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BOARD #127: WIP: Assessing aerospace students' human-centered engineering design competency across multiple required courses

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I am currently the Associate Director of Assessment and Research team at the Siebel Center for Design (SCD) at the University of Illinois at Urbana-Champaign. I work with a group of wonderful and talented people at SCD's Assessment and Research Laboratory to conduct research that informs and evaluates our practice of teaching and learning human-centered design in formal and informal learning environments.

My Research focuses on studying students' collaborative problem solving processes and the role of the teacher in facilitating these processes in STEM classrooms.

WIP: Assessing Aerospace Students' Human-Centered Engineering Design Competency Across Multiple Required Courses

Introduction

In four-year engineering programs, learning progressions, or strategic tracks that outline students' learning journeys throughout the program [1], are important for tracking students' competency development. These progressions are often informed by program educational objectives and can be used to develop formative assessment measures. Literature has defined the value of learning progressions in K–12 science and math education as well as how to design them in these contexts [2, 3, 4]. However, there are limited examples in which these progressions have been used as a strategic tool to support students' competency development in post-secondary education, particularly engineering education [5]. We argue that there is a need for these efforts in engineering education, which must balance program educational objectives (PEOs) with requirements from governing bodies such as ABET [6]. Indeed, learning progressions can help strategically plot students' development of relevant competencies and set the stage for ongoing assessment.

Furthermore, there is a need to explore learning progressions that focus on the development of students' competencies relevant to human-centered engineering design (HCED). In previous work, we have argued that engaging students in HCED is integral to a well-rounded engineering curriculum that supports the development of both objective, technical skills and subjective, empathic skills [7]. We treat HCED as the integration, and resulting practices, of human-centered design (HCD) in technical engineering design. Human-centered design is a problem-solving approach that uses design thinking tools to identify unmet needs of a population and collaboratively and iteratively develop meaningful and innovative solutions for that population's benefit [8]. It is becoming more common for post-secondary institutions to seek ways to integrate human-centered design methods into their engineering programs [9, 10]. Our work seeks to support this integration; thus, our team is focused on promoting the practice of HCED.

Background

We are an interdisciplinary design team at the University of Illinois Urbana-Champaign that is composed of Grainger College of Engineering faculty and researchers from the Siebel Center for Design (SCD) [11]. Since 2019, SCD researchers have been using HCD to develop programs and design activities that can help students learn about HCD processes and practices and develop its mindsets [12].

To successfully integrate human-centered design within engineering education, it is important to consider both the course and program levels. In our ongoing collaboration with an accredited, four-year aerospace engineering program, we are working both to implement tools for integrating human-centered design at the course level as well develop longitudinal tools to evaluate students' learning at the program level.

In this paper, we discuss the co-development of program-level learning progressions that connect directly to program educational objectives as well as ABET student learning outcomes [6]. These progressions also connect to the Kern Family Foundation (KEEN)'s entrepreneurial mindset [13], which proposes a set of attitudes, dispositions, habits, and behaviors that shape a unique, desirable engineering problem-solving approach.

Learning Progressions Framework Development

In previous work, we piloted the development of program-level learning progressions that connect directly to program educational objectives and ABET student learning outcomes [14]. This included developing a framework that identifies a set of pertinent competencies and breaks them into naive, intermediate, and informed stages through which students should progress during their time in the program. We described the process of developing learning progressions across a sequence of three required aerospace engineering courses (one in each of years two, three, and four of the program) and collecting preliminary data to begin investigating the presence of activities and content related to these progressions in the classrooms. Data collection included the pilot survey, ethnographic classroom observations, and written individual reflections from students. These efforts also included developing a new design-for-requirement mini-project, now referred to as the glider-catapult project [15].

The progressions focused on the following six competencies: understanding of HCED; application of empathy-related skills; application of iteration-related skill; consideration of implementation dimensions; application of oral and written communication skills; and application of cognitive and social collaboration skills. A summary of the framework is provided in Table 1.

Table 1. Summary of Learning Progressions Framework

		Technical Competency			**Global Competency**	**Professional Competency**	
		Understanding of HCED	**Application of Empathy-Related Processes**	**Application of Iteration-Related Processes**	**Consideration of Implementation Dimensions**	**Application of Oral & Written Communication Skills**	**Application of Cognitive & Social Collaboration Skills**
Naive ↕ **Intermediate** ↕ **Informed**	***Description of Learning Progression***	Use knowledge of HCED to synthesize working definition.	Identify and apply empathic processes to advance a design problem.	Identify and apply iterative processes to advance a design problem (physically, digitally).	Consider design problem and solution through engineering, ethical, cultural, social, health, environmental, safety, and economic dimensions.	Lead, support, and participate in effective communication with diverse audiences.	Lead, support, and participate in effective collaboration with diverse groups.

Current Work

In this work-in-progress paper, we demonstrate a method for using statistical analysis to inspect students' competency development. These findings are used to inform future course development efforts as well as empirically validate our learning progressions framework. Because our framework is intended for use at the program level, ongoing work will continue to track students as they move through the sequence of required courses toward graduation.

Methods

For the Fall 2024 semester, we focused on the same required 200-level (i.e., second-year) course from our original three-course sequence as well as a required 400-level (i.e., fourth-year) lab course separate from the capstone. We used the same pre-/post-test survey instrument, published and validated in previous work [14], in both courses. For the 400-level course, we added an additional survey question to identify the students who had previously taken the 200-level course with the instructor from our team, who taught the same course for the previous three semesters. Doing so allowed us to separate the survey data for the 400-level students into two samples so that we could track the cohort of students that had previously passed through a course in our sequence.

Participants

The 200-level course focused on flight mechanics and had 58 students total. Of these, 48 participated in the survey. The 400-level course focused on building and testing physical drones and had 149 students total. Of these, 139 participated in the survey. For purposes of comparison, we only included participating students who answered both the pre- and post-test.

Survey Structure and Reliability

The survey includes seven sections, one per each of our six learning progressions (Sections 1–6) and the entrepreneurial mindset (Section 7) [16]. Section 1 consists of one short-answer prompt that asks students to define human-centered engineering design. Sections 2–7 each consist of 6 to 14 items assessed on a 10-point Likert scale, totaling 58 items. Survey sections are shown in Table 2; demographic items are provided in the appendix.

Table 2. Survey Sections and Items

Section 1. Understanding of HCED

What is your definition of human-centered engineering design? (1-2 sentences)

Section 2. Application of Empathy-Related Processes

For each of the items below, rate your degree of confidence to perform the following tasks by recording a number from 0 to 10 (0 = low, 5 = moderate, 10 = high)

- Conduct background research (e.g., internet search, market investigation)

- Empathize with stakeholders to identify underlying needs
- Resolve conflicting information from stakeholders
- Define the goals of the design problem
- Frame design needs so that solutions can be developed
- Communicate design solution to stakeholders

Section 3. Application of Iteration-Related Processes
For each of the items below, rate your degree of confidence to perform the following tasks by recording a number from 0 to 10 (0 = low, 5 = moderate, 10 = high)

- Assess feasibility of design ideas
- Create rough prototypes to get intermittent feedback
- Select viable prototyping methods (e.g., physical prototyping, wireframing, simulations)
- Iterate based on findings from prototyping
- Clearly identify the purpose of creating the prototypes
- Evaluate the effectiveness of an implemented design solution

Section 4. Understanding of Aerospace Safety
For each knowledge area below, rate your degree of confidence in applying this knowledge to make sound engineering judgement.

High confidence in your knowledge would be that you think you can make sound judgment because you have already been successfully taught the topic or have a good understanding of it on your own.

Low confidence in your knowledge would be that you do not trust your engineering judgement in this area because you have not been taught the topic, have patchy understanding of the topic, or would not know what to do if you encountered a problem in this knowledge area.

(0 = low confidence, 10 = high confidence)

- Knowledge about the aerospace engineering industry
- Knowledge about aircraft
- Knowledge about spacecraft
- Knowledge about aerospace vehicles
- Knowledge about the aerospace engineering vehicle design process
- Knowledge of applied mechanics: statics and dynamics
- Knowledge of incompressible flows
- Knowledge of compressible flows
- Knowledge of viscous flows
- Knowledge of aerospace materials
- Knowledge of aerospace structures
- Knowledge of aerospace dynamical systems
- Knowledge of aerospace control systems
- Knowledge of aerospace propulsion systems

Section 5. Application of oral and written communication skills
For each item below, rate the extent to which you do the following (never/rarely/sometimes/often/always)

- Present with ease in front of an audience
- Take the lead in a group discussion

- Give constructive feedback to peers
- Consider the knowledge of your audience when giving a presentation
- Gather information from different sources for a report
- Use published standards (e.g., IEEE, AIAA) to structure a technical report
- Compose professional correspondence (e.g., emails to colleagues)
- Produce error-free technical reports

Section 6. Application of cognitive and social collaboration skills

For each item below, rate the extent to which you do the following (never/rarely/sometimes/often/always) **when working in groups**:

- Remind the group how important it is to stick to schedules
- Construct strategies from ideas that have been raised
- Clearly define the roles of each group member
- Move the group's ideas toward a strategy
- Evaluate how well the group is progressing toward a goal
- Use feedback from group members to suggest a possible solution
- Take initiative to interact with group members
- Provide emotional support to my group members
- Be sensitive to the feelings of other people
- Show that I care about my group members
- Be there for others when they need me
- Be open and supportive when communicating with others
- Negotiate different ideas with group members to achieve a resolution

Section 7. Entrepreneurial Mindset

For each item below, rate the extent to which you agree with the following (strongly disagree/disagree/slightly disagree/slightly agree/agree/strongly agree):

- I tend to get involved in a variety of activities
- I enjoy being involved in a variety of activities
- I participate in a wide range of hobbies
- The idea of tackling society's biggest problems motivates me
- I believe it is important that I do things that fix problems in the world
- I am driven to do things that improve the lives of others
- I can easily tune into how someone else feels
- Other people tell me I am good at understanding their feelings
- I know when I need to ask for help
- I am comfortable asking others for help

Reliability of sections 2–7 was assessed using Cronbach's alpha. Constructs were classified based on their alpha values:

- $\alpha < 0.60$: Invalid grouping (questions do not align cohesively).
- $0.60 \leq \alpha < 0.80$: Valid grouping.
- $\alpha \geq 0.80$: Optimal grouping.

Reliability results are summarized in Table 3.

Table 3. Reliability Results per Survey Section

Learning Progression/KEEN Construct	**200-Level**		**400-Level**	
	Pre	Post	Pre	Post
Sr. 2: Empathy-Related Processes	0.861	0.889	0.827	0.887
Sr. 3: Iteration-Related Processes	0.916	0.931	0.849	0.911
Sr. 4: Understanding of Aerospace Safety	0.939	0.945	0.884	0.927
Sr. 5: Oral & Written Communication Skills	0.784	0.814	0.728	0.747
Sr. 6: Cognitive & Social Collaboration Skills	0.888	0.917	0.896	0.909
Sr. 7: Curiosity	0.827	0.821	0.800	0.857
Sr. 7: Create Value	0.839	0.914	0.858	0.894
Sr. 7: Make Connections	0.745	0.787	0.723	0.743

In the pre-test, all sections for the 200-level course achieved optimal reliability, with Cronbach's alpha values consistently exceeding 0.80. Similarly, for the 400-level course, sections 5 ($\alpha = 0.728$) and 7: Make Connections ($\alpha = 0.723$) demonstrated valid reliability, while the other sections achieved optimal reliability. In the post-test, all 200-level sections exhibited optimal reliability, except Section 7: Make Connections ($\alpha = 0.787$). In AE483, all sections except for Section 5 ($\alpha = 0.747$) and Section 7: Make Connections ($\alpha = 0.743$) achieved optimal reliability ($\alpha \geq 0.80$).

Written Reflections

The 200-level students completed written reflections for two in-class, team-based mini-projects and one final project to capture qualitative insights toward their learning and teamwork experiences. For the first mini-project, which took place during one class period, students answered four questions about their prior exposure to similar tasks, initial observations, challenges encountered during group work, benefits of collaboration, and suggestions for improving teamwork in future exercises. For the second mini-project (glider-catapult), students responded to five questions focused on a hands-on design and testing project. Their reflections included describing the intended user's experience, safety considerations, group collaboration challenges, previous teamwork adjustments, and potential strategies for future improvements. The final project reflection followed a similar format, with students addressing five questions related to their individual roles, difficulties and benefits of teamwork, comparisons between current and past projects, and identifying one teamwork strategy they intended to carry forward.

Survey Data Preparation

Written responses for section one were coded using a rubric that assessed definitions as being naive (level 1), intermediate (level 2), or informed (level 3). Table 4 describes the rubric.

Table 4. Coding Rubric for HCED Definitions

Definition Level	**Description**	**Examples**
Naïve (1)	The definition is broad and does not indicate that HCED is a problem-solving approach.	"Engineering design focused on the human element." "Design that is centered around usability and accessibility." *In these examples, design is treated as a product (i.e., a final design) and not a process.*
Intermediate/ Developing (2) *For this level, specify which practice(s) are included.*	The definition indicates that HCED is a problem-solving approach. It may point out at least one of its major practices (empathy, iteration, consideration of implementation dimensions). *Implementation dimensions should be considered in global/real-world context. Considerations connecting directly to user needs constitute empathy.*	"Designing primarily around the needs of human users." "A program for finding solutions to real-life issues using engineering concepts." "Human-centered engineering design is design with a focus on accessibility and use for people." "HCED is designing something with an engineering basis while also keeping in mind the people who it is designed for by iterating multiple times and getting feedback from stakeholders multiple times so that the product is best designed to achieve its intended purpose for its intended audience." *These examples show evidence of an ongoing or actionable process but do not encompass all three major practices. Any reference to an approach, method, or project happening over time indicates a process.*
Informed (3)	The definition indicates that HCED is a problem-solving approach and points out all three major practices (empathy, iteration, consideration of implementation dimensions).	"Human-centered engineering design is the process of design in which the engineers prioritize the user experience and needs. This involves identifying the main design goals, empathizing with the user, then implementing those ideas and iterating based on feedback." "Human-centered engineering design focuses on creating solutions that prioritize the needs, experience, and limitations of people bny integrating empathy, usability, and feedback into the design process. It seeks to enhance functionality and user satisfaction by addressing both technical and human factors."

Students' responses to Likert-scale items were averaged per section for pre-/post-test comparison. Responses in Sections 5 and 6, ranging from "never" to "always" (see Appendix), were encoded on a scale of 1 to 5. Questions in Section 7 were grouped into the following three sub-constructs based on KEEN's 3Cs framework: "curiosity," "make connections," and "create value." Histograms and bar plots were used to highlight response distributions and group differences. These visualizations provided a clear depiction of variations in survey responses, making it easier to identify trends and outliers.

The pre-post analysis was conducted using the Wilcoxon Signed-Rank test to evaluate significant changes across the three courses. To ensure consistency, the pre-post analysis was performed only with the subset of students who completed both the pre-survey and post-survey.

Comparative Samples in 400-Level Course

Analysis of the 400-level student data included a subgroup comparison between students who had previously taken the 200-level course with our participating instructor and those who had not. A Wilcoxon Rank-Sum test was performed to compare the score distributions of these independent groups using both pre-survey and post-survey data.

Results

Section 1: HCED Understanding

The encoded responses were analyzed using a combination of visualizations and percentage counts for each level. The majority of responses were concentrated at Levels 1 and 2 (naive and intermediate, respectively), with very few responses at Level 3 (informed).

For the 200-level course, the pre-test results showed that 62% of students (23) were at Level 1, 35% (13) at Level 2, and 2% (1) at Level 3. Post-test results indicated improvement, with now only 29% of students (11) at Level 1 and 68% (26) at Level 2. Figure 1 depicts these percentages.

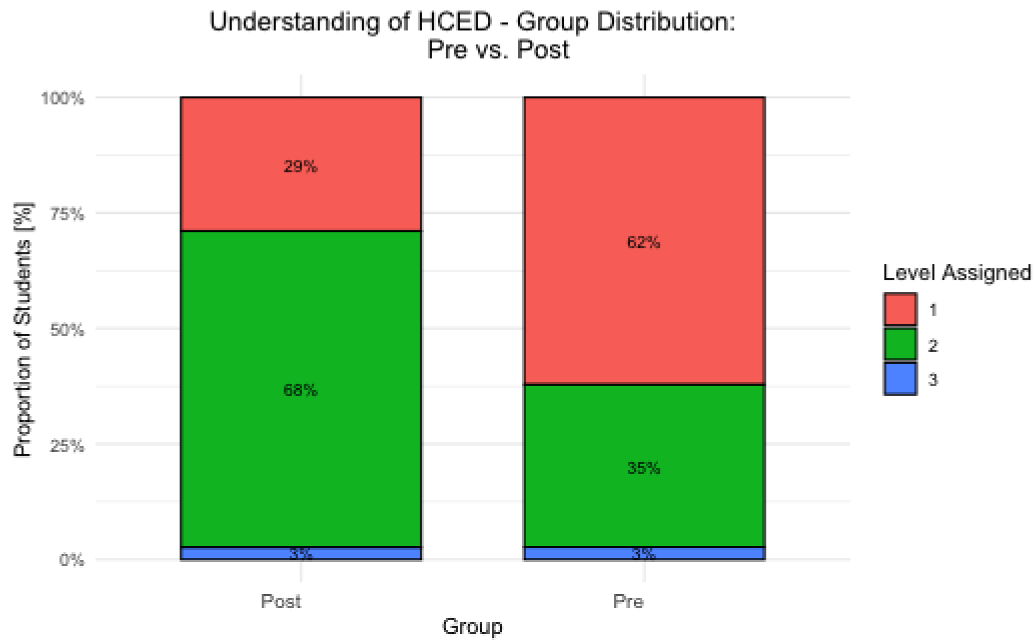

Figure 1. Comparison of Section 1 Definitions for 200-Level Course

Similarly, for the 400-level course, the pre-test results showed that 59% of students (78) were at Level 1, 41% (54) were at Level 2, and 1% (1) at Level 3. The post-test results highlighted progress among levels, with 35% of students (46) at Level 1, 62% (83) at Level 2, and 3% (4) at Level 3. Figure 2 depicts these percentages.

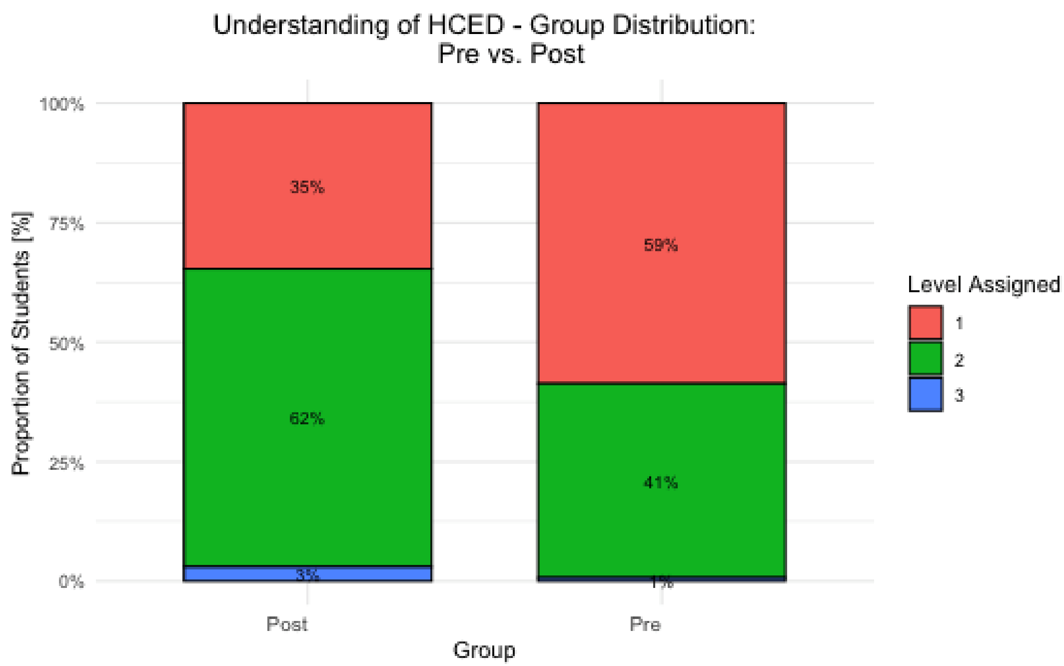

Figure 2. Comparison of Section 1 Definitions for 400-Level Course

Within the 400-level course, subgroups were compared to track the cohort of students that had previously completed the 200-level course with our participating instructor. Figure 3 shows the comparison of subgroups who did (i.e., "yes" group) and didn't (i.e., "no" group) take the 200-level course with our instructor.

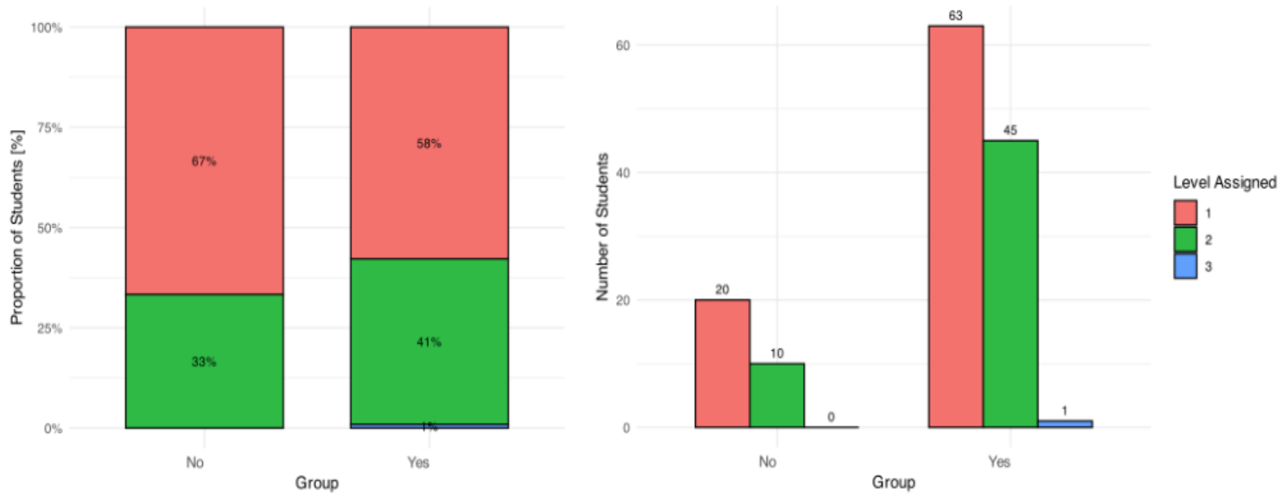

Figure 3. Comparison of Student Subgroups in 400-Level Course

Pre-survey results showed no statistically significant differences across all sections and subconstructs. These results suggest that prior experience during the 200-level course did not significantly influence the pre-test scores scores for any survey sections in the 400-level course. Inspection of the "yes" and "no" pre-test groups (Fig. 3) indicates that a higher proportional level 2 response rate, and the only level 3 response, occurred within the group of students who had previously taken the 200-level course. Post-survey results followed a similar trend, with no significant differences observed between the two groups for all sections and subconstructs.

Sections 2–7: Normality Testing

The normality of the average response distributions for Sections 2–7 per student was evaluated using the Shapiro-Wilk test. These results determined the choice of subsequent statistical tests. Depending on the normality and independence of samples, the following tests were applied:

- Paired-sample T-tests (normally distributed data) or Wilcoxon Signed-Rank tests (non-normally distributed data) for related samples.
- Two-sample independent T-tests (normally distributed data) or Mann-Whitney tests (non-normally distributed data) for unrelated samples.

The significance level (α) was set at 0.05 for all tests. Given that certain samples were not normally distributed (discussed more in detail in the results section), non-parametric tests were applied for all comparisons. The p-values from the Shapiro-Wilk tests performed are presented in Table 5.

Table 5. Significance per Survey Section

Learning Progression/KEEN Construct	200-Level		400-Level	
	Pre	Post	Pre	Post
Sr. 2: Empathy-Related Processes	0.061	0.381	0.010	0.102
Sr. 3: Iteration-Related Processes	0.005	0.254	0.001	0.280
Sr. 4: Understanding of Aerospace Safety	0.322	0.924	0.000	0.095
Sr. 5: Oral & Written Communication Skills	0.068	0.359	0.001	0.200
Sr. 6: Cognitive & Social Collaboration Skills	0.031	0.153	0.017	0.174
Sr. 7: Curiosity	0.000	0.004	0.000	0.000
Sr. 7: Create Value	0.000	0.000	0.000	0.000
Sr. 7: Make Connections	0.033	0.402	0.000	0.002

For the pre-test, the 200-level sections 2, 4, and 5 were normally distributed, while sections 3, 6, and all subconstructs of section 7 deviated from normality. For the 400-level course, every section failed the normality test ($p \leq 0.05$). For the post-test, the 200-level sections 2, 3, 4, 5, and 6, and section 7 (Make Connections) exhibited normality, while the other two subconstructs of Section 7 deviated from a normal distribution. In the 400-level course, sections 2, 3, 4, 5, and 6 were normally distributed, while all subconstructs of Section 7 continued to fail the test. These results primarily highlight the heterogeneity of the samples' distribution, which motivated the decision of performing non-parametric tests for the comparisons.

Sections 2–7: Significance Testing for Pre-Post Comparison

A Wilcoxon Signed Rank-Sum Test (Mann-Whitney U Test) was used to compare the distributions between the Pre and Post samples. This test checks if there is a significant difference in the central tendencies (medians) in the group after the treatment. If the p-value is less than 0.05, we can reject the null hypothesis and conclude that the distributions between the two groups are significantly different. Table 6 provides the p-values per survey section.

Table 6. P-Values per Survey Section

Learning Progression/KEEN Construct	Pre-Post Comparison Test: p-values	
	200-Level	400-Level
Sr. 2: Empathy-Related Processes	0.000	0.000
Sr. 3: Iteration-Related Processes	0.000	0.000
Sr. 4: Understanding of Aerospace Safety	0.000	0.000
Sr. 5: Oral & Written Communication Skills	0.000	0.012
Sr. 6: Cognitive & Social Collaboration Skills	0.039	0.194
Sr. 7: Curiosity	0.066	0.300
Sr. 7: Create Value	0.219	0.130
Sr. 7: Make Connections	0.178	0.514

For the 200-level course, significant differences were observed in Sections 2, 3, 4, 5, and 6. A statistically significant difference is exemplified in Figure 4, which depicts the pre- and post-test results for survey section 4.

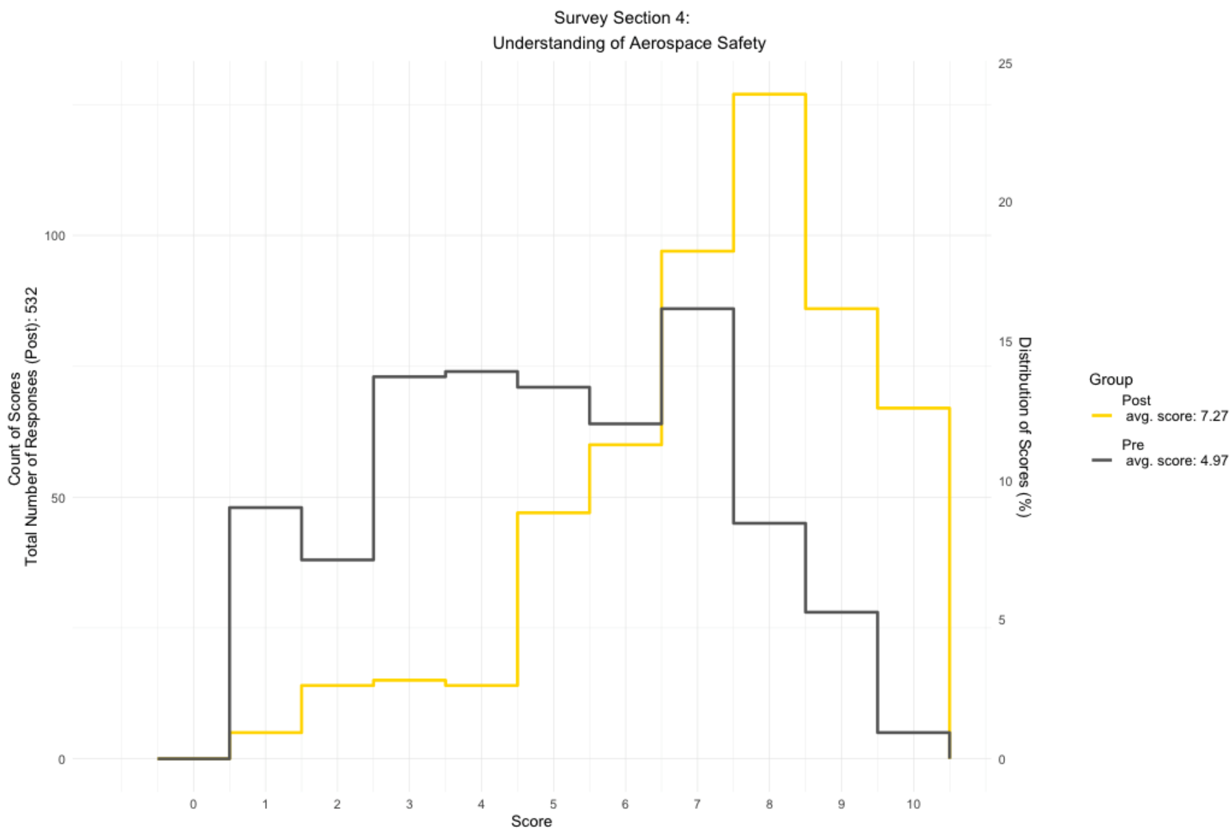

Figure 4. Pre- and Post-Test Average Responses for Section 4 (Safety-Related Processes)

The pre-survey distribution (black line) is more evenly spread across the lower scores, with a peak around 5. This indicates a concentration of responses at the midpoint of the scoring scale, with fewer participants selecting higher scores. In contrast, the post-survey distribution (yellow line) shows a significant shift towards higher scores, with a pronounced peak around 8 and 9. The post-survey distribution is also narrower, with fewer responses at the lower end of the scale, indicating a more consistent perception of understanding across participants. Moreover, the average score increased from 4.97 (pre-) to 7.27 (post-).

During the reflection for the glider-catapult mini-project, eight of the participating students explicitly addressed safety concerns in their responses. For instance, one student reflected on the challenges faced in early testing and how safety measures evolved throughout the project with reference to the glider's catpilot (i.e., user):

"The catpilot flew on three prototypes in total, including the competition glider. The first prototype and the competition prototype both flew well, and the gliders landed safely in most cases, while the second prototype performed poorly and had significant safety issues. After the first incident when the prototype flew into a wall in the narrow corridor, subsequent tests were performed in a much more spacious area to avoid similar accidents. The catpilot was protected by the clay on the competition glider to achieve maximum safety protection."

Another student described the progression from a lack of safety considerations to a more structured approach:

"Looking back on my cat pilot's experience during the project, I would describe it as a scary but exciting experience. The team lacked safety features at first, but quickly learned from their mistakes to ensure successful flights with minimal accidents. They secured me to the plane to ensure there was no chance of the pilot falling out during testing. Towards the end, I believe our cat pilots felt very safe knowing we successfully flew several flights with no accidents."

For the 400-level course, significant differences were identified in Sections 2, 3, 4, 5, and 6, as well as in the "Create Value" subconstruct of Section 7. A statistically significant difference is exemplified in Figure 5, which depicts the pre- and post-test results for survey section 2.

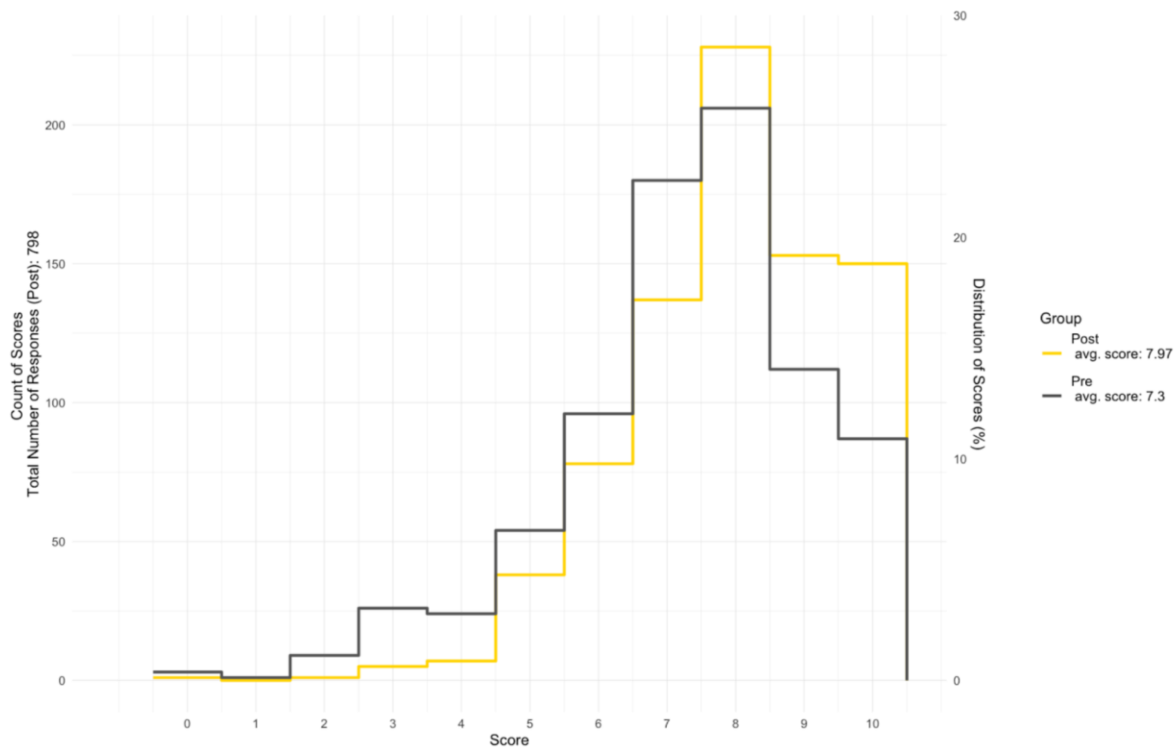

Figure 5. Pre- and Post-Test average Responses for Section 2 (Empathy-Related Processes)

The pre-survey distribution (black line) peaks around scores 6 and 7, with a broader spread across lower scores, indicating that many participants rated their empathy-related processes in the mid-range prior to the intervention. The post-survey distribution (yellow line) shifts noticeably toward higher scores, with a peak at 8 and a clear reduction in responses in the lower score range (e.g., scores below 4). Furthermore, the average score increased from 7.3 (pre-survey) to 7.97 (post-survey).

While the difference in the distributions suggests improvement, the overlap between the curves around scores 6 and 7 suggests that not all participants experienced a significant shift. Nonetheless, the post-survey distribution's higher peak and reduced spread at lower scores demonstrate a positive trend in participants' perceived application of empathy-related processes.

Analysis of students' definitions of human-centered engineering design (HCED) revealed an increase in explicit references to empathy. Per our coding scheme, in the pre-test, only one student (0.75%) explicitly mentioned empathy, whereas in the post-test, three students (2.24 %) included empathy-related language (reflecting a 200% increase in such responses). One example of a post-test definition that highlights empathy is:

"Human-centered engineering design is an approach that prioritizes understanding and addressing the needs, capabilities, and experiences of people throughout the design process. It integrates empathy, user feedback, and iterative problem-solving to create solutions that are practical, accessible, and impactful for the intended users."

Takeaways

Our ongoing efforts are twofold; first, to develop strategic program-level learning progressions; and second, to develop methods for tracking, and evaluating, students as they follow these progressions toward graduation. In previous work, we collaboratively developed a set of six proposed learning progressions based on aerospace PEOs and college-level accreditation requirements. We articulated naive, intermediate, and informed-level performance indicators for each learning progression. In ongoing work, we will continue to seek feedback toward refining these progressions.

In this paper, we focused on our second objective—tracking a cohort of students from one course to another (in this case, from the 200-level to 400-level course). Keeping in mind ABET's call for continuous improvement, we also continued to monitor students in our 200-level course, as we have used the learning progressions framework to co-develop new course activities meant to more deeply engage students in HCED practices (discussed in previous work) [14].

Our statistical analysis found no significant difference between the 200-level and 400-level students who took the pre-test, meaning that students coming into the 400-level course did not answer the survey significantly differently than those coming into the 200-level course. This indicates a need to continue targeting students' engagement in competency-building activities during the lower-level course so that they grow to bring more experience into the 400-level course. However, both courses saw significant differences in students' answers from pre to post, and visualizations confirm that these differences represent shifts from average lower to higher confidence. For both courses, there were significant differences for application of empathy-related processes, application of iteration-related processes, understanding of aerospace safety, oral & written communication skills, and cognitive & social collaboration skills. For the 400-level course, there was also a significant difference for KEEN's "create value" construct. These trends suggest that students' participation in each course may have impacted their feeling of confidence regarding items pertaining to these competencies.

It is also promising to compare the subgroups of students in the 400-level course who did and didn't previously take our 200-level course. Nominally, the proportional increase of intermediate-level definitions, as well as the presence of an informed-level definition, demonstrate a favorable trend in terms of students building on previous experience. More importantly, the comparison demonstrates our ability to track cohorts of students from course to course, which is valuable for program-level design and formative assessment measures. Tracking students' journeys through the program also sets the stage for earlier, more frequent interventions with students to support their competency development.

Limitations and Next Steps

We recognize that students continue to grow and learn outside of and beyond the university environment. This study does not capture or control for students' opportunities to develop competencies outside of our participating classrooms, which narrows our view of their progress. The ability to track students beyond graduation would also be informative for future studies, as this would allow us to both investigate the potential benefits and drawbacks of our program's design as it relates to the workplace, as well as witness further skills development.

While the survey results show promise, further evidence is needed to determine a causal relationship between course activities and students' confidence levels. Students who previously took the 200-level course would have also taken the survey previously, meaning that repeated interactions with the survey may have inflated their self-reported confidence. More in-depth analysis is required to establish a relationship between survey results and the impact of interventions in each course.

In ongoing work, the research team will continue to track the cohort of students through the capstone senior design course. The team will also continue to focus on implementing activities among courses that engage students in developing the specified competencies—in other words, building out measurable learning progressions across the sequence of required courses.

Conclusion

We used a pre-/post-test survey to track a cohort of students across two required courses in a four-year aerospace engineering program. The survey's items corresponded to our previously-developed learning progression framework, which outlines a set of six desirable competencies for engineering students to develop as they move through the program. These efforts are part of ongoing work to establish learning progressions across a sequence of required courses in the program. Our pre-/post-test results indicated significant differences in the majority of sections, with all but one survey section experiencing a positive shift in average responses from pre to post (in other words, an increase in reported confidence level). We also demonstrated the ability to differentiate among cohorts of students, and inspected their responses for differences. In our 400-level lab course, students who had previously taken our 200-level course tended to define HCED at an average intermediate level, whereas those who did not tended to define HCED at an average naive/beginner level.

While more in-depth analysis is needed to establish causal relationships between students' confidence levels and course activities, these efforts demonstrate a viable tracking method that can be continued in future semesters of the program. Future work will investigate the impact of our course activities on students' competency development. Our work seeks to contribute to program development for engineering education by promoting the implementation of strategic learning progressions that engage students in developing relevant 21st-century skills.

Appendix

Fall 2024 Pre-/Post-Test Survey Demographic Items

Race/Ethnicity: Which of the following best describes you?

- Asian or Pacific Islander
- Black or African American
- Hispanic or Latino
- Native American or Alaskan Native
- White or Caucasian
- Multiracial or Biracial
- A race/ethnicity not listed here
- Prefer not to answer

Gender: Which of the following best describes you?

- Female
- Male
- Transgender
- None of these
- Prefer not to answer

References

[1] J.D. Plummer and L. Maynard, "Building a learning progression for celestial motion: An exploration of students' reasoning about the seasons," *Journal of Research in Science Teaching*, vol. 51, pp. 902–929, 2014.

[2] National Research Council, "A framework for K–12 science education: Practices, crosscutting concepts, and core ideas," Washington, DC: The National Academies Press, 2012, doi:10.17226/13165.

[3] National Research Council, "Taking science to school: Learning and teaching science in grades K–8," Washington, DC: The National Academies Press, 2007, doi:10.17226/11625.

[4] T. Corcoran, F.A. Mosher, and A.D. Rogat, "Learning progressions in science: An evidence-based approach to reform," *New York, NY: Columbia University, Teachers College, Center on Continuous Instructional Improvement*, 2009. https://files.eric.ed.gov/fulltext/ED506730.pdf

[5] L. Kaldaras, K. Haudek, and J. Krajcik, "Employing automatic analysis tools aligned to learning progressions to assess knowledge application and support learning in STEM," *International Journal of STEM Education*, vol. 11, no. 57, pp. 1–17, 2024.

[6] "Criteria for accrediting engineering programs, 2025–2026," abet.org. Accessed: Jan. 10, 2025. [Online]. Available: https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2025-2026/.

[7] T. Tucker, A. Pagano, and S. Shehab, "Merging human-centered design with engineering design: Synthesizing a human-centered engineering design framework," in *The 2023 ASEE Annual Conference & Exposition, Baltimore, Maryland, USA, June 25–28, 2023.* ASEE, 2023.

[8] T. Brown, "Design thinking," Harvard Business Review, pp. 1–9, 2008.

[9] S. Shehab and C. D. Schmitz, "WIP: The impact of human-centered design modules on students' learning in an introduction to electronics course," 129th ASEE Annual Conference. Minneapolis: American Society for Engineering Education, 2022.

[10] A. Pagano, S. Shehab, and L. Liebenberg, "WIP: Introducing Students to Human -Centered Design in a Design for Manufacturability Course," in 2020 ASEE Virtual Conference, 2020, p. 12.

[11] "Siebel Center for Design," designcenter.illinois.edu. Accessed: Jan. 9, 2025. [Online]. Available: https://designcenter.illinois.edu/

[12] L. Lawrence, S. Shehab, and M. Tissenbaum, "The development and implementation of a taxonomy for teaching and learning human-centered design," in *The American Society for Engineering Education Virtual Conference, July 26–29, 2021.* ASEE, 2021.

[13] Kern Family Foundation, "The KEEN framework: A guide for entrepreneurial mindset," engineeringunleashed.com. [Online]. Available: https://orchard-prod.azurewebsites.net/media/Framework/KEEN_Framework_v5.pdf

[14] T. Parks, S. Shehab, T. Bretl, E. Wroblewski, and M. Lembeck, "WIP: Using a human-centered engineering design framework to develop learning progressions in an aerospace engineering program," in *the 2024 ASEE Annual Conference & Exposition, Portland, Oregon, USA, June 23–26, 2024.* ASEE, 2024.

[15] E. Wroblewski, “Glider-catapult laboratory with catpilot stakeholders,” engineeringunleashed.com. Accessed: Mar. 10, 2025. [Online]. Available: https://engineeringunleashed.com/card/4338
[16] S.R. Brunhaver, J.M. Bekki, A.R. Carberry, J.S. London, and A.F. McKenna, “Development of the Engineering Student Entrepreneurial Mindset Assessment (ESEMA),” in *Advances in Engineering Education, Fall 2018.* American Society for Engineering Education, 2018.