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Work In Progress: Investigating and Coding Design Signatures using Longitudinal Report Data in a Capstone Engineering Course

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Introduction

In modern engineering education, instructors often face the challenge of balancing heavy course content and limited lecture time with large class size and fast-paced projects. Yet, the ability to provide feedback, and correction when necessary, to student teams during these projects is critical for supporting teams' project outcomes. Feedback and prompted self-reflection are particularly important during high-stakes, team-based design projects, which often have significant impact on students' final grades and also represent an opportunity for students to apply and practice the knowledge and skills they developed in their course or sequence of courses. Atman et al. [1] noted that design has been increasingly taught in engineering courses over the last decade, meaning that there are ongoing opportunities to improve the effectiveness of design learning for students. It follows that, as students engage in a collaborative design project, it is important for them to reflect on their design process and progress as a team. Furthermore, understanding teams' progress on complex projects is critical for instructors to provide timely, comprehensive feedback and support.

Background

Need for Design Process Visualization in Engineering Education

Atman et al.'s playground study [2], which compared the design processes of first-year students, fourth-year students, and experts for the same design problem, demonstrated that different skill levels exhibit different design activity patterns. It follows that inspecting these patterns can be beneficial for both students and instructors. Doing so can build an understanding of the nature of the students' design process, which in turn can support them in evolving their process (and their design skills). Instructors can also use this information to scaffold students' engagement in patterns that more closely resemble those of experts.

Design education research [e.g., 1] has advocated for engineering programs to support students in visualizing and understanding their own design processes. Learning sciences literature [e.g., 3] indicates that students' knowledge building and application is influenced by how they organize the knowledge they take in, and that they are more likely to be able to transfer knowledge when they organize it in a meaningful conceptual framework [4].

Design Signatures

One conceptual framework that can support students in real-time reflection during a design project is the design signature, which has been established as a tool used for visualizing and characterizing an individual's or team's design journey [5]. These are labeled visualizations of design timelines, or the sequence of design processes in which a team engaged over time [5]. Brehmer et al. [6], building on work from Aigner et al. [7], note that timelines depict a sequence of events, which is a form of interval data that is distinguishable from instant or continuous data. To produce a design signature, teams must reflect on the design processes in which they engaged during their task, activity, or project. Teams can continue generating design signatures throughout the duration of the task or project, meaning that the signatures will become richer with information as the teams continue to work. Atman [5] notes that typical models of design have lost the "potential complexity of the flow of design processes" (p. 140), whereas reflecting on a team's timeline provides insight toward the team's unique design activity.

Evaluating the Content of Design Signatures using Human-Centered Design

While these signatures provide a structured visual representation of teams' design activities, they do not indicate the extent to which team members accurately characterized their own design behaviors. Thus, there is a need to be able to evaluate the quality of the signatures so that instructors can both support teams in their process and correct or guide their process when the teams encounter obstacles or misconceptions. Furthermore, evaluating their own process can support students in building richer design knowledge. To pilot a method for evaluating design signatures, we relied on the human-centered design (HCD) taxonomy outlined in Lawrence et al. [8], which describes HCD as a non-linear design process made up of five spaces that are each comprised of four defining practices. The diagram of the HCD taxonomy is depicted below (Figure 1).

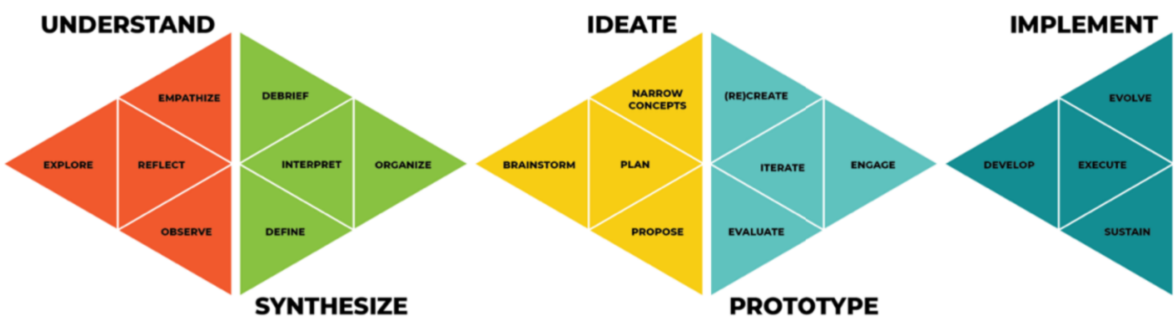

Figure 1. HCD taxonomy: Spaces and practices

Positionality & Research Questions

We are a team of researchers from the Siebel Center for Design and faculty in the Materials Science & Engineering (MatSE) Department at the University of Illinois Urbana-Champaign. In this work-in-progress paper, we describe efforts to develop design signatures in a capstone two-semester engineering course sequence. In previous work [9, 10], our team collaborated on the redesign of this course, which included the integration of human-centered design within the capstone projects. In this paper, we present the process of generating and evaluating design signatures using evidence from teams' progress reports. Our ongoing work seeks to answer the following research questions:

RQ1: What do teams' design signatures look like during a capstone design project?
RQ2: How can the teams' design signatures provide insights into the teams' HCD journey during the capstone project?

Research Methods

In this paper, we use a multi-case study design to compare the design signatures of three capstone teams. Each team's case illustrates a common pattern characterizing the design journey of multiple teams in the capstone course. For purposes of showcasing the method of producing design signatures from progress reports, in this paper we rely solely on the information provided in the reports. The primary researchers never interacted directly with students, and no member of the team provided feedback to students regarding their design signatures or shared the design signatures with teams, which would be a step in future work.

Progress Reports

Teams' weekly progress reports included prompts for students to identify the HCD spaces and processes (i.e., subspaces) in which they engaged, and to identify the activities they completed that fit each space and process. Figure 2 (below) shows the prompts that teams answered each week, marking the spaces and processes and writing out the activities they had completed that aligned with each selection. A complete report template is provided in the Appendix (Figure A). In the first semester of the course sequence, teams received a lecture that introduced the HCD taxonomy and its role in engineering design projects. The lecture content served to familiarize teams with taxonomy prior to engaging with it in the reports. Teams were then explicitly instructed to reflect on their human-centered design activity in their weekly reports. We did not assess the extent to which students accurately understood the HCD taxonomy following the lecture, although all students had the opportunity throughout the course to clarify information as needed. Future work could assess the lecture's impact using a pre-/post-test survey, in-class quiz, or similar measure.

Understand	Synthesize	Ideate	Prototype	Implement
Explore	Debrief	Brainstorm	Create	Support
Observe	Organize	Propose	Engage	Sustain
Empathize	Define	Plan	Evaluate	Evolve
Reflect	Interpret	Narrow Concepts	Iterate	Execute

3. Provide a brief list of activities that were done and their corresponding HCD space(s) and subspace(s) (add rows if necessary):

Activity	HCD space(s)	HCD subspace(s)

Figure 2. The human-centered design-focused section of the weekly progress reports

For purposes of this study, we focused primarily on the report section shown in Figure 2, using additional information from other sections of the report to supplement our assessment of each team's activities when possible. Individual team members were not identified in reports. Team names were blinded for data analysis.

Development of Design Signatures Generation Process

The research team inspected the progress reports from all 13 teams who participated in the two-semester capstone course sequence during the Fall 2024–Spring 2025 academic year. We focused on the progress reports from the Spring 2025 semester, which was the second semester in the sequence and the one during which teams developed and tested prototypes of their design solutions.

To be able to easily compare information provided in the reports, we drew on the example set by the design signatures application [11] and constructed a form of design signature that visualized the spaces (Figure 3, column 1 from left) and practices (Figure 3, column 2 from left) selected by a team each week. We used a binary format in which all possible choices were marked as 0 unless selected by the team, at which point they were assigned a 1. Figure 3 depicts an initial design signature for one team constructed from our inspection of the reports.

	Week	3	4	5	6	7	8	9	10	11	12	13
Understand	Explore	1	1	1	1	0	0	0	0	0	0	0
	Observe	1	0	0	0	0	0	0	0	0	0	0
	Empathize	0	1	1	0	1	0	0	0	0	0	0
	Reflect	1	1	1	1	0	0	0	0	0	0	0
Synthesize	Debrief	0	0	1	0	0	0	0	0	0	0	0
	Organize	1	0	1	0	0	1	0	0	0	0	0
	Define	1	0	0	0	0	0	0	0	0	0	0
	Interpret	0	0	1	0	0	0	0	1	1	0	0
Ideate	Brainstorm	1	1	0	1	1	0	0	1	0	0	0
	Propose	1	0	1	0	1	0	0	1	1	0	0
	Plan	1	0	1	1	1	0	0	1	1	0	1
	Narrow Concepts	0	0	0	0	0	0	0	0	0	0	0
Prototype	Create	0	0	0	0	0	1	1	1	0	0	0
	Engage	0	0	0	0	0	1	0	0	1	0	0
	Evaluate	0	0	1	1	1	1	1	1	1	0	0
	Iterate	0	0	1	0	1	0	1	0	0	0	0
Implement	Support	0	0	0	0	0	0	0	0	1	0	0
	Sustain	0	0	0	0	0	0	0	0	0	0	0
	Evolve	0	0	0	0	0	0	0	0	0	1	0
	Execute	0	0	0	1	0	0	1	1	1	1	1

Figure 3. Example of initial design signature generation using binary format

From comparing the spaces and practices that each team had selected, we determined that teams could roughly be divided into one of three patterns of reported design journeys : 1) engagement across all HCD spaces, 2) heavy engagement in one HCD space with some engagement in other spaces, and 3) near-exclusive engagement in one HCD space.

Team Selection

We omitted teams who had not submitted a complete set of weekly progress reports, which were submitted for weeks 3–13 of the 16-week semester (11 reports total per team). This reduced the population of teams from 13 to nine. From the remaining teams, we selected one team that seemed to illustrate each of our three patterns of design journeys based on their reports and initial signatures. This reduced our data set to 33 reports among the three teams.

Coding Scheme Development

We discussed insights from our initial inspection of the reports and formulation of categories with members of the teaching team to formulate a coding scheme, which we then refined through the process of coding reports and discussing the results. We found that the reports typically did not contain enough evidence to properly evaluate the practices identified by teams, which had been included in the initial design signatures generation depicted in Figure 3. Thus, we moved to evaluate the signatures at the HCD space level. The finalized coding scheme is presented in Table 1 below.

Table 1. Coding scheme for weekly progress report data

Color	**Definition**	**Examples** *(student responses)*
Green	Teams select an HCD space and provide evidence for their selection that aligns with the definition of the selected HCD space.	Selection: prototype Evidence: *simulation work (fixed animation)*
Yellow	Teams select an HCD space but do not provide supporting evidence for their selection.	Selection: prototype Evidence: *Finished research poster covering introduction, methods, data analysis, future work, interviews, and conclusion* (unclear how finishing the poster fits the proposed space)
Red	Teams select an HCD space and provide evidence that does not align with the definition of the selected HCD space	Selection: implement Evidence: *Conducted data analysis of impact testing* (this evidence fits the prototype space)
(blank)	Space not selected	

Data Analysis

To establish reliability, two researchers each coded nine of the 33 progress reports (27%) of the progress reports and compared their results. The reliability data set included one report from each of the three teams for the first, middle, and last week of the 13-week period. Discrepancies were resolved through discussion, with a final reliability of 100% agreement. Once reliable, one researcher coded all remaining progress reports for the three teams. Once trained on the coding scheme, the coding took three minutes on average per report. The reports were then compiled into design signatures with the additional evaluation layer added. Instead of the binary system shown in Figure 3, we counted the number of instances in which teams selected each space each week. For example, if a team provided three different activities that were assigned to the prototyping space in week 3, they would receive a 3 for that space. To count these instances, we treated each activity line filled out in the table provided in each design report as one unit of analysis. We present these signatures as Cases 1, 2, and 3 below.

Results

Figures 4, 5, and 6 show the evaluated design signatures of the three selected teams. In each of these figures, we delineated by color so that the signatures show the counts of code type per each space. Thus, each week's column has been separated into three subcolumns to show the numbers of green, yellow, and red codes per space, with blanks indicating zero.

Case 1

	Week																																
Space	**3**			**4**			**5**			**6**			**7**			**8**			**9**			**10**			**11**			**12**			**13**		
Understand	1			3			1		1			1	1																				
Synthesize	1						2		1							1											1						
Ideate			1			1	2		1	2			2									1				1							1
Prototype			1						2	1			2			3	1		2			4			3								
Implement												1									3	3		1		1	3	2	1			1	

Figure 4. Case 1 design signature across 11 weeks

The Case 1 design signature demonstrates engagement in all five HCD spaces. Furthermore, the team engaged more in the understand and synthesize spaces earlier in the semester, and transitioned to more engagement in prototyping and implementation later in the semester. Of all coded HCD activities (62), 60% (37) were coded as aligned with the correct HCD space, 30% (19) were coded as misaligned, and 10% (6) were coded as having insufficient evidence. This team reported more than twice the number of HCD activities than either of the other teams.

Case 2

	Week																																
Space	**3**			**4**			**5**			**6**			**7**			**8**			**9**			**10**			**11**			**12**			**13**		
Understand	1						1									1																	
Synthesize	1																1																
Ideate	1			2			1	1		3			2						1							1		1	1			1	
Prototype																						3			1								
Implement																					1												

Figure 5. Case 2 design signature across 11 weeks

The Case 2 design signature demonstrates a majority engagement in the ideation space, with some engagement in the other spaces during select weeks. The team reported engagement in ideation in all but two of the 11 weeks. Their next highest level of engagement focused on the understand space, which was reported in three different weeks. Of all coded HCD activities (25), 76% (19) were coded as aligned with the correct HCD space, 4% (1) were coded as misaligned, and 20% (5) were coded as having insufficient evidence. This team has the highest percentage of correctly aligned responses and the lowest total number of HCD activities reported.

Case 3

	Week										
Space	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Understand											1
Synthesize											1
Ideate		1									1
Prototype	1	1	2	2	3	3	2	2	2	1	2
Implement											1

Figure 6. Case 3 design signature across 11 weeks

The Case 3 design signature demonstrates a nearly exclusive focus on the prototyping space, with very limited engagement in the other spaces. This team reported nearly the same number of HCD activities (26) as the team in Case 2, with 73% (19) coded as aligned with the correct HCD space and 27% (7) coded as misaligned.

Discussion

In comparing the results of the design signatures, there are some obvious differences among the teams that can help us understand how these visuals can provide insights toward the teams' human-centered design journeys. Case 1 demonstrates a noticeably higher volume of reported HCD activities, which may suggest stronger engagement in the design project under the assumption that all three projects were comparable in scope and difficulty. This difference in behavior may also indicate impact from other factors—for example, in a situation in which the three projects were not designed equally, the difference in behavior could indicate that all three teams appropriately scoped and participated in their projects per the level of difficulty or complexity provided. Thus, the design signature can help us identify discrepancies in teams' design processes that can highlight where further review of the project materials, team dynamics, or other factors may be needed.

Case 1 is also the only one in which the team accurately engaged in all five HCD spaces, which speaks both to the efficacy of their self-reflection and the extent of their immersion in the human-centered design process. While HCD is not a linear process, it is natural that designers engage more in the understand and synthesize spaces early in their design journey, when they are framing the problem and gathering and synthesizing information. Once designers have done this, it is then logical to assume that they will spend more time ideating and prototyping, as they now have information that can guide their brainstorming. Case 1 demonstrates this behavior over time, with heavier engagement in the understand and synthesize spaces in weeks 3–8 and heavier engagement in ideating, prototyping, and implementing in weeks 9–13.

Comparatively, Cases 2 and 3 demonstrate much narrower design processes. These cases indicate a different sort of design pattern, in which specific HCD spaces were targeted, whether inadvertently or by design. Furthermore, as previously discussed, if we assume that all projects in the course are comparable in scope and level of difficulty, then the reduced volume of HCD activities reported in these cases may indicate a lower level of engagement in the projects. The similarity in Cases 2 and 3 indicate that these teams' deviation from the design behaviors demonstrated in Case 1 resulted in similarly reduced levels of activity. However, both of these teams still reported the majority of their activities accurately, and had a higher percentage of accurate activities than did the team in Case 1. Thus, the idea that the projects themselves may have differed significantly, or that the teams' design behavior may have been impacted by other factors, indicates the need for deeper review in order to provide comprehensive feedback.

All three of these cases provide valuable insights toward the teams' design journeys. In Case 1, the design signature could be used to highlight instances in which the team inaccurately reported their HCD space, as well as opportunities where more evidence could be provided. From a reflective standpoint, this information can benefit the team's design learning by helping them to correct misconceptions and guiding them in articulating their activities. In Cases 2 and 3, the design signatures can help teams to evaluate their design process within the bigger picture of the full taxonomy. For example, it is likely that Case 3's targeted focus on prototyping did not happen on purpose, but rather was the result of other factors such as the team members' previous experiences (or lack thereof) with design. Helping them to evaluate their design process could support them in making conscious design decisions moving forward.

For instructors, these design signatures visualize opportunity areas for targeted feedback. They can also highlight areas that may require review or where iteration may be needed to improve the project experience for future teams. Furthermore, they support instructors in scaffolding students' engagement in the design process. In Case 1, an instructor might note that the team incorrectly selected the ideation space during the first three weeks and intervene with the team to address any misconceptions that may be influencing their choices. In Case 2, the shift from prototyping back to ideation toward the end of the 13 weeks may indicate that the team found reason to revisit their ideas for the final design or generate new ideas. An instructor could check in with this team to make sure they are on track to complete their final deliverables. In Case 3, an instructor could discuss the team's persistent focus on prototyping to determine whether guiding them to spend time in other spaces would be beneficial to their process.

Limitations

We did not have sufficient evidence to be able to evaluate the teams' design signatures at the HCD processes level. Future iterations of the progress reports can include more explicit prompts for teams to provide process-level activities evidence. As we analyzed at the team level, we did not control for team formation nor collect demographic information from the teams. While all teams received the same prompts for providing the activities that corresponded to their HCD engagement each week, we did not control for the level of detail provided by each team. We did not control nor inspect the comparative level of difficulty of the capstone projects.

Conclusion & Next Steps

In this paper, we demonstrated a method of generating and evaluating design signatures using evidence provided in the weekly progress reports from student teams working on design projects in a capstone course. We showcased this method through manual coding, which can be replicated by other research teams. However, we recognize that teaching teams have limited time and bandwidth to produce design signatures manually. Thus, in ongoing work that will be disseminated in a future publication, we are working to automate the coding process using machine learning, with the long-term goal of developing a tool that instructors can use to produce signatures in real time.

Our method uses a human-centered design taxonomy established in literature [8] as the basis for generating and evaluating these signatures. These efforts are significant for engineering design education because they lay the foundation for inspecting teams' design signatures in real time, which can support instructors in providing comprehensive feedback during the project and also engage students in reflecting on their design learning. Future work should pilot the process of providing such feedback to students and evaluate the impact of these interventions on teams' performance.

In ongoing work, we plan to compare the generated design signatures to teams' performance on their projects. We will also use the demonstrated method to generate design signatures that can evaluate teams' engagement with KEEN's three Cs [12], which can support instructors in scaffolding teams' entrepreneurial mindset development during collaborative projects.

Appendix

Progress Reports are graded on the (i) write-up of what has been accomplished and (ii) the amount of said progress on the overall project.

1. Group Number and Title:

2. Week: and Date:

Understand	Synthesize	Ideate	Prototype	Implement
Explore	Debrief	Brainstorm	Create	Support
Observe	Organize	Propose	Engage	Sustain
Empathize	Define	Plan	Evaluate	Evolve
Reflect	Interpret	Narrow Concepts	Iterate	Execute

3. Provide a brief list of activities that were done and their corresponding HCD space(s) and subspace(s) (add rows if necessary):

Activity	HCD space(s)	HCD subspace(s)

4. What blocks was work focused on this week?

5. What was accomplished? (4-5 bullet points, include data/charts if applicable)

6. What challenges are still outstanding? (2-5 bullet points)

7. As you engaged in human-centered engineering design activities this week, do you think you became curious about any new content? If yes, how?

8. As you engaged in human-centered engineering design activities this week, do you think you made any new connections (e.g. connections between ideas, connections between people, etc.)? If yes, how?

9. As you engaged in human-centered engineering design activities this week, do you think you created any value (e.g. identified a way to work together more efficiently, found a way to improve your idea or design, etc.)? If yes, how?

10. What feedback did you obtain from the instructor or TA last week that you addressed in your work this week?

Figure A. Weekly progress report template

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