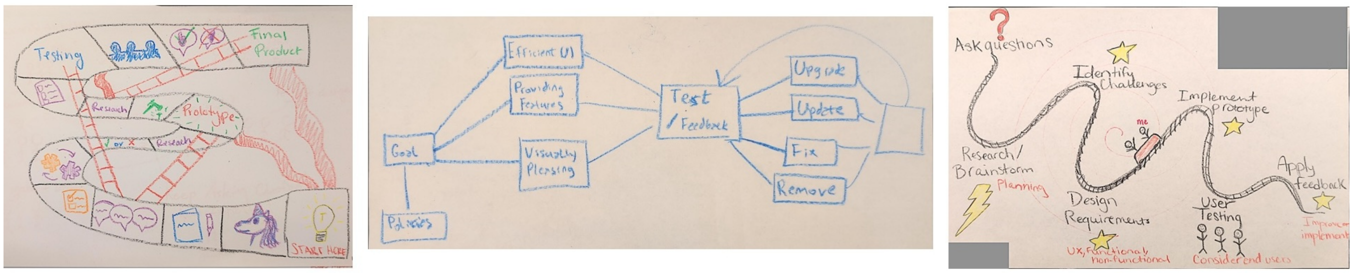
Visualizing Human-Centered Design: A Replication and Extension Study

Alannah Oleson
Computer Science
University of Denver
Denver, CO, USA
alannah.oleson@du.edu

Yuliya Kim
Computer Science
University of Denver
Denver, CO, USA
yuliya.kim@du.edu



(a) (b) (c)

Figure 1: Computing students' drawings of what human-centered design means to them. (a) A multicolor loop-shaped map image that depicts design as a board game from an undergraduate in the *Early* activity; (b) A monochromatic loop-shaped flow chart diagram with neutral emotional valence from a graduate student in the *Early* activity; (c) A multicolor narrative linear-shaped image that depicts design as a roller coaster from an undergraduate in the *End-of-Class* activity.

Abstract

Replication studies are rare in human-computer interaction (HCI) and computing education research, but they are a foundational part of building robust, generalizable HCI pedagogies. In this paper, we present the results of a *replication* of Gorichanaz's 2025 EduCHI paper "Visual Representations of Human-Centered Design by Students in Computer and Information Science" in a novel setting, following the original study's quantitative content analysis & metaphor analysis methods augmented by our own inductive analyses to characterize unique features of our data set. We also *extend* the insights of the original study by adding a temporal component: We had students complete the human-centered design (HCD) drawing activity *early* in the course and once at the *end*, to explore how depictions changed over time. We found that the end-of-course drawings resembled the original study's results in most aspects, with some notable exceptions in the overall shape of the design process depicted and ratio of text to imagery used. However, the early drawings were much more diverse and seemed to contain more creative portrayals of design, with a notable focus on natural images (flowers, trees, etc.) that was lost in the end-of-class drawings. Our insights contribute to broader discussions about HCI learning across diverse contexts, creativity vs. conformity in HCI education, and what we as educators should emphasize in our pedagogy to best support students' design learning.

EduCHI '26, Toronto, ON, Canada

ACM ISBN 979-8-4007-2430-5/26/05
https://doi.org/10.1145/3803869.3803881

CCS Concepts

• **Software and its engineering** → Designing software; • **Human-centered computing** → *Interaction design process and methods*; *Empirical studies in interaction design*; • **Social and professional topics** → **Computing education**.

Keywords

HCI education, human-centered design, concept mapping, drawing-to-learn, design process, visual representation, replication

ACM Reference Format:
Alannah Oleson and Yuliya Kim. 2026. Visualizing Human-Centered Design: A Replication and Extension Study. In *EduCHI 2026: 8th Annual Symposium on HCI Education (EduCHI '26), May 20–22, 2026, Toronto, ON, Canada.* ACM, New York, NY, USA, 15 pages. https://doi.org/10.1145/3803869.3803881

1 Introduction & Background

Human-computer interaction (HCI) is a complex, interdisciplinary field which touches upon technology development, design methods, and socio-behavioral theory, among other areas [19]. With the general trend toward ensuring computing students are capable not only of the creation of technology, but also of analyzing technology's usability and its impacts on people [2, 11], many computer and information science post-secondary curricula include at least one introductory HCI course, even if only as an elective [36]. Basic HCI principles are considered a core knowledge area in the 2023 ACM recommendations for computer science curricula [27], which many institutions use as a guideline for their four-year programs.

Of these HCI courses, many teach a design approach based in elements of *Human-Centered Design (HCD)* [24], a design approach that centers understanding end users' needs and designing artifacts that help solve problems those users experience. Though critiques of HCD abound (e.g. [3, 17]), many of which decry the approach's tendency to monolithize users as a homogeneous population [8] or perpetuate stereotype-based perspectives on user groups [29], it remains a common foundational framework for introductory HCI courses in computing contexts.

Exactly *how* to best teach HCD, especially to STEM and computing students, remains a question of ongoing debate among educational researchers. Zoltowski et al. [38] conducted a phenomenographic analysis of the ways engineering students verbalized their concrete experiences "designing for others" in order to understand how these students perceived HCD. They found that engineering students' conceptions of HCD were largely technology-focused, but that more immersive design experiences with real clients and real users help to shift students' perceptions toward more person-centered understandings. In the domain of HCI education research, Oleson et al. [31] identified several learning challenges computing students experienced in introductory HCI courses, including several involving HCD elements like understanding stakeholders and designing for human diversity. Similarly, Frich and Hansen [15] described student learning challenges related to user-centered components of activities based on Davis' *Mechanisms and Conditions* framework [10] for affordance analysis, finding that students had difficulty situating designs in broader sociocultural contexts. Though the challenges of teaching HCD are relatively well-documented, we still lack definitive insights into generalizable pedagogies for human-centered design processes.

Replication of existing HCI education research can help us develop transferable best practices for teaching HCI and HCD through attempting to confirm a previous study's findings in similar learning contexts [21]. Unfortunately, as with many scientific fields, HCI faces a reproducibility crisis [7], in no small part due to the inherent difficulties of working with human participants [14]. Classroom contexts also present a unique challenge to replicating HCI education research, since the sociocultural context of a class and the institution it is situated within can deeply impact students' learning [1]. Nonetheless, some sort of validation of results across context is necessary to gain insights into cross-cutting pedagogical principles for HCI education.

By viewing replication not as a strict validation of existing results, but as one strategy we can use to understand different facets of a problem and/or solution space [6], we can begin to build toward more generalizable HCI pedagogies. In this paper, we adhere to the perspective presented by Hüffmeier et al. [22] that replication studies should be viewed as a *sequence* of related studies which serve to provide researchers insight into alternative explanations for a phenomenon, critical contingencies upon which a result rests, and real-world relevance and applicability of findings. Further extending this perspective, replication-extension studies (e.g., [23]) can both validate insights of original works while contributing valuable new knowledge to the domain.

Toward this end, we conducted a *replication-extension* study to understand fundamental elements of HCD learning. We implemented a pedagogical intervention described by Gorichanaz in their 2025 EduCHI paper titled *"Visual Representations of Human-Centered Design by Students in Computer and Information Science."* [18]. Gorichanaz's original study asked students to draw their own depictions of the human-centered design (HCD) process after they had completed a term-long introductory HCI course, subsequently analyzing these drawings through quantitative visual content analysis and metaphor analysis to characterize how computing students understood design processes. In this study, we *replicate* Gorichanaz's pedagogical activity in a new learning context with computing students at another institution, comparing insights from our course to help define which aspects of Gorichanaz's results generalize across contexts. We also *extend* the original study by adding a temporal component, having the same set of students complete the HCD drawing activity both at the beginning of their design learning journeys and at the end of the course.

Our research questions were:

(1) How do computing students visualize human-centered design during their first course on the topic? *[replication]*
(2) How did these visualizations change over time? *[extension]*

In this paper, we build upon Gorichanaz 2025 with a small (n=22-23) replication of the activity and analysis methodology, reinforcing the presence of some trends in computing students' visualization patterns for HCD processes while noting where our results diverged from the original study. We also contribute initial insights into how computing students' visualizations of HCD change over time, which can inform more grounded HCD learning trajectories. With this knowledge, we extend the ever-growing body of pedagogical content knowledge [30, 35] HCI educators need to teach design concepts well, with the goal of developing robust, generalizable HCI pedagogies based on theoretically and empirically grounded insights.

2 Method

2.1 Course Context

This study was conducted in the *Introduction to Human-Computer Interaction* course in the Computer Science department at the University of Denver (DU), a mid-sized, private, research-intensive university in the Mountain West region of the United States that emphasizes small classes and hands-on learning. The University of Denver is on the quarter system, with ten-week courses followed by one week for final exams.

We did not collect class-level demographic data for this study, but undergraduate students enrolled in the School of Engineering and Computer Science in Fall 2025 (of which computing majors make up about 50% of enrolled students) self-identify as roughly 75% men and 25% women, and graduate students self-identify as roughly 73% men and 27% women. Non-binary gender identities were not reported. About 3.5% of undergrads and 17% of grads self-identified as international students. The University of Denver is a predominantly white institution (PWI) at the undergraduate level, with about 58% of students self-identifying as white, 19% as Hispanic or Latino, 6% as Asian, 4.5% as Black/African American, and less than 1% as American Indian/Alaska native or Native Hawaiian/Pacific

Islander, respectively. About 5.5% of undergraduate students identified as two or more ethnicities, and about 2.7% declined to state. Demographics for graduate students in the school were similar.

Intro to HCI is an elective course for undergraduate and graduate CS majors, though the majority take it because it is one of the few courses that fulfill the *Ethics* breadth requirement for the degree. Students from other departments like business or engineering may enroll in the course as part of a second major or minor in computing. For many, it is the first time they are exposed to design concepts. This offering of the course enrolled 24 students (19 undergraduates and 5 graduates). Of the 19 undergraduates, 14 were fourth-year students and 5 were third-years. Of the 5 graduate students, 3 were master's students and 2 were early-stage Ph.D. students.

The *Intro to HCI* course as taught in this iteration used the textbook "Designing the User Interface: Strategies for Effective Human-Computer Interaction (6th ed.)" by Schneiderman et. al [4] as core learning material, supplemented by papers from the HCI field. The course did not emphasize any particular design model during instruction, instead briefly showing students several models (including design thinking [13], spiral [5], design squiggle [9], double diamond [26], and engineering design[16]) to emphasize diversity of representations, and focusing more on the methods of design work.

The class met for two hours, twice per week. A typical two-hour class consisted of one hour of new content delivery on the topic of the day, a short break, and a studio where students worked in partners or small groups to apply their new design knowledge in a hands-on activity. Students spent the first six weeks of the course learning basic HCI theories and concepts through lectures, quizzes, and peer-led discussions on content from the Schneiderman book. During this time, they also learned how to frame design problems, conduct secondary research, and work in Figma through the studios. In the last four weeks of the course, students formed teams of 3-4 and collaboratively defined, prototyped, and evaluated a design addressing a problem of their choice in that aligned with the class's theme of *promoting social connections and community care*. Lessons in the last four weeks focused on the basics of HCI user research methods, and student teams designed and ran small usability studies on their projects, presenting their results to the class at the end of the term. The instructor of the course was the first author (see Positionality below).

2.2 Classroom Activities

We followed the activity structure provided in Gorichanaz's original study [18], adapting minor elements of it to suit our class context. The Appendix contains the full text of the learning activities. Course materials are available upon request to the first author.

At a high level, each activity began with an individual concept mapping [28] exercise to help students activate their HCI learning, which they then compare and expand upon with a partner. Next, students were provided paper and writing materials (pencils, markers, crayons) and asked to draw their response to the prompt: *"What does human-centered design mean to you? Draw your vision of the design process on the paper we provide."* Students were given 10 minutes to draw and encouraged to be creative and incorporate the ideas they had come up with during concept mapping. Once finished with the drawings, students formed groups of 3-4 and shared their drawings, noting similarities and differences across representations. Finally, students shared out in a class discussion. Students were asked to turn in their drawings if they did not want to keep them, and not to write their names on them, but instead to write "grad" or "undergrad" in a corner according to their class standing[1].

2.3 Data Collected

We conducted two instances of the drawing activity: One in Week 3/10 of the quarter, when students had just been introduced to the idea of design "processes" through chapter four of the textbook [4], and one in Week 10/10 of the quarter, after students had been through the full curriculum described above.

For the *Early* activity in Week 3, we collected 23 drawings (5 grad, 18 undergrad). For the *End-of-class* activity in Week 10, we collected 22 drawings (5 grad, 17 undergrad). A research assistant scanned and uploaded copies of each drawing to a secure folder for analysis.

2.4 Visual Analysis of Drawings

The first and second authors conducted a quantitative visual analysis [33] of the visual aspects apparent in students' drawings of the human-centered design process. A single drawing created by a single student constituted the unit of analysis.

We first deductively applied the codebook described in the original study, then inductively generated our own codes based on the unique features of our class's drawings to fully describe the data. For example, we modified the *emotional valence* code from the original study to include a fourth category of "both positive and negative", since we noted multiple drawings that depicted strong emotional elements on both ends of the spectrum simultaneously. Table 1 contains our codebook, noting which codes were taken directly from the original study and which we modified and/or generated inductively.

Since we did not collect identifying information about which student completed which drawing, we could not analyze individual students' learning trajectories or changes in their design model conceptions. Instead, we applied the same codebook to all the drawings uniformly. The first and second authors collaboratively coded several drawings to establish a baseline understanding, aligning our working definitions for each code until both were satisfied that we understood them similarly. The second author completed the remainder of the initial coding, then met with the first author to verify and discuss coding efforts. We adhere to the perspective on qualitative coding put forth by Hammer and Berland [20], opting to treat the results of our coding as organizations of claims about data rather than quantitative data in and of themselves. As a result, we did not calculate inter-rater reliability metrics during our coding process. Instead, we used a process of collaborative alignment to resolve discrepancies, discussing each disagreement and together deciding on the final categorization. Finally, the first

[1]Some students still wrote their names or other identifying information on their drawing, even when instructed not to. In the images presented in this paper, we cover up identifying information.

Category	Description	Possible Values
Image vs. Diagram	High-level distinction between diagram (more schematic, abstract) and image (more expressive, figurative)	Diagram, Image
Image Subtype	More granular description of the type of image	Flow chart, List, Mind map, Pyramid, Timeline, Word cloud
Diagram Subtype	More granular description of the type of diagram	Narrative image, Map, Series of images, Single image
Shape	Description of the overall form of the drawing	Circle, Development, Ecosystem, Linear, Loops, Spiral, Thought process, Web
Text vs. Images	Proportion of words and imagery, ranging from all words with no images to all images with no words	All words, Words with illustration, Words as labels, No words
Imagery Description	Brief labeling of what is depicted in the imagery, if applicable	Open text
Color	Presence of color within the drawing	Monochromatic, 2+ colors
User Presence	Rough quantification of how much presence end users have in the drawing	None, 1-2 mentions, 3+ mentions
Ending	Does the design process as depicted come to a decisive conclusion?	Yes, No
"Final"	Does the drawing include scare quotes around the word "finished," "final," etc. indicating that the design process is not really finished?	Yes, No
Contains Conversation	Does the drawing contain the designer having a conversation with users about the design?	Yes, No
Emotional Valence	Overall emotion communicated through the drawing, if applicable	Positive, Negative, Both positive and negative, Neutral
Reflection	Does the drawing include any mention of designer reflection?	Yes, No
Scoping	Does the drawing indicate a process that moves from many ideas to fewer ideas, or many alternatives to fewer alternatives?	Yes, No
Accessibility	Does the drawing include any mention of accessibility, inclusive design, or user diversity?	Yes, No

Table 1: Code categories used in the visual content analysis of students' drawings, based on Gorichanaz 2025 [18]. Underlined values indicate our own inductively generated codes. We modified one category (*Contains Conversation*) from the original "Ends with Conversation" to better fit our data. We opted not to include two categories from the original study in our analysis due to differing course content: Double *Diamond* and *Funnel,* which both indicated whether a drawing evokes that specific design model in the original study. Students in our course were not exposed to these models more than in passing reference.

author reviewed and verified all the codes applied to the drawings, conducting post-hoc analyses to determine final counts and temporal trends reported below.

2.5 Metaphor Analysis of Drawings

For further insight into how students understood human-centered design beyond coding the visual elements of the drawings, we conducted a qualitative analysis that focused on metaphors in the drawings. We followed the general approach used and defined by Gorichanaz, identifying metaphors when students illustrated design as something more evocative than simply a process-based flowchart, such as growth, energy, a system, a game and so on.

First, the second author coded each drawing for whether or not it included a metaphor. A drawing was considered metaphorical if its imagery depicted the design process using concepts outside of typical design terminology. When a metaphor was present, they then coded it as the closest *"Design is..."* metaphor label from Gorichanaz's paper [18] that best described how the design process was represented. Drawings that showed stages of design using conventional labels and arrows of a flow chart, and not mapping the design process onto another domain, were coded as not containing a metaphor. Similarly, drawings with small or decorative illustrations that did not contribute to the overall representation were not coded as metaphorical.

Whenever possible, we used metaphor categories from Gorichanaz's original study. When a drawing did contain a metaphor, but did not fit an existing category, we inductively created a new metaphor category based on the specific imagery depicted in the student's drawing. In more ambiguous cases, we used a conservative approach, preferring to align with the original study's categories to avoid overcategorization. Finally, the first author reviewed the coded metaphors and rationales to ensure clarity and consistency in the final results.

2.6 Positionality of Researchers

The first author is an HCI education researcher with over a decade of experience studying software design methods and how computing students learn to apply them. They have about five years of experience teaching HCI classes, all of which were based in human-centered design paradigms. They approached this project with the belief that computing students often struggle to learn HCI content due to the way that traditional STEM pedagogies discourage creative ideation and open-ended exploration of "wicked" problems. Their goal in leading this project was to learn more about how computing students internalized and remembered the HCD process over time, with hopes of contributing to more effective HCI pedagogy. They were also the instructor for the course in which this study took place.

The second author is a Master's student in Computer Science with a background in psychology and emerging research interests in qualitative approaches to studying learning, artificial intelligence and technology use. She joined the project after data collection was completed and did not interact with students enrolled in the course. Before beginning the analysis, she was provided context of the course and study design by the first author which gave her understanding of how the drawings were produced while still maintaining distance from the participants. Her primary contribution to this work was the metaphor analysis of student drawings, as well as participating in the initial deductive coding. Although she has limited formal training on human-computer interaction and qualitative analysis, she approached the drawings with an interpretive mindset, but also as cautious about over-interpreting students' work.

3 Results

The following sections report the formal qualities, content, expression, and metaphors present in each batch of drawings. For ease of comparison with Gorichanaz's original study [18], we present our findings in roughly the same order and structure. For the *End-of-Class* drawings, we additionally provide comparisons of consistency with the original results as well as with the *Early* results, highlighting those that may indicate temporal elements of students' HCD learning.

3.1 Early Drawings

Figure 2 shows the results of the visual content analysis for the 23 *Early* HCD drawings.

3.1.1 Formal Qualities. When drawing the human-centered design process, students depicted design through either *diagrams* (conceptual, schematic pictures that were often text-heavy and emphasized relationships between ideas) or *images* (often-concrete depictions of situations, objects, people, or emotions). Of the 23 *Early* drawings, we categorized 13 (57%) as diagrams and 6 (26%) as images. This is roughly consistent with the original study, where the majority of drawings were diagrams.

4 (17%) drawings contained both diagrams and images, e.g., a drawing of a team of designers conferring next to a flowchart of the design process as in 3. When further categorizing subtypes of each representation, we opted to analyze drawings that contained both kinds of representation according to their most salient feature. Three of the dual-type drawings were analyzed with the images, bringing the total number of image drawings to 9; One was analyzed with the diagrams, for a total of 14.

Of the diagrams, *timelines* were the most common subtype (6/14, 43%) while *flow charts* were close behind (5/14, 36%). Timelines depicted a one-dimensional passage of time, and typically were structured along a line with marked points for different stages in the design process. Flow charts typically depicted design as a set of labeled boxes representing stages of the process, indicating movement through the process with directed, sometimes labeled, arrows. Figure 3 contains a flow chart, and Figure 4 contains a timeline. These two categories being the highest is relatively consistent with the original study, though Gorichanaz saw more flow charts than timelines.

Other diagram subtypes were less common, such as *mind maps* which manifested as a collection of written concepts that might or might not be connected (2/14, 14%) and *pyramids*, which structured design as having foundational "building blocks" upon which the rest of the process rested (1/14, 7%).

Of the images, *narrative* images were the most common (4/9, 44%), followed closely by image *series* (3/9, 33%). Narrative images as in (c) of Figure 1 depict moments from distinct times in one coherent composition, while image series show discrete images in distinct sets, often drawn in "boxes" or with lines between them to indicate separation. We categorized 1 image (1/9, 11%) as a *single* image, which showed only one situation at only one point in time. We also categorized 1 image (1/9, 11%), shown in (a) of Figure 1 as a *map*, which had a distinct spatial component to how parts of the drawing were laid out relative to each other. The image subtype proportions from our *Early* drawings were also relatively consistent with the original study.

To better understand the drawings, we also analyzed the content of the visual imagery present in each drawing. Of the 23 *Early* drawings, the majority depicted *people* as designers, users, or other stakeholders (17/23 = 73% of all drawings, or 89% of the 19 drawings that contained any imagery). Slightly less than half the drawings (11/23, 48%) contained some sort of *emotional signal*, such as an angry face, a happy person giving a thumbs-up, or users crying when a design didn't meet their needs. For instance, one student drew a heart shape around two stick figures wrote *"Designer + user = BFF [best friends forever]"* (Figure 5), which we categorized as a positive emotional signal. 10 drawings (43%) contained some sort of *decorative* or abstract imagery, while 8 (34%) contained representations of *light*, such as lightbulbs, lightning bolts, or the sun. Typically, light was used to signify new ideas or sudden realizations, as in brainstorming or creative ideation. *Tools* like hammers and ladders featured in 7 (30%) drawings. Students drew *nature* elements, like trees, leaves, flowers, or mountain ranges, in 6 (26%) of their drawings, while depicting *technology* like computers or smartphones in 4 (17%) of drawings. Besides these categories, a

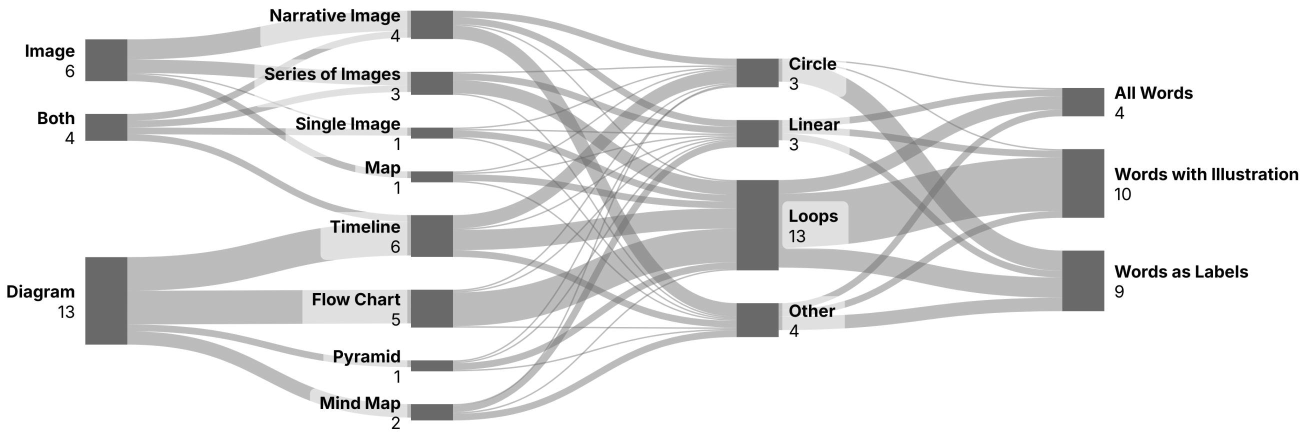


Figure 2: The proportions of key characteristics of the 23 *Early* student drawings collected in Week 3/10: First, images vs. diagrams, then type of representation, then shape of representation, then proportion of text vs. images. Drawings depicting *both* an image and a diagram in the first column are categorized according to their most salient feature in subsequent columns. Created with SankeyArt.com.

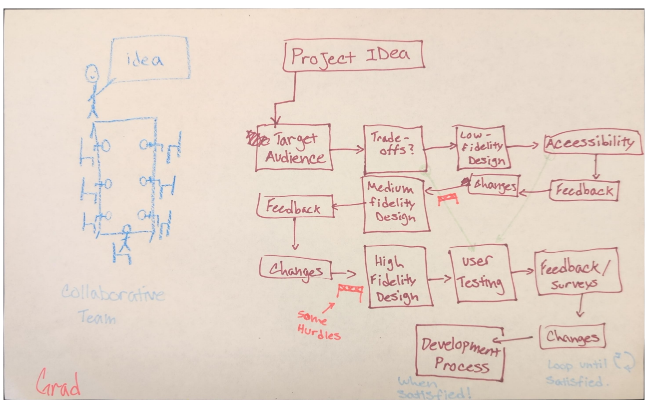


Figure 3: An *Early* loop shaped drawing by a graduate student depicting both a single image of a meeting and a flow chart diagram in the same composition. It contains mostly words with some illustration, is multicolored, and has high user presence (3+ mentions).

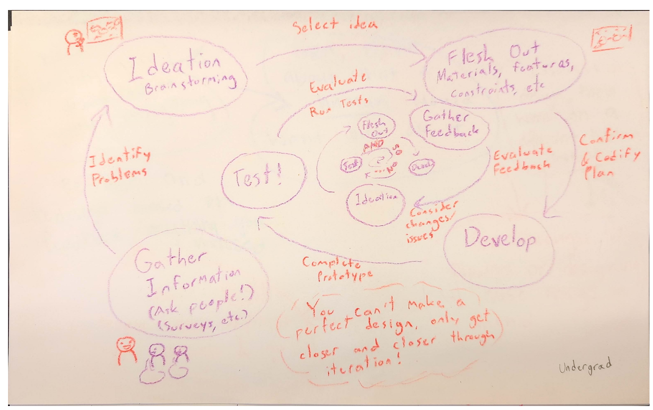


Figure 4: An *Early* spiral shaped drawing by an undergraduate depicting a timeline diagram. It contains mostly words with some illustration, is multicolored, and has some user presence (1-2 mentions).

small number of drawings also included documents, buildings, or animals. Compared to the original study, we saw many of the same content categories arise, such as light, computers, documents, and tools. However, our *Early* drawings seem to depict a notable focus on nature.

We further categorized all 23 drawings by the overall *shape* of the design process represented within it. *Linear*-shaped drawings had a clearly defined start and end point, and progressed straight through with no doubling-back or cycles. *Loop*-shaped drawings had clear start and end points, but included cycles or repetitions in the process. Finally, *circle* drawings depicted a process where there was no clear start or end point, with stages progressing in a directional fashion but where the "last" stage was connected back to the "first". In the *Early* drawing set, loops were by far the most common shape (13/23, 57%), with *circle* and *linear* shapes each arising in only 3 (13%) drawings each. We also noted 4 (17%) drawings that depicted *other* shapes for the design process. According to inductive analyses and discussion, we categorized these as:

- 2 *thought process* drawings (Figure 6), which depicted a designer individually considering several aspects of the process without acting on them;
- 1 *spiral* drawing (Figure 4), which had a defined starting point but an implied endpoint that trailed off into infinity; and
- 1 *ecosystem* drawing (Figure 7), which represented the design process as a natural landscape through which designers cultivated plants, built houses, and experienced weather representing different parts of the process.

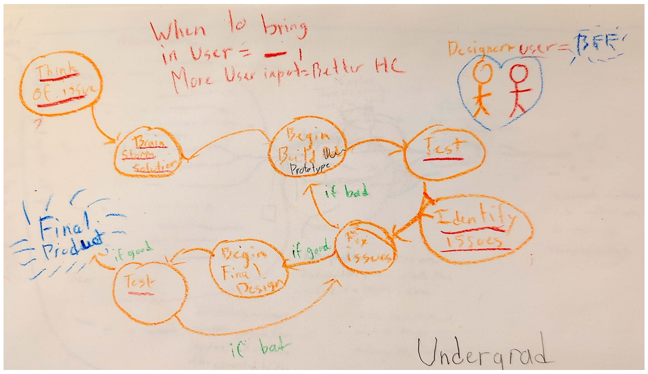


Figure 5: An *Early* loop shaped drawing by an undergraduate depicting a flow chart diagram. It has high user presence and depicts positive emotional signals by showing designers and users as best friends.

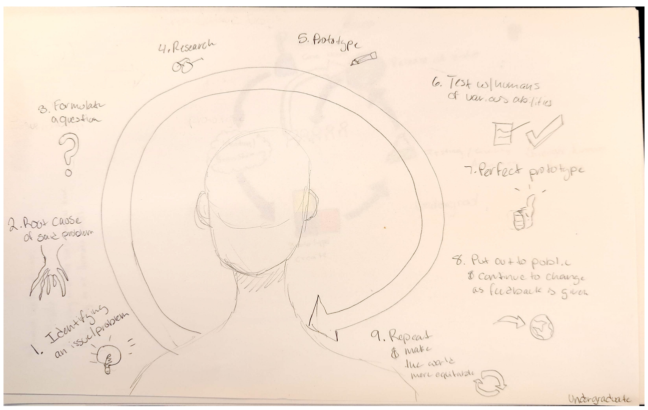


Figure 6: An *Early* thought process shaped drawing by an undergraduate depicting narrative image. It is monochromatic, uses imagery to support the text, has some user presence, and depicts positive emotion through the "thumbs up" icon.

Figure 7: An *Early* ecosystem shaped drawing by an undergraduate depicting a narrative image. It is multicolored, mostly imagery with some words as labels, has no user presence, and contains many natural elements.

These shape results exhibit our first inconsistency with the original study: While Gorichanaz saw mostly *linear* drawings, our *Early* drawings had larger proportions of *loops* and *other* shapes.

Drawings also varied in the ratio of text to imagery they contained. 4 (17%) of the *Early* drawings were *all words* with no images at all, but the majority of drawings contained at least some imagery. We categorized 10 (43%) as *words with illustration*, where the majority of the drawing comprised of text, but there were a few small images drawn, typically to illustrate some feature of the text. 9 (39%) drawings were categorized as *words as labels*, where the majority of the drawing was imagery, but then used text to label images or depict conversations (e.g., in speech bubbles). Notably, no drawings were imagery-only: All 23 contained at least some text. This is also inconsistent with Gorichanaz's original study, where most drawings were text-only, and a small minority of drawings were imagery-only with no text at all.

Finally, we analyzed the use of color in students' drawings. The majority of the drawings (18/23, 78%) used at least two colors to depict the design process, while the rest (5/23, 22%) were monochromatic. This proportion is relatively consistent with the original study.

3.1.2 Design as Expressed. When students draw their ideas of human-centered design, they express specific understandings of what design entails and how it works through the way they choose to visualize the process. For example, public deployment of a piece of designed software may be viewed as the terminus of HCD by some students (especially if they are from more traditional software development backgrounds), but by others, it may instead be part of a broader design process that continues collecting feedback and iterating on the design of the product. In this class, the instructor frequently emphasized that design was an ongoing and iterative process, and that while it *could* conclude with the release of a product, it often extended beyond that.

To better understand how students expressed their knowledge of design, we leveraged Gorichanaz's original categorizations [18] for whether students' depicted design process came to a decisive *ending*, and whether they recognized any tensions in labeling an ending as *"final"* with "scare quotes," indicating that the end was not really the end. As it turned out, students' endings were relatively evenly split: 12 of the 23 collected drawings (52%) had a clearly defined end point for their design process, while the other 11 (48%) did not. We did not see any use of "scare quotes" in this dataset, though some students used ellipses or a trailing spiral (as mentioned above) to indicate continuance. These results present a minor inconsistency with the original study: Whereas most drawings in Gorichanaz's dataset had a clear ending, ours were relatively evenly split.

Gorichanaz's original study also analyzed drawings for the proportion that ended with the designer having a conversation with users about the design [18]. To better reflect our data, we modified this code to include *any* instance of designers conversing with users, since it was often difficult to tell what the end of the process was meant to be. About a third (7/23, 30%) of the *Early* drawings contained a conversation, while the majority (16/23, 70%) did not.

We also categorized the depth of *user presence* in students' drawings. A large majority (20/23, 86%) of drawings mentioned users in some way, such as images or descriptions of people participating in user testing or designers co-developing requirements with stakeholders. Only 3 (13%) of drawings had no user presence at all. Of the 20 drawings that depicted users, we rated 7 (30% of the total drawings, and 35% of the 20 that featured users) as having particularly deep engagement with the design process, reflected in three or more mentions of users throughout a single drawing. The 13 other drawings engaged with users more shallowly, only mentioning them 1-2 times. These results are consistent with the original study, with our *Early* drawings having slightly higher deep engagement proportions.

Similar to the original study, designerly *reflection* was a concept that we emphasized throughout the course in which this study took place. Students were frequently asked to reflect upon why they made the choices they did and justify their rationale on nearly every one of the weekly project checkpoint assignments. In the 23 *Early* drawings from Week 3 of the course, only 3 (13%) depicted a reflective component to the design process. The original study had similarly small numbers of reflective drawings.

We also analyzed drawings for the overall *emotional valence* they portrayed, indicating whether students viewed design as a positive, neutral, or negative process. Most (13/23, 57%) drawings were emotionally neutral, with 3 (13%) depicting positive valence only. No drawings implied only negative feelings about the design process. However, we noted that about a third (7/23, 30%) of the drawings contained *both* positive and negative emotional indicators simultaneously. For instance, multiple drawings depicted designers as "sad" when their design didn't work as intended during usability texting and later "happy" when they changed their design to better fit users' needs. This simultaneous representation may have reflected students' own emotional journeys as they began to learn about the different components of design. In Gorichanaz's original study, a large majority of drawings were of neutral valence, whereas in our results, only a slight majority were.

Finally, we analyzed the drawings for the presence of two other concepts that were central to this offering of the HCI course: *scoping* and *accessibility*. The instructor frequently described design as a process of decision-making and problem-solving, framing the design process as one way to try to make sense of complex, wicked problems. As a result, they often emphasized how well-grounded design decisions helped designers define the *scope* of their designs, starting with many plausible concepts and narrowing down to fewer feasible solutions. In the 23 *Early* drawings, only 3 (13%) students depicted any notion of scoping down from many alternatives to one (or a few) chosen idea or solutions. Similarly, *accessibility* and inclusive design were discussed throughout the course. Students were encouraged to think about potential stakeholders' diverse abilities, backgrounds, and prior knowledge, and early on in the course conducted an activity about unintentional biases in the design process. In the 23 *Early* drawings, 4 (17%) students integrated some mention of accessibility, inclusion, or marginalization into their drawings.

3.1.3 Metaphors Employed. Metaphors can reveal important insights about students' learning, showcasing what funds of knowledge [1, 37] they draw upon to make sense of the HCD process as they learn it. In the original study, about a third of drawings contained some identifiable metaphor beyond the design models students were taught in the course. In our 23 *Early* drawings, 6 (26%) contained identifiable metaphors. We categorized 3 of these 6 drawings according to metaphor definitions provided by Gorichanaz (definitions reprinted from [18]):

- Design is directing energy (1 drawing): These drawings showed dots or waves pulsing throughout the design process. This metaphor emphasizes the mental effort and attention involved in design.
- Design is growth and transformation (1 drawing): These drawings depict natural phenomena of change, such as [...] flowers growing in the rain. This metaphor evokes the changes that occur both within the design taking shape and within the designer.

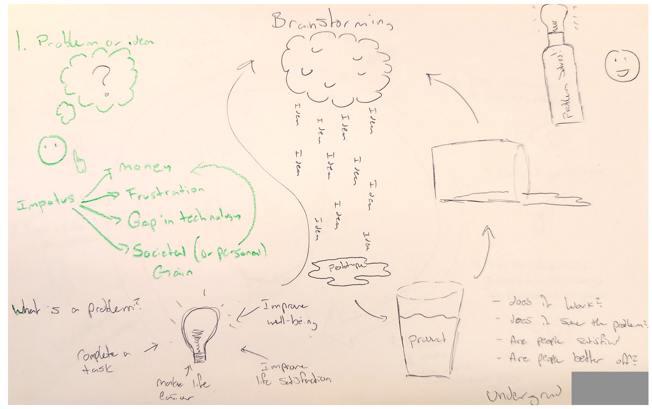


Figure 8: An *Early* loop shaped drawing by an undergraduate depicting both a mind map diagram and a series of images. It is multicolored, uses mostly words with some illustrations, depicts both positive and negative emotional valence, and portrays design as the water cycle.

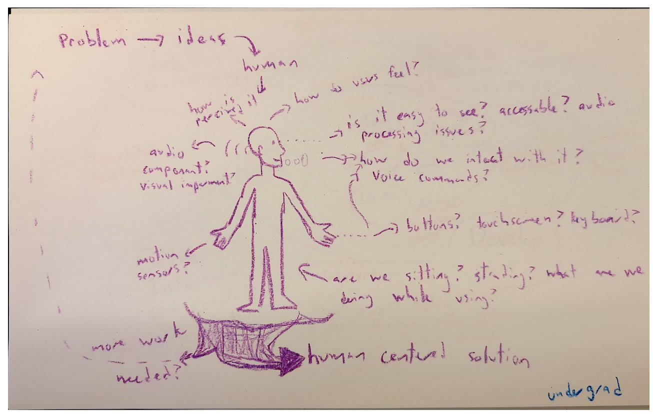


Figure 9: An *Early* loop shaped drawing by an undergraduate depicting both a mind map diagram and a single image. It is monochromatic, uses mostly words with some illustrations, has high user presence, and portrays design as a sensory experience.

- Design is working together as a team (1 drawing): These drawings centrally depict the design team working, such as during an affinity diagramming activity. This metaphor emphasizes that HCD is typically done on teams.

The other 3 metaphors we identified did not fit cleanly into the existing definitions, so we created our own categories:

- Design is a game (1 drawing, (a) in Figure 1): This drawing depicted design as a board game, with designers "playing" the game to progress through the design process, setbacks indicated by "return to previous space" paths, and "winning" the game as releasing a quality artifact that fit user needs. This metaphor emphasizes the playful and creative aspects of HCD, and the agency of the designer in driving movement through the process.
- Design is like the water cycle (1 drawing, Figure 8): This drawing depicted design work as a water cycle, with ideas "raining" down from a cloud, "condensing" into a formless puddle which was then used to fill a glass representing a solution, and water "spilling" out of a glass to represent modifications needed after user studies. This metaphor emphasizes the fluid and cyclical nature of HCD process.
- Design is a sensory process (1 drawing, Figure 9): This drawing emphasized the traditional 5 senses (vision, hearing, touch, smell, taste) and cognition (brain) with a labeled image of a human body, depicting design as finding a way to engage all senses, while keeping in mind those whose sensory abilities differ. This metaphor emphasizes the user's abilities as a key consideration within HCD and the importance of accessibility.

3.2 End-of-Class Drawings and Changes in HCD Visualization Over Time

Figure 10 shows the results of the visual content analysis for the 22 *End-of-Class* HCD drawings. We categorized the *End-of-Class* drawings using the same scheme as in the previous section, so below we omit repetitions of category definitions for brevity's sake.

3.2.1 Formal Qualities. During the *End-of-Class* drawing activities, students visualized the human-centered design class slightly differently than before. Of the 22 drawings collected, we categorized 11 (50%) as *diagrams* and 8 (36%) as *images*, with 3 drawings (14%) containing *both* diagrams and images. Of those four dual-type images, we categorized two as diagram-dominant and one as image-dominant, bringing the total for further analysis to 13 diagrams and 9 images. This is roughly consistent with the *Early* drawings.

Of the diagrams, flow charts predominated (10/13, 77%), while timelines (3/13, 23%) made up the rest. No other subtypes of diagrams were seen in the *End-of-Class* drawings. The flow chart majority in these later drawings is consistent with Gorichanaz's original study. However, it signifies a temporal trend within our dataset: While *early* drawings contained more diversity in the diagrams, *End-of-Class* diagram representations narrowed to mostly flowcharts, some timelines, and no other diagrammatic representations. Of the images, a slight majority (5/9, 55%) were *narrative* images, 3 (33%) depicted a *series* of images, and 1 (11%) was a *single* image representation of the design process. Similar to the diagrams, these *End-of-Class* image proportions are roughly consistent with the original study's results, but represent a narrowing of diversity from our *Early* dataset.

15 of the *End-of-Class* drawings depicted *people* (68% of all drawings, or 88% of the 17 drawings that contained any imagery). Only 4 (18%) contained some sort of *emotional signal*, while 10 (45%) had at least one *decorative* or abstract shape. *Light* appeared in about a third (7/22, 31%) of the drawings, while *tools* featured in 5 (23%) drawings. Elements of *nature* appeared in only 2 (9%) of students' drawings, while *technology* like computers and smartphones was depicted in 8 (36%) drawings. A small handful also depicted documents, buildings, and animals. Overall, these *End-of-Class* contents are relatively consistent with the original study. However, in comparison to the content of our *Early* drawings, we noted a few temporal trends. The presence of *emotional signals* dropped starkly in later drawings. Also, whereas the *Early* drawings contained more *nature* imagery than *technology* imagery, this proportion is flipped in the *End-of-Class drawings*, with technology now predominating.

With respect to the *shape* of the design process within the 22 drawings, *loops* (7/22, 32%) were the most prevalent of the original categories, with slightly fewer *circle*-shaped drawings (5/22, 23%) and only a few *linear* drawings (2/22, 9%). However, *other*-shaped drawings actually made up the majority of this dataset (8/22, 36%). We inductively categorized these latter 8 drawings into:

- 3 *thought process* drawings;
- 1 *spiral* drawing;
- 1 *ecosystem* drawing;
- 1 *web* (Figure 11), which portrayed several many-to-many connections among icons and phrases;
- 1 *collage* (Figure 12), depicting a series of unconnected and unordered phrases and images; and
- 1 *development* image, which depicted a lone designer interacting with a computer.

These categorization spreads are consistent with the *Early* drawings from our dataset, though they remain inconsistent with Gorichanaz's original findings due to our high proportion of *loop* shapes, while Gorichanaz saw a majority of *linear* shaped drawings [18]. In the *End-of-Class* drawings, we also saw a the original study's *collage* shape arise, while our *thought process* and *development* categories could conceivably fall under the *single image* category from the original study. On the other had, our *web* shape appears novel, suggesting at least one student viewed HCD as a set of highly interconnected elements.

When analyzing the text-to-image ratio of drawings, all 22 drawings contained at least some text (which is consistent with our *Early* activity results). We categorized 5 drawings (22%) as *all words* with no imagery at all, 8 (36%) as *words with illustration*, and the slight majority (9/22, 41%) as *words with labels*. This represents a temporal trend within our data toward slightly more imagery over time. However, we note that our results remain inconsistent with Gorichanaz's original study: Whereas the original study found the majority of their drawings to be *all words*, our largest text-to-image category was *words as labels*.

Finally, slightly fewer student drawings used multiple colors in the *End-of-Class* activities, though single-color drawings were still in the minority: 14 (64%) of drawings contained two or more colors,

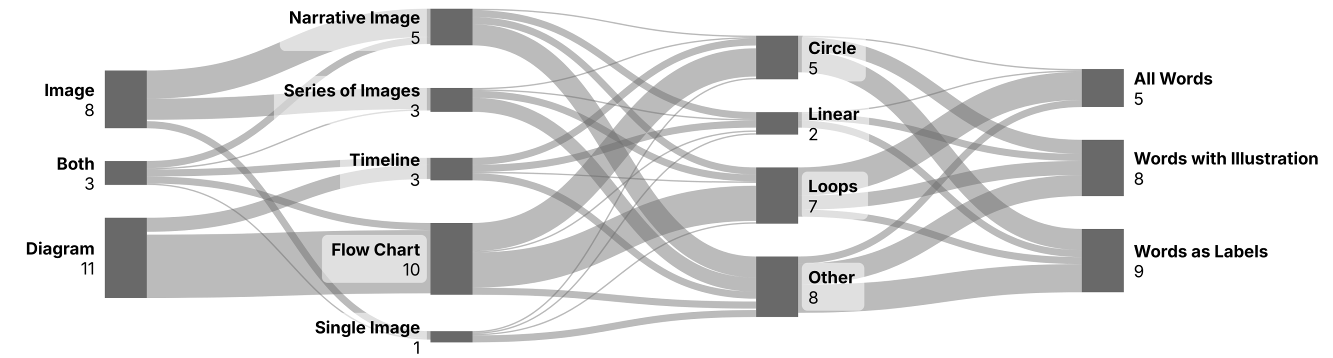


Figure 10: The proportions of key characteristics of the 22 *End-of-Class* student drawings collected in Week 10/10: First, images vs. diagrams, then type of representation, then shape of representation, then proportion of text vs. images. Drawings depicting *both* an image and a diagram in the first column are categorized according to their most salient feature in subsequent columns. Created with SankeyArt.com.

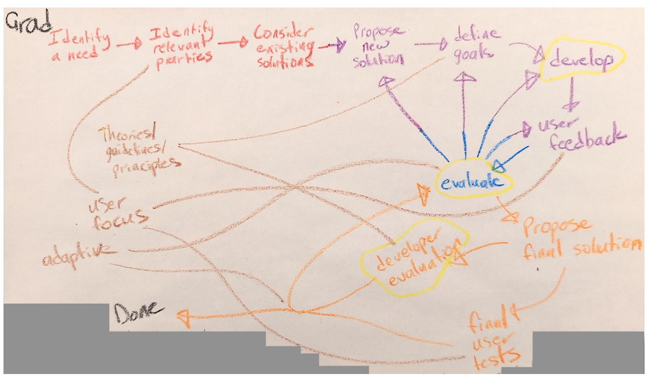


Figure 11: An *End-of-Class* web shaped drawing by a graduate student depicting a flow chart diagram. It is monochromatic, uses mostly words with some illustrations, has some user presence, and a definitive ending.

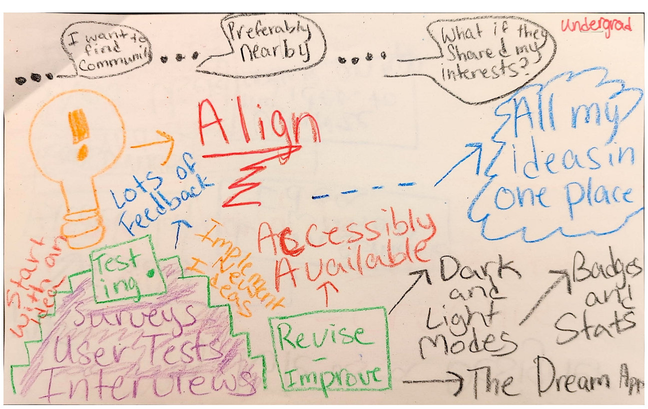


Figure 12: An *End-of-Class* collage shaped drawing by an undergraduate depicting a series of images. It is multicolored, uses mostly words with some illustrations, has some user presence, a definitive ending, and neutral emotional valence.

while 8 (36%) were monochromatic. Within our study, this appears to be a slight temporal trend, with the monochromatic proportion of *End-of-Class* drawings slightly increasing compared to the *Early* drawings. Our results are still consistent with Gorichanaz's original study which found the majority of drawings to contain multiple colors.

3.2.2 Design as Expressed. Many facets of the *End-of-Class* HCD drawings resembled students' *Early* HCD drawings, which may be expected given the short duration of the course. For instance, of the 22 later drawings, 10 (45%) had a clear *ending* for their design process depiction, while 12 (54%) did not. We did see 1 (5%) drawing use *"scare quotes"* around the word "final" to indicate that the design process was not really finished, something that was not observed in the earlier drawings, but the proportion overall was still quite small. About a third (8/22, 36%) of the later drawings depicted designers having direct *conversations* with users, while the majority (14/22, 64%) did not. On the other hand, a majority (21/22, 95%) of drawings did contain *user presence* in some way, either in drawings of users themselves or in written descriptions. Only 1 (5%) had no user presence at all. Of the 21 drawings which showed users, 7 (31% of the total drawings, and 33% of the 21 that featured users) reflected deep user presence, with users mentioned or depicted at least three times. 14 drawings (64% of the total drawings, and 67% of the 21 that featured users) engaged with users in shallower ways with only 1-2 mentions. Explicit depictions of design as a process of *scoping* were even more rare than before, with only 1 (5%) of the 22 *End-of-Class* drawings indicating a design process which narrowed down many alternatives to one (or a few) chosen idea or solutions. All of the above facets of design expression were relatively consistent with the *Early* HCD drawings provided by students in Week 3.

Temporally, we noted a handful of differences in the way design was expressed in *End-of-Class* drawings vs. *Early* drawings. For instance, designerly *reflection* was depicted in slightly about twice as many *End-of-Class* drawings (6/22, 27%) than it was in *Early* drawings, even though the majority of drawings (16/22, 73%) still contained no indication of reflection. Figure 13 shows an example

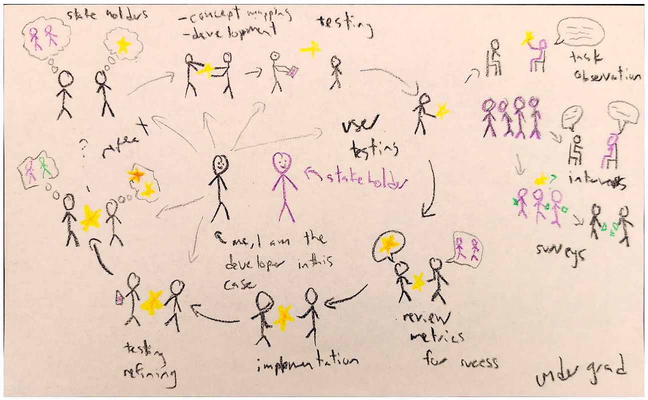


Figure 13: An *End-of-Class* circle shaped drawing by an undergraduate depicting a flow chart diagram. It is multicolored, contains a conversation with users, uses words as labels for illustrations, has high user presence, and depicts a designer reflecting on their process.

of reflection. Though this proportion is still small (which is consistent with Gorichanaz's original results [18]), this may indicate an increase in students' understanding of reflection as an intrinsic and necessary part of the HCD process.

Another notable difference arose in the proportion of drawings which portrayed some kind of *emotional valence*. While the majority (15/22, 68%) of drawings portrayed design neutrally, and no drawings depicted only negative feelings about design–which are both consistent with our *Early* drawings–the proportion of drawings that portrayed design with purely positive valence increased (6/22 or 27% of the *End-of-Class* drawings, up from 3/23 or 13% of the *Early* drawings). The number of drawings containing *both* positive and negative emotional indicators also dropped substantially (1/22 or 5% of the *End-of-Class* drawings, down from 7/23 or 30% of the *Early* drawings). This shift may indicate that students tended to view the design process more positively as they gained confidence and competence in their skills, or at least that they were less confused or anxious about HCD by the end of the course.

Finally, we noted more students including elements of *accessibility* in their HCD drawings at the end of the course. In the 22 *End-of-Class* drawings, nearly half (10/22, or 45%) of students integrated depictions of accessibility, inclusion, or marginalized users into their drawings. This is a substantive increase over the *Early* drawings, where only 4 (17%) drawings indicated accessibility content. Though this is to be expected given the instructor's expertise and emphasis on inclusive design, it is still heartening to see that more students considered accessibility more central to HCD at the end of the course.

3.2.3 Metaphors Employed. 7 (31%) of our 22 *End-of-Class* drawings contained identifiable metaphors. 4 of these 7 drawings aligned with metaphor definitions provided by Gorichanaz [18], which were the same as the *Early* drawings:

- Design is directing energy (2 drawings)
- Design is growth and transformation (1 drawing)
- Design is working together as a team (1 drawing)

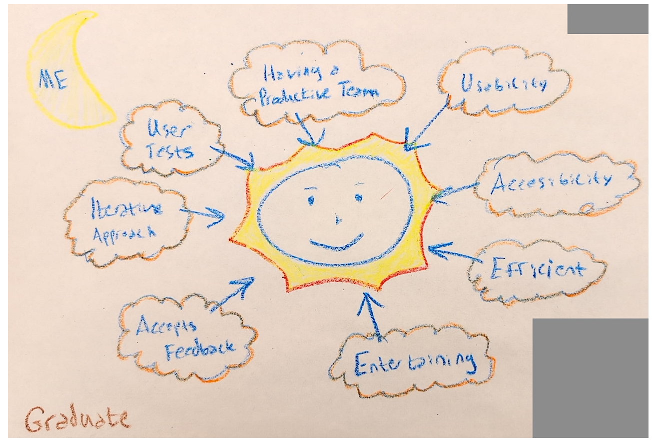


Figure 14: An *End-of-Class* ecosystem shaped drawing by a graduate student depicting a narrative image. It is multicolored, has high user presence, uses words as labels for illustrations, shows positive emotional valence, and portrays design as a solar system.

Of the other 3 metaphors identified within the *End-of-Class* drawings, 1 was the same as a previous metaphor from our study's *Early* drawings, while the others we defined as below:

- Design is a sensory process (1 drawing)
- Design is the solar system (1 drawing, Figure 14): This drawing depicted elements of the HCD process as "clouds" orbiting around a central sun which was labeled as the user. This metaphor emphasizes the end user's needs and preferences as central to all parts of HCD.
- Design is a rollercoaster (1 drawing, (c) in Figure 1): This drawing represented the design process as a roller coaster, with designers in a car going down the tracks. This metaphor emphasizes the unpredictability and emotionality of HCD, along with the "ups and downs" designers experience through successes and setbacks during the process.

4 Discussion & Concluding Remarks

Figure 15 shows the formal qualities of the full 45 human-centered design drawings we collected in our study, while Figure 16 shows the results of Gorichanaz's original study [18].

At a high level, most of our results were consistent with the original study's, validating several trends in how students visualized human-centered design. This resemblance was particularly pronounced in drawings from the *End-of-Class* activity, whereas the *Early* drawings seemed to span a broader spectrum of categories. Notably, in our *Early* HCD drawings, we saw a definitive focus on natural imagery and natural landscapes that all but disappeared in the *End-of-Class* drawings. The University of Denver is located in Denver, Colorado, USA, a city that is known for outdoor recreation, and many students here participate in outdoor activities. This presence of nature may indicate that students were drawing upon their background funds of knowledge [34] to sensemake about HCI early on, but did not feel they needed to rely on their outside knowledge

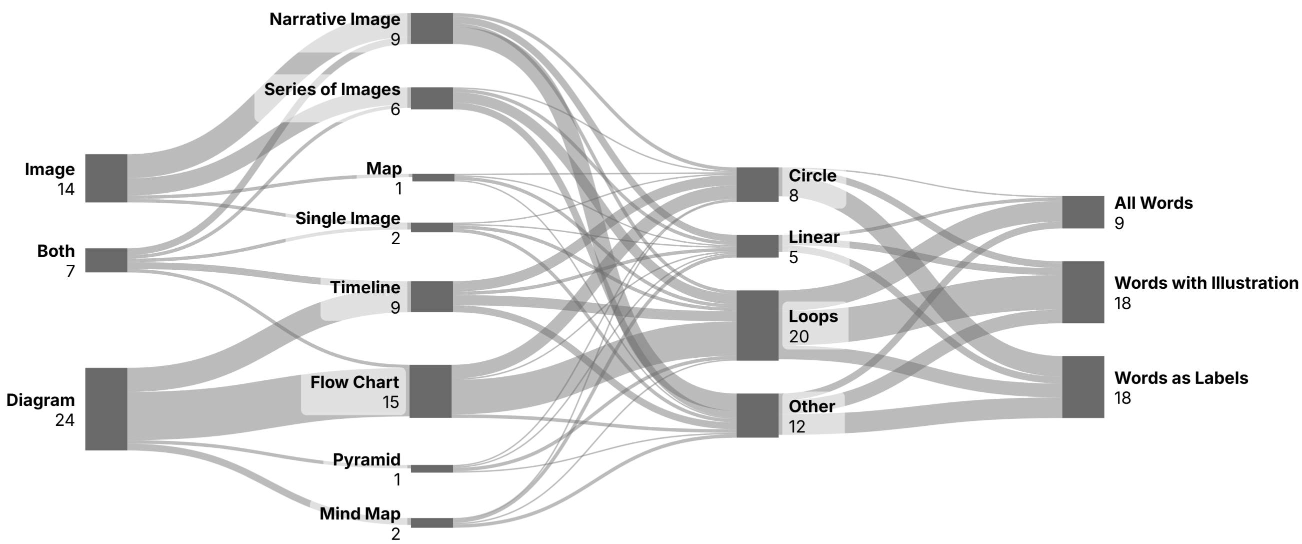


Figure 15: Results of our replication & extension study showing the proportions of key characteristics of all 45 student drawings we collected: First, images vs. diagrams, then type of representation, then shape of representation, then proportion of text vs. images. Created with SankeyArt.com.

as much at the end of the course. We also saw an increase in technological imagery such as computers and smartphones from the *Early* to the *End-of-Class* drawings. This technological focus aligns with prior work from engineering education which noted students' technologically-focused definitions of HCD [38], though it may also have been due to our HCI course's heavy focus on Figma prototyping in the last four weeks of the curriculum. Another notable trend in our temporal data was a substantial increase in students who conceptualized accessibility as a core element of human-centered design by the end of the course, which is perhaps not surprising, but it is at least heartening to suggest that students can integrate more inclusive design perspectives over time through HCI education. Finally, we also found a few new evocative design metaphors to extend the set provided in the original study, including like *Design is a rollercoaster* and *Design is a game*. These metaphors, together with Gorichanaz's original set, suggest that some students might appreciate a more playful approach to learning design, such as through gamification principles or game-focused design challenges.

Nonetheless, these insights should be interpreted in light of the limitations of our context. We conducted this study with students from one offering of one HCI course, which means that our sample size was smaller than Gorichanaz's original study. Though we saw several similarities in proportion among our results compared to the original study, a larger amount of students might have provided more direct comparisons of HCD drawings. The University of Denver's ten-week quarter system model provides less instructional time than schools on semester models, which may have had a ceiling effect on how much students' conceptions of HCD could really change between the *Early* and *End-of-Class* drawing activities. Further, we did not collect identifying information for each drawing, so we have no way of analyzing individual students' trajectories in their comprehension of HCD. Future work should attempt to explore more deeply how individuals experience and internalize HCD within the context of HCI education.

Despite these limitations, our results present interesting implications for HCI education research. Our study contributes one of the first attempts to formally replicate HCI education research in a classroom, providing a flexible and lightweight exemplar others can leverage to formally validate and extend HCI pedagogy. We hope that this paper inspires others to integrate HCI education learning activities into their courses and rigorously document the results of these interventions, so we as a community can build toward more robust foundational knowledge for HCI education.

Our results also raise intriguing questions around the goal of HCD pedagogy and HCI education more broadly. Overall, the *End-of-Class* drawing set contained less diversity in model shape and imagery content than the *Early* drawing set. Students' inclusion of *emotional signals* and non-neutral emotional valence declined over time as well, implying students may have initially considered emotion as an important element of human-centered design, but did not by the end of the course. One way to interpret these trends is that they are a direct result of students' learning: Indeed, one should *expect* students to have more well-defined and standardized definitions of human-centered design after they have spent ten weeks learning about it. However, another interpretation is that students may have actually become *less* creative in the ways they portrayed design over time. Creativity is often seen as a fundamental design skill [12, 25], with many design education activities aiming to help students practice creative ideation [32]. If we teach computing students to adhere to standardized models in what may be their only exposure to design in the entire curriculum, what impact might this have on students' creativity? What values may we implicitly endorse in HCI pedagogy that contradict our explicit desires for students to creatively express themselves? Future work

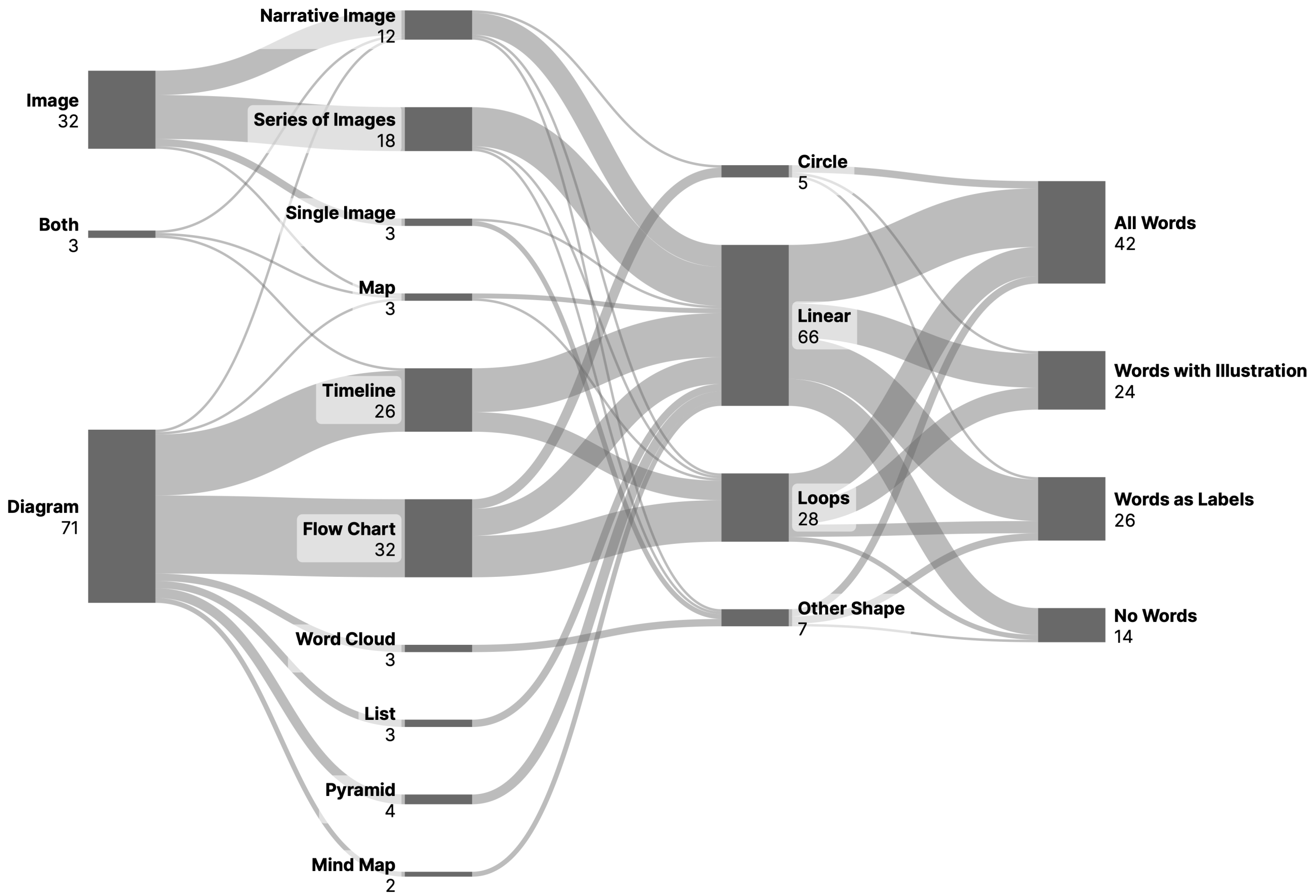


Figure 16: Results of Gorichanaz's original study [18] showing the proportions of key characteristics of student drawings in the dataset: First, images vs. diagrams, then type of representation, then shape of representation, then proportion of text vs. images. Created with SankeyArt.com. Reprinted with the permission of the author.

in this space should explore the normalizing effects of HCI pedagogies through longitudinal studies and try to determine how our practices impact our students' conceptions of the world.

Finally, we note that while these drawings depict students' visualizations of the human-centered design process, they do not provide us any information about how students conceptualize their *own* responsibilities in relation to design. During the *End-of-Class* activity, we collected additional data about how students view their own role in the design process and why they feel that way (see the Appendix for an overview). This data was not analyzed for this paper due to time and paper length considerations, but we hope to present these initial findings at a future HCI venue soon. We hope that this additional perspective can support broader conversations around ethical agency in technological design processes.

Acknowledgments

We wish to thank and acknowledge the hard work of the students whose drawings went into this paper's analysis. Thanks also to Mars Kaplan, who supported this project in initial data collection.

References

[1] Adriana Alvarez, Leah Peña Teeters, William R. Penuel, and Moisès Esteban-Guitart. 2023. Considerations to engage a funds of identity approach as a vehicle toward epistemic justice in educational settings. *Learning, Culture and Social Interaction* 40 (June 2023), 100718. doi:10.1016/j.lcsi.2023.100718

[2] Sherif G. Aly, Brett A. Becker, Amruth N. Kumar, and Rajendra K. Raj. 2024. Computer Science Curricula 2023 (CS2023): Rising to the Challenges of Change in AI, Security, and Society. In *Proceedings of the 2024 on Innovation and Technology in Computer Science Education V. 2 (ITiCSE 2024)*. Association for Computing Machinery, New York, NY, USA, 852–853. doi:10.1145/3649405.3659537

[3] Jeffrey Bardzell and Shaowen Bardzell. 2016. Humanistic HCI. *interactions* 23, 2 (Feb. 2016), 20–29. doi:10.1145/2888576

[4] Ben Shneiderman, Catherine Plaisant, Maxine S. Cohen, Steven M. Jacobs, and Niklas Elmqvist. 2017. *Designing the User Interface: Strategies for Effective Human-computer Interaction* (6th ed.). Pearson.

[5] Barry W. Boehm. 1988. A spiral model of software development and enhancement. *Computer* 5 (1988), 61–72.

[6] Douglas G. Bonett. 2012. Replication-Extension Studies. *Current Directions in Psychological Science* 21, 6 (Dec. 2012), 409–412. doi:10.1177/0963721412459512

[7] Ed H. Chi. 2011. On the Importance of Replication in HCI and Social Computing Research – Communications of the ACM. https://cacm.acm.org/blogcacm/on-the-importance-of-replication-in-hci-and-social-computing-research/

[8] Sasha Costanza-Chock. 2020. *Design Justice: Community-led practices to build the worlds we need.* MIT Press.

[9] Damien Newman. 2024. The Squiggle. https://thedesignsquiggle.com/

[10] Jenny L. Davis and James B. Chouinard. 2016. Theorizing Affordances: From Request to Refuse. *Bulletin of Science, Technology & Society* 36, 4 (2016), 241–248. doi:10.1177/0270467617714944 _eprint: https://doi.org/10.1177/0270467617714944.

[11] Catherine Delcourt, Sukrit Venkatagiri, and Eshwar Chandrasekharan. 2024. What's in a Social Computing Course: Analyzing Computer and Information Science Syllabi. In *Proceedings of the 6th Annual Symposium on HCI Education (EduCHI '24)*. Association for Computing Machinery, New York, NY, USA, 1–8. doi:10.1145/3658619.3658623

[12] Halime Demirkan and Yasemin Afacan. 2012. Assessing creativity in design education: Analysis of creativity factors in the first-year design studio. *Design Studies* 33, 3 (May 2012), 262–278. doi:10.1016/j.destud.2011.11.005

[13] Kees Dorst. 2011. The core of 'design thinking' and its application. *Design Studies* 32, 6 (Nov. 2011), 521–532. doi:10.1016/j.destud.2011.07.006

[14] Florian Echtler and Maximilian Häußler. 2018. Open Source, Open Science, and the Replication Crisis in HCI. In *Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems (CHI EA '18)*. Association for Computing Machinery, New York, NY, USA, 1–8. doi:10.1145/3170427.3188395

[15] Jonas Frich and Lone Koefoed Hansen. 2024. Teaching Affordances: Challenges and Mitigations when integrating the Mechanisms and Conditions framework in HCI. In *Proceedings of the 6th Annual Symposium on HCI Education (EduCHI '24)*. Association for Computing Machinery, New York, NY, USA, 1–8. doi:10.1145/3658619.3658631

[16] Molly Hathaway Goldstein, Camilo Vieira Mejia, Robin Adams, Şenay Purzer, and Mitch Zielinski. 2016. Developing a measure of quality for engineering design artifacts. In *2016 IEEE Frontiers in Education Conference (FIE)*. 1–7. doi:10.1109/FIE.2016.7757346

[17] Tim Gorichanaz. 2024. Toward Humanity-Centered Design without Hubris. In *Extended Abstracts of the CHI Conference on Human Factors in Computing Systems (CHI EA '24)*. Association for Computing Machinery, New York, NY, USA, 1–7. doi:10.1145/3613905.3644060

[18] Tim Gorichanaz. 2025. Visual Representations of Human-Centered Design by Students in Computer and Information Science. In *Proceedings of the 7th Annual Symposium on HCI Education (EduCHI '25)*. Association for Computing Machinery, New York, NY, USA, 1–12. doi:10.1145/3742901.3742913

[19] Colin M. Gray and Austin L. Toombs. 2024. Themes, Lenses, and Materials: Three Perspectives on HCI Program Development. In *Proceedings of the 6th Annual Symposium on HCI Education (EduCHI '24)*. Association for Computing Machinery, New York, NY, USA, 1–5. doi:10.1145/3658619.3658622

[20] David Hammer and Leema K. Berland. 2014. Confusing claims for data: A critique of common practices for presenting qualitative research on learning. *Journal of the Learning Sciences* 23, 1 (2014), 37–46.

[21] Kasper Hornbæk, Søren S. Sander, Javier Andrés Bargas-Avila, and Jakob Grue Simonsen. 2014. Is once enough? on the extent and content of replications in human-computer interaction. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '14)*. Association for Computing Machinery, New York, NY, USA, 3523–3532. doi:10.1145/2556288.2557004

[22] Joachim Hüffmeier, Jens Mazei, and Thomas Schultze. 2016. Reconceptualizing replication as a sequence of different studies: A replication typology. *Journal of Experimental Social Psychology* 66 (Sept. 2016), 81–92. doi:10.1016/j.jesp.2015.09.009

[23] Barbara A. Israel and Toni C. Antonucci. 1987. Social Network Characteristics and Psychological Well-Being: A Replication and Extension. *Health Education Quarterly* 14, 4 (Dec. 1987), 461–481. doi:10.1177/109019818701400406

[24] Robert Jacobson. 2000. *Human-Centered Design: Chapter in Information Design*. MIT Press. Google-Books-ID: vnax4nN4Ws4C.

[25] Karl K. Jeffries. 2007. Diagnosing the creativity of designers: individual feedback within mass higher education. *Design Studies* 28, 5 (Sept. 2007), 485–497. doi:10.1016/j.destud.2007.04.002

[26] Magda Kochanowska, Weronika Rochacka Gagliardi, and with reference to Jonathan Ball. 2022. The Double Diamond Model: In Pursuit of Simplicity and Flexibility. In *Perspectives on Design II: Research, Education and Practice*, Daniel Raposo, João Neves, and José Silva (Eds.). Springer International Publishing, Cham, 19–32. doi:10.1007/978-3-030-79879-6_2

[27] Amruth N. Kumar, Rajendra K. Raj, Sherif G. Aly, Monica D. Anderson, Brett A. Becker, Richard L. Blumenthal, Eric Eaton, Susan L. Epstein, Michael Goldweber, Pankaj Jalote, Douglas Lea, Michael Oudshoorn, Marcelo Pias, Susan Reiser, Christian Servin, Rahul Simha, Titus Winters, and Qiao Xiang. 2024. *Computer Science Curricula 2023*. Association for Computing Machinery, New York, NY, USA.

[28] Joseph D Novak and Alberto J Cañas. 2008. The theory underlying concept maps and how to construct and use them. (2008).

[29] Alannah Oleson. 2022. CIDER: A Method to Teach Practical Critical Software Design Skills. In *Proceedings of the 2022 ACM Conference on International Computing Education Research - Volume 2 (ICER '22)*. Association for Computing Machinery, New York, NY, USA, 7–9. doi:10.1145/3501709.3544295

[30] Alannah Oleson and Amy J. Ko. 2020. Toward the Development of HCI Pedagogical Content Knowledge. (2020), 6.

[31] Alannah Oleson, Meron Solomon, and Amy J. Ko. 2020. Computing Students' Learning Difficulties in HCI Education. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems (CHI '20)*. Association for Computing Machinery, Honolulu, HI, USA, 1–14. doi:10.1145/3313831.3376149

[32] Alannah Oleson, Brett Wortzman, and Amy J. Ko. 2021. On the Role of Design in K-12 Computing Education. *ACM Transactions on Computing Education* 21, 1 (Jan. 2021), 2:1–2:34. doi:10.1145/3427594

[33] K. Parry. 2020. Quantitative Content Analysis of the Visual. Vol. 2. SAGE, 352–266. https://uk.sagepub.com/en-gb/eur/the-sage-handbook-of-visual-research-methods/book250969

[34] Jean Salac, Alannah Oleson, Lena Armstrong, Audrey Le Meur, and Amy J. Ko. 2023. Funds of Knowledge used by Adolescents of Color in Scaffolded Sensemaking around Algorithmic Fairness. In *Proceedings of the 2023 ACM Conference on International Computing Education Research - Volume 1 (ICER '23, Vol. 1)*. Association for Computing Machinery, New York, NY, USA, 191–205. doi:10.1145/3568813.3600110

[35] Lee Shulman. 1987. Knowledge and teaching: Foundations of the new reform. *Harvard educational review* 57, 1 (1987), 1–23. doi:10.17763/haer.57.1.j463w79r56455411

[36] Lauren Wilcox, Betsy DiSalvo, Dick Henneman, and Qiaosi Wang. 2019. Design in the HCI Classroom: Setting a Research Agenda. In *Proceedings of the 2019 on Designing Interactive Systems Conference (DIS '19)*. ACM, New York, NY, USA, 871–883. doi:10.1145/3322276.3322381

[37] Amy Wilson-Lopez, Joel Alejandro Mejia, Indhira María Hasbún, and G. Sue Kasun. 2016. Latina/o Adolescents' Funds of Knowledge Related to Engineering. *Journal of Engineering Education* 105, 2 (2016), 278–311. doi:10.1002/jee.20117 _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1002/jee.20117.

[38] Carla B. Zoltowski, William C. Oakes, and Monica E. Cardella. 2012. Students' Ways of Experiencing Human-Centered Design. *Journal of Engineering Education* 101, 1 (2012), 28–59. doi:10.1002/j.2168-9830.2012.tb00040.x _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1002/j.2168-9830.2012.tb00040.x.

A Human-Centered Design Drawing Activities

For the drawing activities, we followed the structure outlined in Gorichanaz 2025 [18] with minor modifications to promote clarity of prompts or better fit our learning context.

A.1 Early Activity (Week 3)

In this subsection, we denote modifications to the original study's activity structure with <u>underlined</u> text followed by a descriptive footnote.

This activity was conducted as a warm-up at the beginning of the day's class, adhering to the structure of a typical class session. The title of the warm-up activity was given as *"What does 'human-centered design' mean to you?"* and this header was visible throughout the activity on the slides displayed to students. Students were given the following prompts and amounts of time in parentheses to work on their drawings. These prompts were displayed on a projection screens at the front of the room while students were working.

(1) Think of all the activities, stages, concepts, tools, etc., that <u>you know of so far which</u>[2] are involved in the design process. Without looking at your notes or talking to your neighbor, see how many you can list. Don't worry about order! (<u>2 min.</u>[3])
(2) Compare <u>your list</u> with someone nearby. Refer to the syllabus, textbook, your notes, etc. as needed. Make sure both of you have as much accounted for as you can. (3 min.)[4]

[2]Added to the early activity to emphasize that students were still early in the design learning process and should not worry about incomplete answers.
[3]Extended time by 1 min.
[4]Minor text addition for clarity.

(3) Now, draw your vision of the design process on the paper we provide[5]. (10 min.[6]) *[Students are provided with 11×17-inch paper and colored markers and crayons[7], and instrumental music is played on low volume.]*
   - Try to make it your own, not just copy one of the ones from the book. Is it a diagram? a map? a word cloud? an image?
   - Try to incorporate concepts that we talked about in class, as well as your experiences so far actually doing the design process (e.g., brainstorming).[8]
   - Did you experience things in the design process that aren't captured in the course materials, such as feelings or emotions? Try to draw those too.[9]

Next, students had 5 minutes to get into small groups of 3-4 and share their drawings as well as why they chose to represent the design process in that way. They were asked to identify similarities and differences among each others' drawings. Additionally, the following prompts were displayed on the projection screen during the small group discussion[10], to encourage reflection:

- Get into groups of 3-4 people. Each person should share their design process picture. Then, together, discuss:
  - Did anything surprise you in this activity? Anything you noticed?
  - What formats did you see among your classmates' drawings? (step-by-step, word cloud, image...)
  - Is there anything in your drawings that is missing from the course materials? Anything in the course materials[11] that is missing from your drawing?

Finally, groups shared out one or two insights to the whole class, and the instructor led the class in a follow-up discussion. The whole class discussion covered the three small-group prompts above[12] and lasted about 10 minutes.

A.2 End-of-Class Activity (Week 10)

This activity was kept as similar to the *Early* activity as possible, including the timing at the beginning of the class session, the ordering and content of prompts, and even the music played during the drawing activity itself. In this section, we denote modifications to the *Early* activity with underlined text followed by a descriptive footnote.

Modifications we made to the *End-of-Class* activity included:

- During Step 3 (drawing), we amended one of the prompts given to students to *"Try to incorporate concepts that we talked about in class, as well as your experiences so far actually doing the design process (e.g., brainstorming, user testing, iterating, working with teams)."* [13]
- We added an additional step directly after the drawing and before the small group discussions, prompting students as follows:
  - Draw a representation of yourself as a human-centered designer (if you don't have one already).
    - What is your role in this process? Where are you? What are you responsible for?
    - Label yourself clearly–e.g. with a circle or arrow labeled "Me."
    - Write a few sentences about why you drew yourself like that. [14]
- During small group discussions, students were prompted with an additional question: *"Where did people place themselves? Any differences?"* [15]

[5]Edited prose to remove "I want you to..." and added paper note for clarity.
[6]Shortened time by 2 min.
[7]Extra art materials provided.
[8]Added concrete example for clarity.
[9]Added for clarity.
[10]Prompts were visible to students rather than just verbally conveyed.
[11]In both instances here, the original study specified "the syllabus and the textbook." We used a range of course materials in our class, so broadened the description.
[12]The original study's discussion also included prompts of "If you had to remove one step from the design process, which would it be?" and "What does the format of the representation mean when it comes to the design process?" We omitted these for time.
[13]Added more concrete examples for clarity.
[14]This prompt was not included in the original study. Written answers to this prompt were not included in our visual content analysis reported in this paper, since students were asked to write on the back of their drawings. We originally intended to extend this replication study with an additional *self-representation* component illustrating how students viewed their responsibility as designers, but opted not to include these results for length and conciseness. We plan to publish these results alongside a more in-depth discussion of ethical agency and responsibility in HCI education in a future venue.
[15]See above footnote.