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SPEAKING OF USERS: ASSESSING THE FREQUENCY, CONSISTENCY, AND DEPTH OF USER-RELATED INTERNAL COMMUNICATION OF STRONG AND WEAK NOVICE ENGINEERING DESIGN TEAMS

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ABSTRACT

In order for students on novice engineering design teams (NEDTs) to develop relevant, impactful products, it is important that they continuously engage potential users throughout their design processes. In successful user engagements, teams may identify individuals who can describe their experiences so students can elicit user needs and design requirements. Users may also provide feedback on design concepts and prototypes so students can iterate and improve their work. Finally, these individuals may connect students to other potential users so that the team can gain further perspectives. These interactions can significantly strengthen NEDTs' design processes and outcomes. Unfortunately, instructors of NEDTs may not be present when students engage with off-campus users. This distance makes it difficult for instructors to assess how well teams are advancing in this critical aspect of design. However, instructors may have access to teams' internal communication, which could help them track user engagement. To understand how student design teams communicate about users, we analyzed a database of 251,744 Slack messages sent by 16 Strong and 16 Weak NEDTs in a senior-level product design course. Searching for the instances in which team members used the word "user," we found that Strong teams discussed users more consistently than Weak teams throughout the semester. All teams' user-related conversations also peaked during periods of design convergence compared to divergence. Finally, to assess the depth of user discussion, a topic modeling analysis of the dataset revealed that Strong teams discussed users alongside more process-focused topics, while Weak teams discussed users alongside more task-focused topics. By elucidating these patterns, we provide valuable insights to instructors who are assessing and coaching NEDTs on user engagements. Student designers themselves can also use these findings to aid in monitoring and structuring their own internal team communication to ensure they are focusing on users consistently and deeply.

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1 INTRODUCTION

Engineering design teams (EDTs) and the products they develop ultimately serve people and society. Designers' focus on user interactions has been linked to product success [1–3], so EDTs regularly engage potential users throughout their design processes to understand their needs, gather feedback, and test prototypes. Due to this importance, novice engineering design teams (NEDTs), such as student teams in a capstone product development course, are often instructed to practice various forms of user engagement, such as observation sessions, interviews, or prototype testing. By practicing user engagement, students gain real-world experience that hones their engineering skills and human-centered design processes [4–7].

As novice designers practice user engagement, it is critical for their instructors to assess meaningful engagement and provide formative feedback, similar to how a manager may coach a professional EDT. Unfortunately, instructors are often not present for all engagements, which may take place off campus or outside of class hours. While attending user engagements might be difficult, instructors can passively monitor teams' progress by assessing how frequently teams discuss their users during the design process. This can be done by attending team meetings or by monitoring their online communication. With the abundance of modern enterprise technologies, the nature of internal team communication has become increasingly virtual or hybrid [8]. Like industry teams, student teams use virtual communication for information sharing, documentation, project management, collaboration, and decision-making. Enterprise communication platforms, such as Slack, have become essential tools for both student and professional engineers, serving tens of millions of users worldwide [9, 10]. The structured communication formats from these platforms provide access to extensive data for quantitative analysis of team communication and collaboration, enabling the identification of patterns in virtual communication content and timing. This presents an opportunity to enhance how instructors can assess their NEDTs' design processes.

Despite the growing amount of recorded data available, user-related internal team communication remains understudied in the literature regarding EDTs, NEDTs, and user engagement. While users themselves may not be included on NEDTs' internal communication channels, team members discuss users and their needs as related to the products teams design. Internal dialogue about users can give instructors a necessary lens into their students' engagements, indicating that users' needs are being considered, even when the users are not present. By analyzing such data, this paper explores three aspects of NEDTs' user-related internal communication: consistency, frequency, and depth.

First, understanding the consistency of user-related internal team communication throughout the design process is important. A study conducted by Maier et al. followed a NEDT's user engagement throughout a senior engineering design course [11]. They showed that user engagement was highest during early problem identification stages. The teams' engagement levels lowered as the teams moved to later stages of problem definition and concept generation. During the concept selection and detailed design, the NEDTs' user engagement fell to near zero. Similar patterns were observed in a separate study that followed three NEDTs [12]. This study observed that one NEDT never interacted with users at all, one team only interacted with users to inform their design requirements, and a third team interacted to both inform requirements and solicit feedback. These examples illustrate a common occurrence in design courses: NEDTs may engage users in the early design stages when setting high-level requirements or in the later stages when conducting final testing. At the same time, novice designers may also lose sight of users' needs when engaging in deep technical challenges. Yet, research shows that there is value in engaging users during all stages of the design process, even co-designing with them [13]. This suggests that teams that consistently consider users throughout their design processes would follow stronger processes and create stronger design outputs. That being said, consistency of user engagement throughout NEDTs' design processes can be difficult for instructors to observe and is not significantly studied in the literature. This gap motivates our first research objective:

RO1: Quantitatively evaluate the relationship between NEDT strength with the consistency and frequency by with which they internally discuss users throughout their design process.

Our second objective addresses how the frequency of user-related internal team communication may change throughout NEDTs' processes. As a product vision develops, designers' roles, and subsequently their relationships with users, shift accordingly. Surma-aho et al. explored how NEDTs empathized with users and stakeholders by taking their perspectives [14]. They followed four NEDTs over the course of 9-month-long design projects and found the emphasis on taking users' perspectives depended on the design stage: concept development, system design, or detailed design. In understanding how and when teams communicate about their users, we similarly explore this temporal relationship. We specifically focus on the differences between user-related communication during stages of design divergence versus stages of design convergence. A widely adopted model of a divergent-convergent design process is the double diamond model, in which designers discover user needs (diverge), define requirements (converge), develop potential solutions to meet such requirements (diverge), and deliver a single, functioning solution (converge) [15]. The value of developing divergent-convergent thinking in engineering design courses has been demonstrated [16], so many courses strive to implement it. Given the importance of these divergent and convergent phases and the temporal nature of designers' relationship with users, it is important to understand how NEDTs discuss users during these stages. This motivates our second research objective:

RO2: Quantitatively evaluate NEDTs' user-related communication patterns during different design stages, particularly periods of design divergence and convergence.

Finally, the degree to which an NEDT meaningfully engages users and integrates them into their design process varies. As students, novice designers may approach an open-ended design course with a task-oriented mindset, explicitly following assignments' instructions or their instructors' feedback. While the assignments and feedback are designed to promote meaningful engagement, they do not guarantee it. How NEDTs internally discuss their users—specifically, the topics they discuss and associations they make related to users—may provide insights into this depth. Topic modeling of internal team communication is a promising method to uncover these insights from large sets of data. Ferguson et al. applied short-text topic modeling to NEDTs' Slack communication to uncover insights into the divergence and convergence of design processes [17]. Topic modeling has also been applied to individual design students' weekly journal entries, demonstrating positive relationships between design team performance and team cohesion [18]. EDTs' e-mail communication has also been analyzed to understand which topics appear in different design stages [19]. To the best of the authors' knowledge, topic modeling has not yet been used to analyze NEDTs' internal communication to understand user engagement as a specific topic of interest. To this end, the present work also applies topic modeling to uncover what associations NEDTs make when communicating about users. This motivates our final research objective:

RO3: Assess topics that commonly co-occur with "user" in NEDTs' internal communication and compare the co-occurring topics of strong NEDTs to those of weaker NEDTs

By elucidating the communication patterns of strong NEDTs, we aim to provide insights to design instructors and students. The patterns investigate the consistency and frequency of user-related communication, as well as the topics that co-occur with the topic of "user." With knowledge of these trends, instructors of NEDTs could better understand the contexts of their teams, assess their teams, and gain insights into how to guide students' communication throughout their design processes. Student members of NEDTs, equipped with the same knowledge, could assess their own communication and work to improve its structure and focus. While novice designers are assessed in this work, there are learnings that could influence how managers or leaders of professional EDTs guide their teams as well.

2 METHODS

This section outlines the methods used to assess NEDT online communication, which are visualized in Figure 1. We begin by describing the dataset and the undergraduate course from which it was collected, providing context for our analysis. Next, we detail the data preprocessing steps, ensuring the dataset was structured for meaningful interpretation. To address **RO1**, we evaluated the consistency of user-related discussions by computing the standard deviation (σ_c) of daily message frequency. This was calculated separately for Strong and Weak NEDTs, resulting in one σ_c value per category. For **RO2**, we examined shifts in user-related discussion patterns across different design stages, particularly during divergent and convergent phases, by analyzing trends in topic usage over time. Finally, in line with **RO3**, we applied topic modeling to identify topics that commonly co-occurred with "user" and compared the linguistic patterns of Strong and Weak NEDTs. This approach allowed us to construct a word vector space that captured differences in how teams integrate users within their design discourse and process.

2.1 Data Collection and Characteristics

This study analyzes a dataset comprising 251,744 Slack messages exchanged between 32 student teams. Participants were enrolled in a senior-level core human-centered product design course in Mechanical Engineering at a major U.S. university between 2016 and 2019. The dataset has been extensively documented in prior research [17], which outlines its collection methodology, structure, and key characteristics. A summary is provided below.

On teams of 15 to 20 students each, novice designers engaged in structured team interactions, which consisted of in-person meetings and virtual collaboration via Slack. Slack is an enterprise communication platform which enables rapid, instant-messaging style communication. The course aimed to give students both technical expertise and project management skills.

The course guided teams through a complete product design cycle in one semester (approximately 93 days), with each team developing a novel consumer product grounded in real-world needs. Project domains spanned healthcare, fitness, accessibility, recreation, and consumer electronics. As a result, students designed products such as wearable medical devices, adaptive tools for people with disabilities, and smart recreational equipment. These diverse project directions led teams to engage with a wide range of user groups—including elderly adults, athletes, children, and working professionals. The course followed a structured seven-phase design process, with each phase culminating in a key deliverable (Figure 2). At the end of the first phase, *Three Ideas*, teams presented six detailed design concepts. In the subsequent *Sketch Model* phase, teams presented rough prototypes of four distinct product concepts, accompanied by basic technical, market, and customer research. The *Mockup* phase fol-

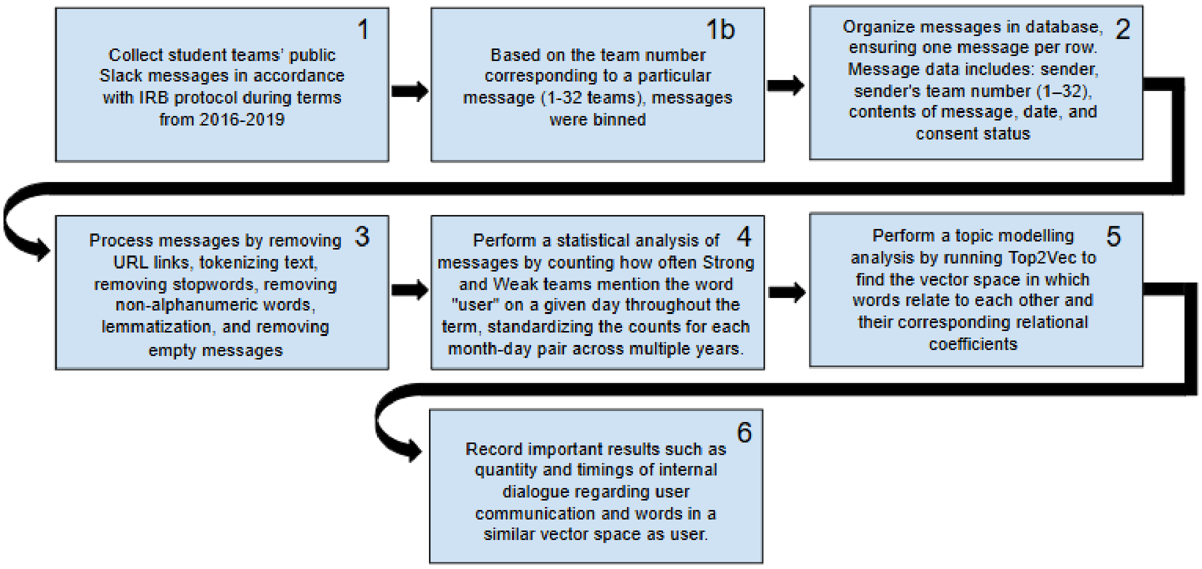


FIGURE 1: An overview of the methods used in this work.

lowed, in which functional or visual mockups of four promising concepts were showcased. At this stage, teams received critical feedback before consolidating their efforts into a single chosen concept during the *Final Selection* phase. From this point, teams refined their product through increasingly detailed design iterations. In the *Assembly* phase, teams presented product architecture models, including user storyboards, computer-aided design (CAD) models, test plans, and electronic designs. The *Technical Review* phase served as the final opportunity for teams to gather expert feedback before their final demonstration. The course culminated in the *Final Presentation* milestone, during which teams showcased functional prototypes alongside their user research and market analysis.

Throughout these phases, teams moved through two cycles of design divergence and convergence—key processes in iterative design. Design divergence refers to the phases during which teams generated and explored multiple ideas, expanding the solution space through ideation and iteration. Earlier in the course, teams engaged in divergent thinking during the Three Ideas, Sketch Model, and Mockup phases, when they explored multiple concepts and iterated on different approaches. In contrast, design convergence occurred when teams narrowed down their options, selecting and refining a single concept to move forward with. The first convergent phase was the Final Selection phase, when teams chose one design to refine and develop further. A second cycle of divergence began with the Assembly and Technical Review phases, during which teams explored different prototype implementations before converging once again on a single, polished prototype for the Final Presentation. This structured transition between divergence and convergence ensured that students experienced the full cycle of product development within an accelerated time frame. Throughout both design cycles, instructors not only actively encouraged teams to engage with users, but also supported this process by providing feedback on interview plans, helping teams identify or connect with user groups, and bringing in industry experts for support. While students were still responsible for developing connections with potential users, instructors' facilitation reinforced the importance of meaningful user engagement in shaping design decisions.

To facilitate collaboration, Slack served as the primary medium for teams' asynchronous discussions, particularly in the lead-up to deadlines. A data collection plan was approved by the institutional review board to collect message data from all public channel interactions for analysis. Participants who chose to participate in the study provided written, informed consent. The dataset excludes private messages, direct communications, and all interactions conducted by team members who chose not to participate in the study. The dataset includes user metadata, message content, replies, and timestamps, allowing for granular analysis of communication patterns.

This dataset enables the evaluation of NEDT performance by providing relevant communication patterns. To assess NEDT team performance, an expert judge—who had served as the course instructor for over 20 years—selected the strongest four teams in a given term. These teams were classified as "Strong," and the remaining four were classified as 'Weak" in order to provide a balanced dataset for analysis. This classification process was conducted for the four studied terms, resulting in 16 Strong

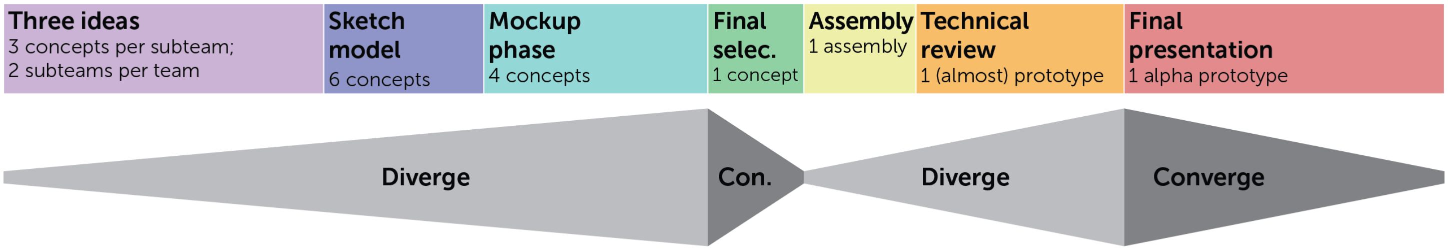


FIGURE 2: The scaled scheduling of milestones followed in the course, which give students exposure to the key stages of the full product design process. The two diverge-converge cycles of the double diamond design process are mapped below the course milestones.

NEDTs and 16 Weak NEDTs. This classification method was previously validated against teams' Technical Review scores, a quantitative metric that averaged assessment ratings of 25–38 professional design instructors [17]. That validation showed the two scoring metrics aligned for 75% of the teams. This alignment suggests a substantial overlap between the expert's holistic classification and the independent Technical Review scores. Given that the Technical Review scores were averaged across 25–38 design instructors per team, this correspondence increases confidence in the expert's knowledge of the teams, derived from over 20 years of collecting and synthesizing scores from numerous design instructors.

Prior research showed that the frequency of Slack usage correlated strongly with impending project milestones, as messaging activity peaked before major deliverables [20]. While these previous studies examined communication broadly, our work hones in on how teams discuss users, offering deeper insights into user-centered interactions. This dataset provides deeper insights into the communication behaviors of NEDTs that indicate successful process execution. By further analyzing this dataset regarding a specific topic (i.e., users), the present study seeks to reveal deeper patterns in team interactions and elucidate how virtual communication dynamics inform on a team's overall design process strength.

2.2 Data Preprocessing

The preprocessing for this study adhered to standard natural language processing (NLP) practices and was informed by previous research that analyzed the same dataset, particularly Ferguson et al. [17]. The goal was to remove noise and ensure consistency in the textual data before analysis. First, URL links were removed using regular expressions (Python's re module), and non-word characters were eliminated to discard irrelevant content. Then, text was tokenized using the word_tokenize function from the Natural Language Toolkit (NLTK) [21], and all words were converted to lowercase to ensure uniformity. This allowed us to treat words such as "User" and "user" as identical. Next, common stopwords (e.g., "and" and "the") were filtered out using NLTK's predefined English stopword list. To further refine the dataset, non-alphanumeric and non-English words were removed based on NLTK's words corpus, retaining only linguistically meaningful content. Lemmatization was then applied using NLTK's WordNetLemmatizer to reduce words to their base forms for consistency (e.g., "users" and "running" became "user" and "run," respectively).

Building on these prior preprocessing techniques, our approach introduced an additional noise-reduction step to optimize the dataset for high-sensitivity topic modeling. Specifically, we excluded messages containing fewer than four words, as they were often too brief to provide meaningful context. After applying these preprocessing steps, a total of 125,800 messages remained for statistical and topic modeling analysis.

2.3 Quantitative Data Analysis Using Statistical Modeling (*RO1* and *RO2*)

To address *RO1* and *RO2*, we quantitatively examined how design teams engaged in user-related discussions throughout the product design process. Specifically, we tracked the raw daily frequency of messages containing the keyword "user"—which we define as "user messages"—for all 32 teams using the preprocessed message database. These counts were not normalized by the total number of words, as our focus was on absolute message trends rather than relative proportions and because the total message counts for Strong (63,045) and Weak (62,855) NEDTs were similar. This approach allowed us to assess the consistency of user-related discussions while also analyzing deviations in communication trends throughout the design process.

To ensure cross-year comparability, we standardized timestamps and aggregated messages based on month-day pairs (MM-DD) independent of the year. While this approach does not control for variations due to the day of the week, our analysis focuses on long-term trends rather than short-term fluctuations. Additionally, given that team activities were spread across multiple years, any weekday effects likely average out across teams and time periods. For each day, we computed the total number of user-related messages (messages that contain at least one use of the term "user"), summing across all teams within each category (Strong or Weak).

To quantify frequency, let $M_{d,t}$ represent the number of user-related messages sent on a given day d by team t, and let c denote the team category (Strong or Weak). The daily frequency of user-related messages for each category on each month-day pair was computed using

$$F_{d,c} = \sum_{t \in c} M_{d,t}$$

where $F_{d,c}$ represents the total user-related messages sent on day d by all teams in category c.

To measure consistency, we quantified fluctuations in daily message frequency by computing the standard deviation (σ_c) for each category (Strong and Weak NEDTs). This metric captured the extent to which teams sustained engagement with user discussions over time. A lower σ_c would suggest that a team consistently discussed user-related topics throughout the design cycle, whereas a higher σ_c would indicate that discussions were irregular and clustered around specific deadlines. For each category, this measurement was calculated using

$$\sigma_c = \sqrt{\frac{1}{N} \sum_{d} (F_{d,c} - \bar{F}_c)^2}$$

where N is the number of days in the dataset, $\bar{F}_c$ is the mean daily count of user-related messages for category c, and σ_c represents the standard deviation of daily user message counts. A higher σ_c would indicate greater fluctuations in user-related discussions, while a lower σ_c would suggest steadier engagement.

Because frequency was computed for each month-day pair while standard deviation was computed as a single value per category, this framework allows us to examine both the overall consistency of user-related discussions (to address **RO1**) and the daily engagement trends during each phase (to address **RO2**). A time-series visualization of user message frequency highlighted key trends, revealing how Strong and Weak teams engaged with user considerations throughout their design processes. This approach provided empirical insights into variations in user-related communication and potential differences in design engagement patterns between Strong and Weak teams.

2.4 Qualitative Analysis Using Topic Modeling (*RO3*)

To examine the contextual usage of the term "user" in team communications, we applied Top2Vec, an unsupervised topic modeling technique, to construct a custom vectorized representation of the language used by the design teams studied here [22]. Unlike traditional topic modeling methods, such as Latent Dirichlet Allocation (LDA), which require predetermined topic counts and often struggle with short text data, Top2Vec automatically determines the number of topics based on the semantic structure of the corpus. This adaptability makes it well-suited for analyzing dynamic, unstructured team discussions where the number and nature of topics may vary across design stages [23].

After preprocessing the data, we trained a Top2Vec model using the Universal Sentence Encoder (USE) embedding model, which captures semantic relationships between words based on both contextual similarity and co-occurrence patterns. Unlike traditional topic modeling techniques such as Latent Dirichlet Allocation (LDA), which rely on bag-of-words representations and require manual hyperparameter tuning, Top2Vec dynamically determines the optimal number of topics by clustering document embeddings in a reduced-dimensional space. Specifically, it applies HDBSCAN, a density-based clustering algorithm, to identify coherent topic regions based on document distribution, optimizing for clusters that are both dense and well-separated in the semantic space. Top2Vec was particularly well-suited for analyzing enterprise communication in our dataset because it leverages dense vector representations instead of sparse word distributions, allowing it to capture semantic meaning rather than relying solely on word frequency. This was crucial for detecting user-related discussions embedded in diverse conversational contexts across different design phases. Top2Vec allows groupings of semantically similar messages even when wording differs significantly. Furthermore, Top2Vec enables direct nearest-neighbor searches in embedding space, making it easier to retrieve representative messages for each topic and gain a more nuanced understanding of communication patterns. By leveraging Top2Vec's embedding-based topic modeling, we were able to more accurately capture how teams engaged in user-related discussions across the design cycle while minimizing the limitations of traditional frequency-based topic models.

To systematically compare how Strong and Weak NEDTs frame discussions around key design concepts, we curated a domain-specific keyword set that reflected two critical aspects of students' work: following a process and executing tasks.

First, process-focused words/phrases—*architecture, concept, contract, customer, decision, design, idea, model, need, opportunity, product, prototype, selection, sketch, test,* and *testing*—were chosen because they capture essential components of design ideation, problem-solving, and evaluation. Topics like *architecture, concept*, and *model* indicate discussions around structuring and defining a design, while *decision, selection*, and *idea* reflect the evaluative and iterative nature of the process. Topics such as *prototype, test*, and *testing* were included to capture how teams validate and refine their designs, while *contract, customer*, and *need* highlight considerations of external requirements and constraints that influence design choices. The inclusion of *opportunity* and *product* ensures that discussions around identifying potential solutions and final deliverables are represented.

Second, task-oriented topics—*interview, lab, meeting, mile-*

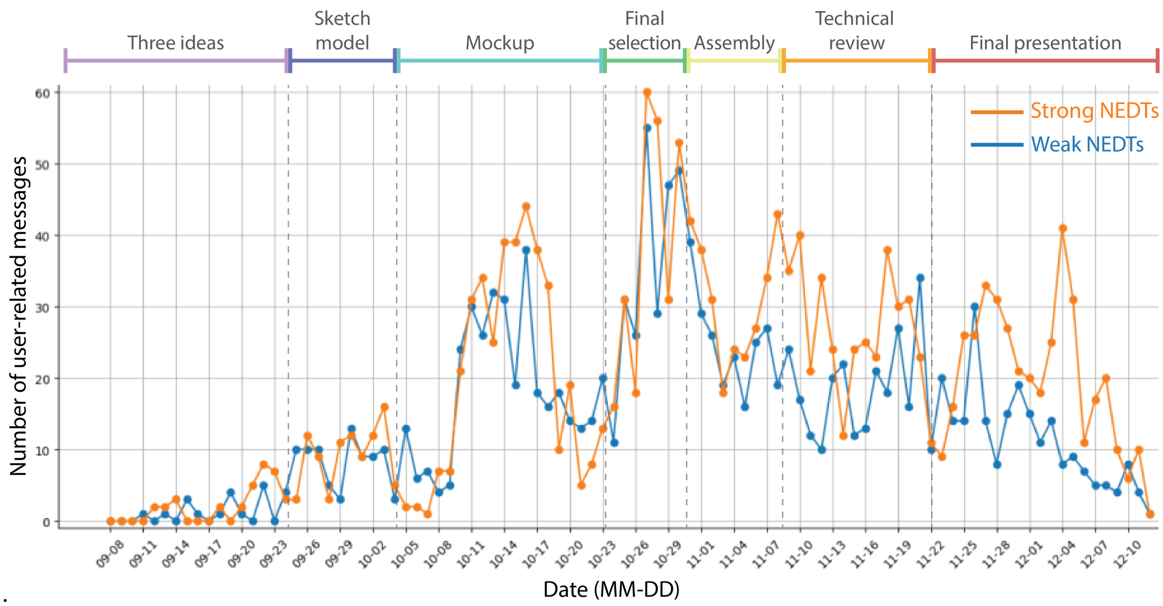


FIGURE 3: User-related message frequency for Novice Engineering Design Teams (NEDTs) over time, showing trends in engagement across design stages.

stone, presentation, schedule, session, shop, and *team*—were selected to track how teams engage in structured activities that support the design process. Topics like *interview* and *lab* represent direct user research and hands-on experimentation, while *meeting, session*, and *team* reflect internal coordination and collaboration. The topics *milestone, schedule*, and *presentation* were included to capture planning and progress-tracking efforts, which are essential for structuring work over time. Finally, *shop* was chosen to account for discussions around physical prototyping and fabrication, reflecting hands-on engineering efforts.

By extracting word embeddings from our trained model and filtering for these predefined topics, we ensured that our analysis remained focused on the discussions most relevant to design practices, decision-making, and collaborative dynamics.

To visualize the semantic structure of these topics, we combined all messages from Strong and Weak NEDTs separately before applying Top2Vec. We then used t-distributed Stochastic Neighbor Embedding (t-SNE), a dimensionality reduction technique, to map the high-dimensional word embeddings generated by Top2Vec into a two-dimensional space. This visualization highlighted how frequently and in what contexts NEDTs discuss critical design elements, offering a high-level view of semantic similarity between topics. To obtain exact measures of semantic proximity to "user," we used cosine similarity between word embeddings, which provided the precise values reported in our rankings.

By comparing the word embeddings of Strong and Weak NEDTs, we examined differences in their emphasis on users as they related to the design process or specific tasks. Specifically, we quantified the semantic similarity between user-related terms and other key design concepts within each team's communication. If teams exhibited a process-focused term that is closer in vector space to "user," it could indicate a stronger integration of user considerations into their design approach. Conversely, a closer association between user and task-oriented topics might reflect a different emphasis in how teams engage with user-related discussions. These comparisons provide insight into the relationship between linguistic patterns and design engagement, allowing us to explore potential distinctions between strong and weak teams.

3 RESULTS

This section presents the statistical and topic modeling results, organized by research objective.

3.1 RO1: Consistency and Frequency of User-Related Discussions

Figure 3 presents the absolute daily message count for each day of the term for both Strong (orange line) and Weak (blue line) NEDTs. On 72.9% of days, Strong NEDTs discussed user messages more frequently than Weak NEDTs.

While early-stage (through the Final Selection phase) discussion patterns were relatively similar between the two categories of teams, Strong NEDTs consistently exhibited higher absolute engagement in user-related discussions as the project progressed. To measure this consistency, we computed the standard deviation (σ_c) of daily user message count. Strong NEDTs demonstrated more consistent engagement with a lower standard deviation ($\sigma_{\text{Strong}} = 11.77$), compared to Weak NEDTs ($\sigma_{\text{Weak}} = 14.57$). This finding indicates that Strong teams engaged in more sustained and structured discussions about users, whereas Weak teams communicated more sporadically, with user-related conversations occurring in bursts.

These findings suggest that both higher frequency and greater consistency in user-related discussions are distinguishing factors of Strong NEDTs. Strong teams not only engaged in user discussions more frequently but also sustained them throughout the design process, whereas Weak teams showed a more erratic pattern of engagement.

3.2 RO2: User-Related Communication Patterns Across Divergent and Convergent Phases

To analyze how user-related communication patterns evolved across design stages, we examined the frequencies of user-related discussions specifically during periods of design divergence and convergence, as shown in Figure 3. Strong and Weak teams exhibited peaks in user message frequency during the first major convergence phase, Final Selection. During this phase, when teams converged on a single opportunity, Strong NEDTs showed higher local peaks in user-related discussions, indicating that they were actively considering user insights during this major decision-making process.

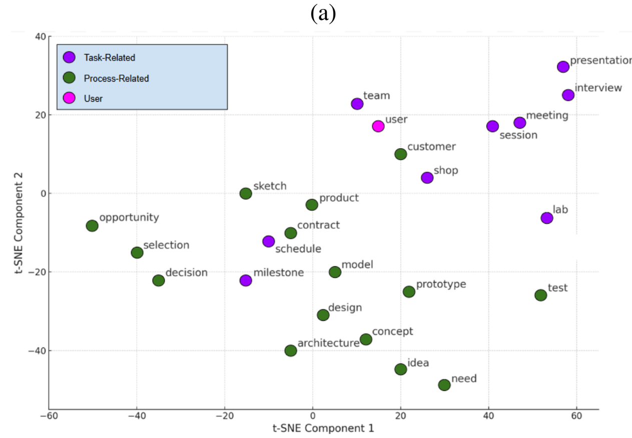
As teams progressed through the second divergent phase (Assembly and Technical Review), overall communication levels declined. However, Strong NEDTs sustained higher levels of user-related discussions than Weak NEDTs, suggesting that they remained more engaged with user considerations even as total messaging decreased. This drop in overall communication could be due to large student design teams shifting from working in smaller subgroups to collaborating as a full team, thereby reducing the number of parallel communication threads and the apparent volume of discussion.

During this second cycle, Figure 3 shows four distinct local spikes for Strong teams that exceed the corresponding peaks for Weak teams. This pattern suggests that Strong teams not only maintain steady engagement with users throughout the design process but also intensify user-related discussions during key convergence milestones. In contrast, Weak teams exhibit more sporadic engagement, often aligned with course-defined deliverables. These trends are again visualized in Figure 3, which captures how teams' user-related communication evolved over time.

3.3 RO3: Depth of User-Related Discussions via Topic Modeling

The depth of user-related discussions was examined using topic modeling. The t-SNE visualizations in Figure 4 illus-

(a)



(b)

FIGURE 4: t-SNE Visualization for (a) Strong and (b) Weak NEDTs. These plots show a 2D projection of high-dimensional word embeddings, offering an intuitive view of how topics cluster semantically around "user." This reduction in dimensionality means distances shown are approximate and may not perfectly reflect true semantic similarity. The distance rankings in Table 1 reflect the true semantic similarity.

trate the semantic relationships between "user" and other design-related terms for Strong and Weak NEDTs, indicating whether each design-related term is task-related or process-related. Additionally, Table 1 quantifies these relationships by providing the rankings of cosine similarity values between "user" and the studied topics, highlighting key distinctions in how Strong and Weak teams focus their discussion topics.

For Strong NEDTs, seven of the top ten "user"-associated topics were process-related terms. For Weak teams, only five were process-related terms. Further, out of the nine task-related terms evaluated, six co-occurred with "user" more closely in Weak team communication, while only one co-occurred more closely in Strong team communication. The remaining two co-occurred similarly in both Strong and Weak teams. These findings suggest that Strong teams frame their communication around users and integrate user considerations into their design processes better than Weak teams do.

TABLE 1: Ranked relative distances of process-related and task-related topics from "user." A topic with a lower ranked distance co-occured more with "user" than a topic with a higher ranked distance. Rankings are based on exact cosine similarity values between word embeddings and reflect precise semantic proximity to "user." For each studied topic, the lower ranked distance (between Strong and Weak teams) is bolded.

Topic	Category	Ranked Dist. (Strong)	Ranked Dist. (Weak)
customer	Process	1	1
contract	Process	**5**	7
product	Process	4	4
decision	Process	**13**	21
model	Process	11	**9**
prototype	Process	21	**11**
design	Process	**9**	15
concept	Process	**6**	17
architecture	Process	**19**	20
idea	Process	**8**	19
need	Process	**7**	23
selection	Process	**14**	22
opportunity	Process	**15**	24
sketch	Process	18	**8**
test	Process	**12**	18
team	Task	2	2
shop	Task	3	3
schedule	Task	16	**10**
milestone	Task	17	**16**
meeting	Task	23	**6**
session	Task	22	**5**
interview	Task	24	**13**
presentation	Task	20	**14**
lab	Task	**10**	12

Stark differences in Strong and Weak team topics are observable. For Weak teams, "user" appears far from "need" (ranked distance of 23) compared to Strong teams (7). As mentioned above, Weak teams' topics were more frequently task-related. These findings indicate that Weak teams may have focused more on the logistics and execution of user-related tasks rather than deeply integrating user needs into their design thinking.

Further observations apply to both Strong and Weak teams. For example, the proximity of topics such as "customer" (top-ranked for both Strong and Weak teams), "contract" (ranked 5 and 7, for Strong and Weak teams respectively), and "product" (4 and 4) to "user" indicates that NEDTs teams incorporate users directly into discussions related to design refinement. Additionally, topics like "model" (11 and 9), "prototype" (21 and 11), and "design" (9 and 15) were further from "user" than expected, as we predicted that teams would consider users in the context of developing and testing physical artifacts.

Overall, the combination of topic modeling visualizations and topic distance metrics suggests that Strong NEDTs sustain more meaningful engagement with users throughout the design cycle, embedding user considerations within their design processes and iterative decision-making. In contrast, Weak teams appear to structure user-related discussions around deliverables and formal milestones, indicating a more reactive rather than integrative approach to user engagement.

4 DISCUSSION

Results of this work can inform how instructors of NEDTs and student members of these teams might assess their own user-centered design with patterns seen in their communication. With these interpretations, they might be able to intervene and correct their design processes to enable better design practices. These results can also motivate researchers to further study how designers engage users at different points in the design process.

Figure 3 shows that for both Strong and Weak NEDTs, the highest frequencies of user-related discussions occurred mid-process, during the Final Selection stage when teams settled on a single product opportunity to pursue. This alignment suggests that user considerations, while always important, are potentially most critical when teams make key design decisions. Following this peak, both Strong and Weak NEDTs had more user-related communication in the second half of their design process than in the first. These observations oppose Maier et al.'s work that observed one NEDT and found their user engagement to decrease as the team's design process progressed [11]. Our communication-derived findings might differ from their findings because of sample size or data collection method. This result encourages NEDTs to continually engage users throughout their design processes, not just during early requirement-solicitation stages. This encouragement is increasingly important as the benefits of co-design and participatory design have been validated in many design contexts [13, 24–26].

The high frequencies of user-related communication in the second half of the design process further suggest that other forms of user engagement (e.g., in-person testing) are also high during this time. However, in contrast much of the literature involving NEDTs, professional EDTs, and user engagement focuses on early design stages [27–31]. The present results indicate that there is much to learn about how NEDTs can effectively engage with users in middle and late design stages.

The differences between Figures 4a and 4b and those seen in Table 1 indicate that Strong NEDTs took a deeper human-centered design approach than Weak teams. Strong teams considered users throughout their design discussions and treated them as more than just required engagements for course deliverables. Among others, Strong teams had higher correlations between "user" and "need," "idea," and "opportunity" compared to Weak teams. This indicates that Strong teams actively contextualized how their designs addressed user needs, which could have led to more impactful solutions. In contrast, Weak NEDTs demonstrated closer associations between "user" and task-related words, such as "schedule," "meeting," and "session." This implies that Weak teams may have discussed users primarily in preparation for course deliverables, rather than meaningfully integrating user feedback throughout the process. This task-oriented framing could have resulted in more reactive rather than proactive approaches to addressing user needs, leading to less effective design solutions.

While this study assessed novice designers' processes, the results have potential implications for professional EDTs. These results, derived from student teams, generate important hypotheses to be investigated in professional design settings. Within the literature, this work is among the first to verify best practices regarding user-related internal team communication. The analysis methods of this study, which assessed NDETs in a naturalistic way, could be repeated with communication data of professional design teams to test if the same observed trends hold true for professional designers.

When considering the implications of this study, there are several limitations to consider. First, the dataset was limited to NEDTs' virtual communication and not their in-person communication. We used online communication as a passive indicator of teams' full communication. Further, while teams were instructed to use Slack for all internal coordination and dissemination of information, students had to interact with their user groups through other channels, such as email or in-person meetings. As a result, our analysis captures how frequently teams discussed users internally, but it may not reflect the full extent of their user engagement, particularly external interactions that were not documented in Slack. While extensive and non-intrusive, this dataset is not exhaustive. Future work could investigate how teams' user-related discussions on Slack compares to those outside the platform.

The second limitation concerns the expert rating that sorted teams into Strong and Weak categories. Although this metric was previously validated in prior work [17], it does not allow for more granular strength measurements and is limited to the judgment of one expert individual. Still, the expert rating was chosen over students' final grades since course grades factored in more than just design process strength. Future work could more rigorously assess the Strong and Weak classification with additional expert reviewers.

A third limitation was that team members may have referred to their users in more context-specific terms (e.g., "nursing mothers" or "rock climbers"), and hence, a search for the general term "user" would not return these messages. This introduces the risk of underrepresenting the true extent of user-related communication. We conducted a preliminary analysis that expanded on "user," but incorporating synonyms or context-specific terms into our search introduced inconsistency and bias, as different teams used vastly different domain-specific language depending on their projects. To maintain comparability across teams and ensure a uniform query strategy, we chose to search exclusively for the term "user." Future work could explore more sophisticated natural language processing techniques, such as semantic matching or named entity recognition, to improve recall while preserving consistency.

A final limitation was the presence of noise in the dataset, as many messages were social in nature and unrelated to the design work. These messages could have obscured work-related communication patterns. The topic modeling methods searched for domain-specific topics to reduce the impact of this limitation.

Ultimately, the way NEDTs and EDTs engage users impacts their overall success [1–3]. Hence, the way teams internally discuss users can provide an important indicator of how their user engagement will impact their outcomes. In this study, Strong NEDTs kept users at the core of their conversations, which may have contributed to their development of solutions that better addressed real-world problems. Weak teams, on the other hand, tended to focus on users in relation to tasks, potentially leading to superficial insights or last-minute adjustments rather than deep, user-driven design improvements. Further work would need to be done to investigate these insights more fully.

The results of this study have the potential to impact how NEDT instructors introduce, focus on, and assess user engagement in their design courses. By presenting evidence of the communication patterns of Strong NEDTs, instructors can motivate students to consistently engage potential users. By monitoring NEDTs' user-related discussion in their own courses, instructors could quantitatively evaluate the consistency with which teams discuss users. This information, combined with the results of the present study, could help instructors better assess which teams are struggling with user engagement, even if they cannot attend user engagements with the team members.

These results are valuable to members of NEDTs, too. A student designer could reflect on their own user-related communication. They could use these insights to improve the consistency, frequency, and depth of their team's user-related communication. In particular, student leaders of NEDTs could monitor the metrics assessed in the present study and compare their teams' patterns to the ones published here. Equipped with knowledge of their own team relative to previous Strong NEDTs, they could guide their teammates in ways to increase the consistency, frequency, and depth of user-related communication.

5 CONCLUSIONS AND FUTURE WORK

This study examined the internal digital communication of novice engineering design teams (NEDTs) to assess their engagement in user-related discussions throughout the design process. By analyzing the frequency, consistency, and depth of their user-related virtual communication, we identified key differences between Strong and Weak teams, offering insights into how internal communication patterns relate to the strength of teams' human-centered design processes. Our analysis revealed that strong NEDTs engaged in more consistent user-related discussions throughout the design process, whereas weaker teams exhibited more sporadic communication. Additionally, strong teams demonstrated a deeper incorporation of user considerations into their discourse, as reflected in the semantic relationships between users and process-related terms in topic models of their communication. These insights underscore the importance of ongoing user consideration in design theory and design education and highlight internal team communication as a potential meaningful indicator of engagement with users.

Our results suggest that significant differences exist between Strong and Weak NEDTs' digital communication patterns, which instructors could use to assess and support student teams' engagement with users. By tracking the frequency, consistency, and topical associations of user-related discussions, educators, team leaders, and designers themselves could better critically evaluate teams' design processes.

Several directions exist for expanding this research. Further research could investigate whether teams that maintain strong user-related communication ultimately produce higher-quality or more innovative design solutions, providing empirical evidence for the impact of sustained user engagement. Future work could expand on the present findings by incorporating multi-modal communication analysis, integrating in-person meetings, video calls, and informal discussions to develop a more comprehensive view of NEDTs' internal team communication and external user interactions. Additionally, building on these findings, we envision the development of automated tools that provide real-time feedback on internal team communication, enabling teams to monitor, assess, and refine their engagement strategies dynamically. Finally, while this study focused on novice teams, comparing their communication patterns with those of professional engineering design teams could reveal how user engagement evolves with experience and industry constraints.

By continuing to explore the intersection of digital communication and human-centered design, this work contributes to the growing body of research on engineering design and education and informs strategies to help student designers meaningfully integrate user perspectives throughout the design process.

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REFERENCES

[1] J. Redström, "Towards user design? On the shift from object to user as the subject of design," *Design Studies*, vol. 27, pp. 123–139, Mar. 2006.

[2] M. N. Saunders, C. C. Seepersad, and K. Hölttä-Otto, "The Characteristics of Innovative, Mechanical Products," *Journal of Mechanical Design*, vol. 133, p. 021009, Feb. 2011.

[3] K. Hölttä-Otto, K. Otto, C. Song, J. Luo, T. Li, C. C. Seepersad, and W. Seering, "The Characteristics of Innovative, Mechanical Products—10 Years Later," *Journal of Mechanical Design*, vol. 140, p. 084501, Aug. 2018.

[4] G. Lemons, A. Carberry, C. Swan, and L. Jarvin, "The Effects of Service-Based Learning on Metacognitive Strategies During an Engineering Design Task," *International Journal for Service Learning in Engineering, Humanitarian Engineering and Social Entrepreneurship*, vol. 6, pp. 1–18, Oct. 2011.

[5] J. R. De La O Campos and D. Güemes Castorena, "TOWARDS A BETTER HUMAN CENTRE DESIGN PRACTICE IN AN ACADEMIC CONTEXT," in *Proceedings of the International Conference on Engineering and Product Design Education, EPDE 2023*, The Design Society, 2023.

[6] H. Van Rijn, F. Sleeswijk Visser, P. J. Stappers, and A. D. Özakar, "Achieving empathy with users: the effects of different sources of information," *CoDesign*, vol. 7, pp. 65–77, June 2011.

[7] I. Mohedas, S. R. Daly, and K. H. Sienko, "Requirements Development: Approaches and Behaviors of Novice Designers," *Journal of Mechanical Design*, vol. 137, p. 071407, July 2015.

[8] S. Ferguson, K. Lai, J. Chen, S. Faidi, K. Leonardo, and A. Olechowski, ""Why couldn't we do this more often?": exploring the feasibility of virtual and distributed work in product design engineering," *Research in Engineering Design*, vol. 33, pp. 413–436, Oct. 2022.

[9] Slack, "With 10+ million daily active users, Slack is where more work happens every day, all over the world," Jan. 2019.

[10] Statista, "Number of daily active users (DAU) of Microsoft Teams worldwide as of 2024," Jan. 2025.

[11] J. R. A. Maier, T. Troy, P. J. Johnston, V. Bobba, and J. D. Summers, "Case Study Research Using Senior Design

Projects: An Example Application," *Journal of Mechanical Design*, vol. 132, p. 111011, Nov. 2010.

[12] R. Loweth, S. Daly, K. Sienko, A. Hortop, and E. Strehl, "Student Designers' Interactions with Users in Capstone Design Projects: A Comparison Across Teams," in *2019 ASEE Annual Conference & Exposition Proceedings*, (Tampa, Florida), p. 33291, ASEE Conferences, June 2019.

[13] J. Trischler, S. J. Pervan, S. J. Kelly, and D. R. Scott, "The Value of Codesign: The Effect of Customer Involvement in Service Design Teams," *Journal of Service Research*, vol. 21, pp. 75–100, Feb. 2018.

[14] A. Surma-aho, T. Björklund, and K. Hölttä-Otto, "User and stakeholder perspective taking in novice design teams," *Design Science*, vol. 8, p. e24, 2022.

[15] Design Council, "A study of the design process: Eleven lessons: managing design in eleven global brands," tech. rep., 2007.

[16] C. L. Dym, A. M. Agogino, O. Eris, D. D. Frey, and L. J. Leifer, "Engineering Design Thinking, Teaching, and Learning," *Journal of Engineering Education*, vol. 94, pp. 103–120, Jan. 2005.

[17] S. A. Ferguson, K. Cheng, L. Adolphe, G. Van De Zande, D. Wallace, and A. Olechowski, "Communication patterns in engineering enterprise social networks: an exploratory analysis using short text topic modelling," *Design Science*, vol. 8, p. e18, 2022.

[18] Z. Ball, J. Bessette, and K. Lewis, "Who, What, and When? Exploring Student Focus in the Capstone Design Experience," 2020.

[19] C. Snider, S. Škec, J. A. Gopsill, and B. J. Hicks, "The characterisation of engineering activity through email communication and content dynamics, for support of engineering project management," *Design Science*, vol. 3, p. e22, 2017.

[20] G. D. Van de Zande and D. R. Wallace, "Online Communication in Student Product Design Teams," in *Volume 3: 20th International Conference on Advanced Vehicle Technologies; 15th International Conference on Design Education*, (Quebec City, Quebec, Canada), p. V003T04A002, American Society of Mechanical Engineers, Aug. 2018.

[21] NLTK Team, "Natural Language Toolkit Documentation," Aug. 2024.

[22] D. Angelov, "Top2Vec: Distributed Representations of Topics," Aug. 2020. arXiv:2008.09470 [cs].

[23] B. C. De Lima, R. M. A. Baracho, T. Mandl, and P. B. Porto, "Reactions to science communication: discovering social network topics using word embeddings and semantic knowledge," *Social Network Analysis and Mining*, vol. 13, p. 119, Sept. 2023.

[24] A. Mazzurco, J. A. Leydens, and B. K. Jesiek, "Passive, Consultative, and Coconstructive Methods: A Framework to Facilitate Community Participation in Design for Development," *Journal of Mechanical Design*, vol. 140, p. 121401, Dec. 2018.

[25] B. R. Bhattacharjya and S. K. Kakoty, "An Exploration of Intermediary's Role in Participatory Product Design at the Bottom of the Pyramid: The Case of Improvised Pedal-Operated ***Chaak*** ," *Journal of Mechanical Design*, vol. 142, p. 124501, Dec. 2020.

[26] R. Ross, K. Rouen, and J. Austin-Breneman, "Extending Lead User Theory to Participatory Co-Design: A Case Study in a Base of the Pyramid Context," in *Volume 7: 30th International Conference on Design Theory and Methodology*, (Quebec City, Quebec, Canada), p. V007T06A028, American Society of Mechanical Engineers, Aug. 2018.

[27] M. Fuge and A. Agogino, "Pattern Analysis of IDEO's Human-Centered Design Methods in Developing Regions," *Journal of Mechanical Design*, vol. 137, p. 071405, July 2015.

[28] N. Chaniaud, S. Fleury, B. Poussard, O. Christmann, T. Guitter, and S. Richir, "Is virtual reality so user-friendly for non-designers in early design activities? Comparing skills needed to traditional sketching versus virtual reality sketching," *Design Science*, vol. 9, p. e28, 2023.

[29] A. Häggman, G. Tsai, C. Elsen, T. Honda, and M. C. Yang, "Connections Between the Design Tool, Design Attributes, and User Preferences in Early Stage Design," *Journal of Mechanical Design*, vol. 137, p. 071408, July 2015.

[30] B. Macomber and M. Yang, "The Role of Sketch Finish and Style in User Responses to Early Stage Design Concepts," in *Volume 9: 23rd International Conference on Design Theory and Methodology; 16th Design for Manufacturing and the Life Cycle Conference*, (Washington, DC, USA), pp. 567–576, ASMEDC, Jan. 2011.

[31] R. Duan, N. Karthik, J. Shi, R. Jain, M. C. Yang, and K. Ramani, "ConceptVis: Generating and Exploring Design Concepts for Early-Stage Ideation Using Large Language Model," in *Volume 3B: 50th Design Automation Conference (DAC)*, (Washington, DC, USA), p. V03BT03A042, American Society of Mechanical Engineers, Aug. 2024.

