having the students reflect on the 3 C's through submissions or presentations. In contrast, academic year 2024-25 had explicit classroom discussion on the Engineering Student Entrepreneurial Mindset and had reflection-based assignments for the students in terms of weekly progress reports and their major deliverables, where the teams were tasked with delineating their activities that corresponded to the 3 C's. The 2024-25 survey results show a more uniform trend, where 4 of the ESEMA factors (Empath, Help Seeking, Ideation, and Interest) show little change from pre- to mid-survey followed by a statistically significant increase in the reported self-efficacy for the post-survey. This could be attributed to the weekly progress reports teams completed in the spring semester. In these, the teams were tasked on a weekly basis to describe what activities they engaged in that corresponded to the Engineering Student Entrepreneurial Mindset. In the fall semester, no progress reports were generated; the engagement of the students with the mindset would therefore be significantly lower.

Altruism results, while not statistically different across the surveys, were similar to the previous year [9], remaining relatively high for each surveys. Open Mindedness also had similar results to the previous year, with both cohorts showing a negative correlation in their self-reported self-efficacy as the capstone sequence progressed. This may reflect the natural narrowing of the design project, where the teams have converged upon a given solution, as well as end-of-year factors related to the seniors nearing graduation. Nonetheless, Open Mindedness is a valuable mindset that students and lifelong learners should maintain. As Open Mindedness correlates strongly to divergent thinking, and the HCD spaces provide a framework and allow for both convergent and divergent thinking, the decrease in self-reported self-efficacy for Open Mindedness while increasing for all HCD spaces is not yet fully understood. Further investigation is warranted, perhaps in qualitative data collection through focus groups or interviews, and thus presents an opportunity for future interventions.

As with the ESEMA results, the 3 C's have a clearer trend. Both Curiosity and Creating Value had no change between the pre- and mid-survey; however, they both had statistically significant increase to the post-survey. This correlates well to the class intervention of progress report template submissions in the spring semester. Curiosity, corresponding to Empathy and Interest, follows the ESEMA trends as expected. Creating Value is composed of Altruism and Ideation; with Altruism high but relatively constant, self-efficacy of activities relating to the Creating Value is dominated by the Ideation aligned survey questions.

Connections, similar the previous year, were high and relatively constant throughout the three surveys. Interestingly, Help Seeking and Open Mindedness are the two categories that aggregate into Connections, of which they have opposite trends. Self-report self-efficacy relating to Help Seeking increases throughout the capstone sequence, while Open Mindedness decreases. This implies that the students' self-reported self-efficacy of activities relating to seeking help is increasing at the same time their self-reported self-efficacy of open mindedness activities is decreasing. Deeper exploration and understanding are needed to further disentangle these two seemingly contrary results.

Conclusion

Through survey results, data supports earlier findings that prolonged engagement with the design framework in a two-semester capstone sequence increases the students' self-efficacy of the HCD framework and processes. By learning about the design processes and framework in a low-stakes environment, students were able to engage, learn, and experiment prior to their capstone projects. This early engagement sets the foundation for increased self-efficacy and utilization of the HCD framework through both convergent and divergent thinking. Through targeted interventions, utilizing team-based reflections and template-guided progress reports, self-reported self-efficacy of HCD aligned questions all showed a positive trend through the surveys. These increases in self-reported self-efficacy are statistically significant for all pairwise comparisons in four of the five HCD spaces: Understand, Ideate, Prototype, and Implement, with the fifth space, Synthesize, having a statistically significant increase in self-reported self-efficacy between the pre- and post-surveys.

The results for the Engineering Student Entrepreneurial Mindset had a clearer trend relative to previous course iterations, likely due to the course interventions that explicitly relate to said mindset, namely targeted reflection activities and weekly progress reports. The increased in reported self-efficacy for Curiosity and Creating Value between the mid- and post-surveys correlates to the introduction of weekly progress reports that required teams to delineate activities related to the 3 C's. Interestingly, Connections remained relatively constant through the surveys, as it corresponds to the Help Seeking and Open Mindedness aligned questions in the survey. These two categories had opposing trends, with further investigation necessary to understand the reasoning.

This work had a larger overall and percentage population of the class complete all three surveys (43/57, 75.4%) compared to the previous academic year (25/60, 41.7%) [9]. While still a small sample size, statistically significant differences in self-efficacy were found and can be correlated to classroom activities and interventions. However, there are still limitations beyond this specific course due to the samples size, instructional design, overall curriculum, and general student demographics. Additionally, due to the self-reported nature of the survey, students' perception and understanding of the 3 C's could be inaccurate, as could their bias of their own perceived growth of the mindset. Finally, qualitative data and analysis, e.g., interviews, focus groups, etc., were not conducted in this study; these qualitative measures could provide insight and deeper understanding of how the students develop and engage with the framework and mindset.

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Appendix

The tables below display the results of all pairwise comparisons for each construct, including the mean differences, unadjusted p-values, Holm-Bonferroni adjusted α thresholds, and final significance decisions. All analyses were conducted in OriginPro 2025.

Table A1. Pairwise Comparisons for HCD Spaces.

HCD Space	**Pair**	**Mean Difference**	**p-value**	**Holm α**	**Decision**
Understand	Pre-Post	-13.76	<0.0001	0.01667	Significant
Understand	Mid-Post	-6.94	0.00119	0.025	Significant
Understand	Pre-Mid	-6.82	0.00142	0.05	Significant
Synthesize	Pre-Post	-8.29	1.23E-04	0.01667	Significant
Synthesize	Pre-Mid	-4.34	0.03803	0.025	Not Significant
Synthesize	Mid-Post	-3.95	0.0583	0	Not Tested
Ideate	Pre-Post	-14.73	<0.0001	0.01667	Significant
Ideate	Pre-Mid	-9.07	<0.0001	0.025	Significant
Ideate	Mid-Post	-5.66	0.0095	0.05	Significant
Prototype	Pre-Post	-15.87	<0.0001	0.01667	Significant
Prototype	Mid-Post	-10.29	<0.0001	0.025	Significant
Prototype	Pre-Mid	-5.58	0.00867	0.05	Significant
Implement	Pre-Post	-12.15	<0.0001	0.01667	Significant
Implement	Pre-Mid	-6.34	0.00303	0.025	Significant
Implement	Mid-Post	-5.81	0.00632	0.05	Significant

Table A2. Pairwise Comparisons for ESEMA Factors.

ESEMA Factor	Pair	Mean Difference	p-value	Holm α	Decision
Altruism	Pre-Mid	0.12791	0.12635	0.01667	Not Significant
Altruism	Pre-Post	0.07558	0.3642	0	Not Tested
Altruism	Mid-Post	-0.05233	0.52935	0	Not Tested
Empathy	Pre-Post	-0.3876	0.00187	0.01667	Significant

Empathy	Mid-Post	-0.34109	0.00588	0.025	Significant
Empathy	Pre-Mid	-0.04651	0.70088	0.05	Not Significant
Help Seeking	Pre-Post	-0.49767	2.28E-04	0.01667	Significant
Help Seeking	Mid-Post	-0.39535	0.00297	0.025	Significant
Help Seeking	Pre-Mid	-0.10233	0.43054	0.05	Not Significant
Ideation	Pre-Post	-0.45666	<0.0001	0.01667	Significant
Ideation	Mid-Post	-0.41015	<0.0001	0.025	Significant
Ideation	Pre-Mid	-0.04651	0.61984	0.05	Not Significant
Interest	Mid-Post	-0.37209	0.01049	0.01667	Significant
Interest	Pre-Post	-0.34884	0.01618	0.025	Significant
Interest	Pre-Mid	0.02326	0.87043	0.05	Not Significant
Open Mindedness	Pre-Post	0.42926	<0.0001	0.01667	Significant
Open Mindedness	Pre-Mid	0.27907	0.00595	0.025	Significant
Open Mindedness	Mid-Post	0.15019	0.13252	0.05	Not Significant

Table A3. Pairwise Comparisons for 3 C's Mindset.

Mindset	Pair	Mean Difference	p-value	Holm α	Decision
Curiosity	Pre-Post	-0.36822	3.57E-04	0.01667	Significant
Curiosity	Mid-Post	-0.35659	5.29E-04	0.025	Significant
Curiosity	Pre-Mid	-0.01163	0.90672	0.05	Not Significant
Connections	Mid-Post	-0.12258	0.17595	0.01667	Not Significant
Connections	Pre-Mid	0.08837	0.32795	0	Not Tested
Connections	Pre-Post	-0.03421	0.70427	0	Not Tested
Creating Value	Mid-Post	-0.23124	0.00107	0.01667	Significant
Creating Value	Pre-Post	-0.19054	0.00649	0.025	Significant
Creating Value	Pre-Mid	0.0407	0.55259	0.05	Not Significant