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SKETCHING AS A COMMUNICATION TOOL FOR SHARED UNDERSTANDING IN CONCEPTUAL DESIGN PHASE OF AUTOMOTIVE DESIGN

Mohamad Fairuz Abdul Rahim[1], Nik Shahman Nik Ahmad Ariff[1*], Mazura Omar[2,3]

[1] Department of Creative Artificial Intelligence, Faculty of Artificial Intelligence, Universiti Teknologi Malaysia, Kuala Lumpur, Malaysia
Email: mohamadfairuz.ar@utm.my
Email: nikshahman@utm.my
[2] Kulliyyah of Architecture and Environmental Design, International Islamic University Malaysia, 53100 Kuala Lumpur, Malaysia
Email: mazuraomar@gmail.com
[3] Faculty of Creative Technology and Heritage, Universiti Malaysia Kelantan, Kampus Bachok Kelantan, 16300 Bachok, Kelantan, Malaysia
Email: mazuraomar@gmail.com
[*] Corresponding Author

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Abstract:

Effective communication is essential for fostering shared understanding during the conceptual phase of automotive design, where ambiguity and rapid ideation are common. This study investigates how sketching functions as an effective communication tool in two different interaction modalities: silent (experimental group) and verbal (control group), to support team alignment and idea development. Eighteen Malaysian automotive designers were assigned to three-person teams and completed a two-stage task involving individual ideation followed by collaborative refinement. Using visual link analysis, the study evaluated design moves, refinement patterns, and the balance of contributions across both conditions. Silent groups exhibited more structured individual sketching behavior and greater refinement during the ideation stage, while verbal groups utilized spoken dialogue during collaboration to negotiate and align concepts. Although statistical differences were not significant, consistent behavioral trends emerged across conditions. These findings suggest that sketching operates as a flexible and self-sufficient communication medium, effectively bridging cognitive gaps regardless of verbal interaction. The study provides empirical evidence supporting sketching's dual role as both an individual cognitive tool and a shared visual language in team-based design.

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Keywords:

Sketching, Automotive Design, Shared Understanding, Communication, Conceptual Design, Collaboration

Introduction

Background

In the early stages of automotive design, transforming abstract concepts into tangible visual representations is critical to aligning team perspectives and generating innovation. The conceptual design phase is particularly complex, requiring teams to rapidly generate, evaluate, and refine ideas while aligning diverse perspectives and managing ambiguity (Dell'Era, Magistretti, Cautela, Verganti, & Zurlo, 2020; Wang, Lu, Ponsa i Campanyà, Chen, & Chen, 2025). Within this dynamic environment, sketching serves as a foundational tool that allows designers to externalize ideas, reflect visually, and communicate intentions (Bouchard, Aoussat, & Duchamp, 2006; Das, 2025).

Although sketching is widely recognized for its creative and expressive functions, it also serves an important yet underexplored role in supporting communication within design teams. Sketches can function as boundary objects, which are visual artifacts that help align mental models and promote shared reasoning among individuals from diverse disciplines (Bin Nik Ahmad Ariff, 2020; Gero & Milovanovic, 2020). Prior research shows that sketching enables reflective interaction with external representations (Goldschmidt, 2016), facilitating the alignment of perspectives by making design intentions visible and open to joint interpretation (Ma, 2023; Tversky, 2013). This communicative function becomes significantly more important in collaborative design settings where verbal exchanges may be constrained by hierarchy, cultural differences, or disciplinary jargon (Howell et al., 2024; Oham & Ejike, 2024).

Despite the increasing use of digital tools and Artificial Intelligence (AI) in design workflows, traditional hand sketching remains indispensable in automotive design for its immediacy, flexibility, and effectiveness in visual communication (Piłat, 2024; Rahim, Ariff, Yusof, & Badke-Schaub, 2024). It enables rapid iteration, conveys emotional nuance, and supports early visualization of form-function relationships. These capabilities are crucial for managing the complexity inherent in concept development (Ariff, Eris, & Badke-Schaub, 2013; Tang, Vezzani, & Eriksson, 2020). However, how sketching supports communication under varying interaction conditions, particularly in silent versus verbal collaboration, has received limited empirical attention in existing literature.

Problem Statement

Design teams are often composed of individuals with diverse expertise, cognitive styles, and disciplinary backgrounds. As a result, achieving communication alignment is a persistent challenge (Oham & Ejike, 2024; Sachan & Shukla, 2024). During the conceptual design phase, where objectives are evolving and ambiguity is high, misalignment of mental models can lead to inefficiencies, delayed decisions, and suboptimal design outcomes (N. A. Ariff, P. Badke-Schaub, & O. Eris, 2012; Lengfeld, Zalewski, & Shugar, 2024).

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During the conceptual design phase, where objectives are evolving and ambiguity is high, misalignment of mental models can lead to inefficiencies, delayed decisions, and suboptimal design outcomes(Howell et al., 2024). In contrast, sketching offers a visual and often more inclusive mode of interaction, enabling ideas to be externalized and jointly interpreted. However, sketching does not provide the real-time feedback loop that verbal communication offers, which raises questions about its effectiveness under different interaction conditions.
There is a clear need for empirical research to investigate how sketching facilitates shared understanding in both silent and verbal collaborative design contexts. Such insights are important for improving design team workflows and enhancing communication effectiveness during the early and ambiguous stages of automotive concept development (Dell'Era et al., 2020; Tovey, Porter, & Newman, 2003).

Research Question

This study addresses the following research question:

- How does sketching support shared understanding among automotive designers during the conceptual design phase under different communication conditions (silent vs verbal)?

Aim and Contribution

This study aims to evaluate sketching as an effective communication tool for fostering shared understanding in automotive design teams operating under silent and verbal interaction settings. Through a quasi-experimental protocol involving structured sketching tasks, the research investigates how sketching contributes to team alignment during both individual ideation and collaborative refinement phases. By comparing silent and verbal groups using structured visual analysis metrics, the study highlights how sketching helps bridge communication differences and facilitates convergence in early-stage design.

The contribution of this study lies in demonstrating the role of sketching as a cognitive instrument for individual exploration and a social tool for team coordination. The findings show that sketching adapts effectively to different communication contexts while consistently supporting the development of shared mental models. These insights reinforce sketching's role as an effective and indispensable communication tool in the conceptual design phase of automotive design.

Literature Review

Sketching as a Cognitive Tool in Conceptual Design

Sketching is widely recognized in design literature as a core cognitive activity that externalizes thought, enables rapid ideation, and fosters visual reasoning (Goldschmidt, 1995; Tversky, 2013). In the conceptual phase, where designers must explore form, function, and innovation simultaneously, sketching provides a medium through which abstract intentions are made tangible (Bouchard et al., 2006; Dell'Era et al., 2020). It serves not only to record ideas but also to enable a reflective conversation with the sketch itself, allowing for progressive refinement and self-correction (Goldschmidt, 2016; Ma, 2023).

International Journal of Innovation and Industrial Revolution
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In automotive design, where aesthetics, engineering logic, and brand identity intersect, sketching remains irreplaceable. Despite the availability of digital tools, traditional hand sketching continues to support spontaneity, ambiguity management, and early exploration of form-function relationships (Piłat, 2024; Rahim et al., 2024). These qualities make it ideally suited for navigating the uncertain, iterative nature of early-stage design.

Sketching as a Medium for Shared Understanding

While the cognitive value of sketching is well established, its communicative function within design teams has gained increasing scholarly attention. Sketches act as boundary objects, serving as visual representations that bridge differences in roles, expertise, and perspectives (Gero & Milovanovic, 2020; Vink, Edvardsson, Wetter-Edman, & Tronvoll, 2019). In this role, sketches enable team members to anchor discussions, co-construct meaning, and align mental models during ideation and refinement (Bin Nik Ahmad Ariff, 2020; Ma, 2023).

Shared understanding in design does not emerge solely from verbal discussion. Instead, it is often constructed through mutual interaction with evolving visual representations (N. A. Ariff et al., 2012; N. S. N. A. Ariff, P. Badke-Schaub, & O. Eris, 2012). In team-based contexts, sketching makes thinking visible and interpretable, helping to synchronize goals and resolve ambiguity, particularly when disciplinary language or social dynamics create barriers (Oham & Ejike, 2024; Omar et al., 2022).

However, empirical studies focusing on how sketching facilitates shared understanding remain sparse, particularly in contexts where verbal communication is limited. Existing research often examines sketches in conjunction with spoken interaction but rarely isolates how sketching alone can sustain communication in silence or under constraint.

Communication Modalities in Design Teams

Collaborative design typically integrates both verbal and visual modes of communication. Spoken dialogue allows for negotiation, clarification, and persuasion, while sketching conveys spatial, emotional, and structural intent (Zhang et al., 2024). Yet, in many real-world or experimental contexts, verbal communication may be deliberately restricted due to hierarchy, linguistic barriers, time pressure, or cultural differences (Howell et al., 2024; Stacey, Eckert, & McFadzean, 1999).

Under such conditions, sketching often becomes the primary channel of communication. It must therefore function not only as a tool for ideation but also as a communicative interface capable of expressing design rationale, aligning viewpoints, and guiding collective refinement in the absence of speech (Cash & Maier, 2021; Wang et al., 2025).

While several studies have examined how design ideas evolve through verbal discussion, few have systematically compared sketching behavior across different communication modalities. This is especially true in controlled settings where interaction mode is deliberately varied (Dell'Era et al., 2020; Van der Lugt, 2005). This represents a significant gap in understanding how sketching adapts to various communicative contexts and how it contributes to the formation of shared understanding when speech is absent.

International Journal of Innovation and Industrial Revolution
EISSN: 2637-0972
Volume 7 Issue 22 (September 2025) PP. 764-778
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This study addresses this gap by analyzing how sketching supports shared understanding under silent and verbal interaction conditions. Rather than evaluating final outcomes, it investigates the underlying process patterns, specifically how sketches evolve and connect across individuals and design phases to support communication and alignment.

Methodology

Study Design

This study employed a quasi-experimental design to investigate how sketching facilitates shared understanding in automotive design teams under two distinct communication conditions: silent (experimental group) and verbal (control group). The focus was on the design process rather than final outcomes, examining how sketching functions as a communicative mechanism across different interaction modalities.

A two-stage structure was implemented, consisting of individual ideation followed by collaborative refinement. This approach captured the full spectrum of sketching activity, from personal conceptual development to team-based negotiation and alignment. In the first stage, participants generated initial ideas independently. In the second stage, those ideas were refined collaboratively within teams. The primary objective was to examine how sketching supported communication and shared understanding under each condition.

The study was conducted over a seven-month period, from August 2023 to February 2024, at the Faculty of Artificial Intelligence, Universiti Teknologi Malaysia (UTM), Kuala Lumpur. Sessions were conducted in a controlled indoor studio environment, and all procedures, timing, and environmental conditions were standardized across groups to ensure consistency and reliability.

Participants and Sampling

Eighteen Malaysian automotive designers participated in this study, representing a range of experience from novice (less than five years) to expert (more than five years), consistent with prior research on design cognition and expertise levels (Chen, Yan-Ting, & Chia-Han, 2022). Participants were pre-screened to ensure active involvement in conceptual design tasks.

To reflect the composition of typical design teams, the participant pool was intentionally diversified to include both novice and expert designers. Participants were randomly assigned into six groups of three designers each (triads), a structure demonstrated to balance interaction diversity with analytical clarity in design studies (Goldschmidt, 1995).

Groups were randomly assigned to one of two communication conditions:

- Silent Groups (n = 3): Verbal communication was restricted.
- Verbal Groups (n = 3): Verbal communication was permitted.

Task Protocol

Each group responded to a standardized design brief: “Conceptualize a personal mobility vehicle for wheelchair users, optimized for urban environments, with a focus on accessibility, compactness, and aesthetic appeal.

International Journal of Innovation and Industrial Revolution
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The task was divided into two phases:

- **Phase 1: Individual Ideation (20 minutes)**
  Each participant independently sketched ideas based on the brief, without interaction.
- **Phase 2: Collaborative Refinement (50 minutes)**
  The triad regrouped to combine, evaluate, and refine the initial concepts into a shared design solution.

Figure 1 illustrates the experimental setup, outlining the two-phase structure and communication protocols applied to each group. This setup allowed for consistent comparison of sketching behavior across conditions.

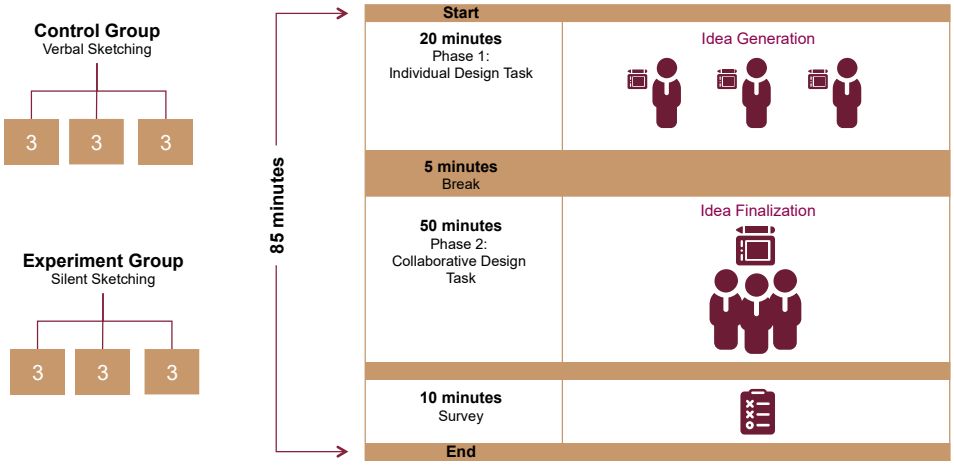

Figure 1: Experimental Procedure For Silent And Verbal Sketching Groups Across Two Stages: Individual Idea Generation And Collaborative Idea Finalization.

Each session followed a standardized workflow, including a 5-minute break between phases. Silent groups completed the task without speaking, relying solely on sketching for communication. Verbal groups were permitted to communicate freely while sketching throughout both phases. This structure isolated the influence of communication modality on shared understanding.

Participants sketched on A3 paper during individual ideation and used a shared A1 sheet during collaboration for refinement. Additional sheets were provided upon request. Each participant used a uniquely colored pen to allow tracking of individual contributions during analysis.

Data Collection

The primary data consisted of sketch artifacts produced during both task phases. Sketches were collected immediately after each session, digitized, and systematically labeled by group, participant ID, and task phase. Color-coded pens enabled clear attribution of individual contributions.

International Journal of Innovation and Industrial Revolution
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All sketching sessions were recorded using a dual-camera setup. A ceiling-mounted 360-degree camera captured a top-down view of the sketching surface, while a side-positioned camera provided a complementary angle to document participant interaction and sketching activity. These recordings were used to verify adherence to task protocols and assist in reconstructing sketch sequences. However, no verbal transcripts or gesture data were analyzed, as the study focused exclusively on visual sketch outputs to assess communication and refinement behavior.

Analysis Approach

The primary analysis employed an adaptation of visual link analysis, a method that maps how design moves (i.e., sketching acts) connect over time and across participants. The analysis was structured around three core dimensions:

1. **Design Moves (Communication)** : Each distinct sketching act that advanced the design was counted and categorized by phase.
2. **Idea Development (Refinement)** : Observations were made on whether sketches built upon previous ones (within or across participants), indicating alignment or divergence.
3. **Contribution Balance (Collaboration)** : The proportion of refinements made during individual vs. collaborative stages was assessed, reflecting how teams built shared understanding.

Sketch timelines were reconstructed by synchronizing participant IDs, move sequences, and visual features. All moves were coded and analyzed using descriptive statistics (frequencies, proportions) and inferential tests, including chi-square and t-tests, to compare sketching patterns between silent and verbal groups. These metrics allowed for structured insights into how sketching supported alignment and communication across conditions.

Process Flow

The research followed eight structured stages, as illustrated in Figure 2, covering the complete process from participant preparation to data analysis. This framework ensured procedural clarity and highlighted the systematic nature of the study.

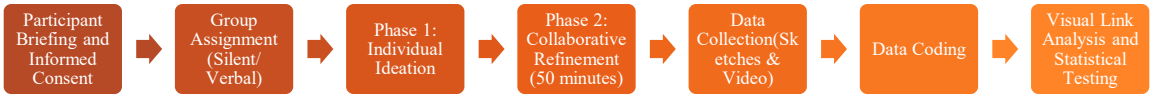

Figure 2: Research Process Flow Outlining Participant Preparation, Task Execution, Data Collection, And Analysis.

Sessions were scheduled independently based on participant availability. Despite the staggered timeline, all sessions adhered to identical protocols, equipment setup, and recording procedures to maintain consistency.

Participants were first briefed and randomly assigned to either the silent or verbal condition. They then completed two tasks under controlled conditions: an individual ideation phase and a collaborative refinement phase, as described in Section 3.3.

International Journal of Innovation and Industrial Revolution
EISSN: 2637-0972
Volume 7 Issue 22 (September 2025) PP. 764-778
DOI 10.35631/IJIREV.722043

All sketching sessions were recorded using a dual-camera setup. Sketches were collected immediately, digitized, and labeled by participant. Individual contributions were tracked using color-coded pens and synchronized with timeline data.

In the analysis phase, visual link analysis was conducted to identify design moves, map idea development, and assess collaboration patterns. Descriptive and inferential statistics were applied to compare sketching behavior across the two communication conditions.

Results and Findings

This section presents the empirical results of the sketch-based analysis, focusing on three core dimensions that reflect how sketching contributed to shared understanding under silent and verbal communication conditions:

1. **Design Moves:** Frequency and distribution of sketching acts (moves),
2. **Idea Development:** Patterns of lateral and vertical refinement links,
3. **Contribution Distribution:** Balance of individual vs. collaborative refinement.

All results are derived from the visual link analysis of sketch artifacts collected during the two task phases.

Communication Through Sketching: Design Moves

Design moves refer to discrete sketch-based contributions made during both the individual and collaborative stages. These moves reflect how participants externalized and communicated design ideas visually.

To compare how communication unfolded through sketching in different group conditions, the number of design moves was recorded and analyzed for both silent and verbal groups across the two phases. Table 1 presents the distribution of these moves, highlighting the extent of sketch-based contributions made individually and collaboratively in each group type. Across all groups, a total of 59 design moves were recorded.

Table 1. Distribution Of Design Moves By Group And Phase

Group Type	Individual Moves	Collaborative Moves	Total Moves
Silent	16	15	31
Verbal	13	15	28

Silent groups produced a higher number of individual moves, suggesting that in the absence of spoken dialogue, participants relied more heavily on visual sketching to articulate and communicate their ideas. This pattern indicates a deliberate use of sketching as a self-explanatory communication medium.

In contrast, verbal groups exhibited more evenly distributed moves across both stages, with fewer initial visual contributions but equivalent collaborative activity. Verbal participants appeared to postpone visual refinement until the group phase, leveraging spoken conversation to frame or co-construct sketch content.

International Journal of Innovation and Industrial Revolution
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Volume 7 Issue 22 (September 2025) PP. 764-778
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A chi-square test of independence was conducted to examine the difference in move distribution between groups:

- $\chi^2(1, N = 59) = 0.29, p = 0.590$

The result was not statistically significant, indicating that while silent groups appeared more visually active during individual ideation, the overall move frequency distribution was comparable across groups.

Idea Development: Lateral and Vertical Links

The progression of design ideas was analyzed by tracking how new sketches built upon earlier ones, whether self-generated or produced by teammates. This process revealed how shared understanding evolved through visual refinement, even under differing communication conditions.

Idea development was categorized using two link types:

- **Lateral connections:** New or divergent ideas
- **Vertical connections:** Iterative refinements of existing ideas

To understand how these patterns differed by communication condition and design stage, the frequency of lateral and vertical links was recorded and compared across groups. Table 2 presents the distribution of these link types in both the individual and collaborative phases.

Table 2. Distribution Of Lateral And Vertical Links

Group	Phase	Lateral Links	Vertical Links
Silent	Individual	9	7
Verbal	Individual	9	4
Silent	Collaborative	0	15
Verbal	Collaborative	0	15

In the individual phase, both silent and verbal groups exhibited equal levels of lateral exploration (n = 9). However, silent groups produced more vertical links (n = 7 vs. 4), suggesting deeper self-refinement via sketching in the absence of spoken dialogue.

During the collaborative phase, both conditions showed a complete shift to vertical refinement (n = 15), with lateral links dropping to zero. This pattern reflects a convergence of ideas through shared sketch-based negotiation, regardless of communication mode.

As shown in Figure 3, both groups exhibited equal levels of lateral exploration during the individual ideation phase. However, silent participants produced a higher number of vertical links, which reflects a greater reliance on sketch-based self-refinement. The chart also demonstrates a clear transition in both groups from lateral to vertical linking as they moved into the collaborative phase. This pattern highlights a shift in focus from idea generation to collective refinement. The visual trend suggests that sketching functioned effectively as a

International Journal of Innovation and Industrial Revolution
EISSN: 2637-0972
Volume 7 Issue 22 (September 2025) PP. 764-778
DOI 10.35631/IJIREV.722043

medium for developing shared understanding in both silent and verbal groups, though the pathways differed slightly based on the communication condition.

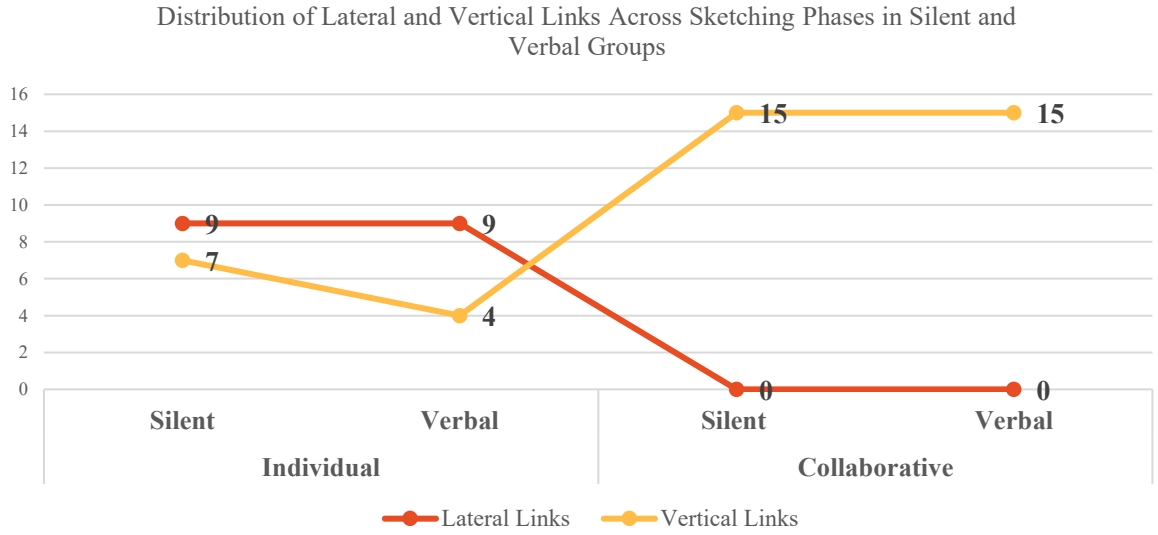

Figure 3: Lateral And Vertical Link Distribution Across The Individual And Collaborative Phases For Silent And Verbal Groups.

A chi-square test comparing vertical links during the individual phase showed no statistically significant difference between groups, χ^2 (1, N = 11) = 1.09, p = 0.296. Nonetheless, the trend indicates that silent participants more frequently refined their own ideas visually, reinforcing the communicative role of sketching when speech was restricted.

Link density (refinement connections per move) was also higher in silent groups (1.73) than in verbal groups (1.47), implying tighter visual idea chains. However, an independent samples t-test revealed no statistically significant difference, t (4) = 1.12, p = 0.320. While not conclusive, the pattern again supports the interpretation that sketching was more integrative in silent teams during early idea development.

Contribution Distribution: Shared Refinement

The contribution of sketching to shared understanding was evaluated by analyzing the distribution of refinements across the individual and collaborative phases. This analysis highlights the extent to which alignment and idea development emerged through personal ideation compared to group interaction. Table 3 summarizes the percentage of refinement activities completed individually versus collaboratively in both silent and verbal groups.

Table 3. Distribution Of Refinements Across Phases By Group Type

Group Type	Individual Refinement (%)	Collaborative Refinement (%)
Silent	50	50
Verbal	44.4	55.6

International Journal of Innovation and Industrial Revolution
EISSN: 2637-0972
Volume 7 Issue 22 (September 2025) PP. 764-778
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Silent groups exhibited a balanced refinement profile, with half of the total refinements made individually and half collaboratively. This pattern suggests that participants developed and clarified their design thinking independently before entering collaboration, and that sketches functioned as self-contained communicative artifacts.

Verbal groups, by contrast, leaned slightly more toward collaborative refinement, indicating a stronger reliance on real-time negotiation and spoken explanation to reach alignment. The verbal mode appeared to reduce the need for extensive individual sketch elaboration prior to group discussion.

A chi-square test of independence revealed:

- $\chi^2(1, N = 36) = 0.50, p = 0.479$

Although these differences were not statistically significant ($p > .05$), the qualitative distinction is relevant: silent groups structured their understanding through visual iteration, while verbal groups tended to reach alignment through dialogue-supported refinement.

Collectively, these findings indicate that while statistical differences were not always significant, the way sketching was integrated into the design process differed meaningfully between conditions. Silent teams relied on visual iteration to build understanding, while verbal teams used sketching as a responsive tool embedded within dialogue.

Discussion

This study investigated how sketching contributes to shared understanding during the conceptual design phase by comparing silent and verbal communication contexts. The results indicate that sketching adapts functionally to the communication mode, supporting both individual clarity and group alignment. While not all comparisons yielded statistically significant results, consistent patterns reveal distinct behavioral tendencies that inform how sketching operates under varying interaction conditions.

Sketching as a Medium for Shared Understanding

The findings reaffirm the notion that sketching functions as a shared visual language within design teams (Gero & Milovanovic, 2020; Vinker et al., 2025). In both silent and verbal groups, sketching was used not only to express individual ideas but also to construct common ground during collaboration.

In the silent groups, sketching became the primary mode of expression and interpretation. Participants made more individual design moves and vertical links during solo ideation, showing that sketches were structured to be self-explanatory and communicative. The balanced distribution of refinements across phases (50% individual, 50% collaborative) suggests that participants took responsibility for clearly articulating their ideas before group alignment, treating sketching as a self-contained communication tool.

In verbal groups, the sketching process appeared to be more responsive and dynamic, particularly during the collaborative phase. Spoken dialogue was used to frame, negotiate, and co-develop sketches. Although verbal participants made fewer individual refinements, they showed an increased reliance on collaborative refinements, using sketches as evolving representations shaped through group discussion.

International Journal of Innovation and Industrial Revolution
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Differences in Cognitive Strategies

The higher number of vertical links and greater link density in the silent groups suggest a more structured and internally cohesive ideation strategy. This supports previous findings that in the absence of verbal feedback, individuals engage more deeply in visual self-reflection and refinement (Goldschmidt, 2016; Tversky, 2013).

Verbal groups, on the other hand, appeared to distribute cognitive effort across the team, depending more on shared discussion to resolve ambiguity and align on design intent. Sketches in these groups were often co-constructed, responding to verbal suggestions rather than evolving independently.

These contrasting strategies suggest that communication modality influences not only the style of interaction but also the depth and timing of visual reasoning. Silent sketching encouraged designers to fully externalize their intent and engage in internal refinement. In contrast, verbal sketching enabled more interactive and negotiated refinement, often postponing visual clarity until group consensus was reached.

Implications for Design Practice

The results offer practical insight into how sketching can be leveraged more strategically in design teams:

- In early ideation stages, silent sketching may support deeper individual exploration and reduce premature group convergence by allowing designers to refine and present their thinking visually before dialogue begins.
- During team alignment, verbal sketching facilitates immediate feedback and faster iteration, enabling teams to converge and validate shared understanding more efficiently.

Design educators and practitioners may consider alternating between silent and verbal sketching modes based on the phase of the design task. Silent sketching is particularly effective during individual ideation, while verbal sketching is well suited for decision-making and collaborative refinement. Training teams to be proficient in both modes can improve communication agility and enhance innovation outcomes.

These insights are especially relevant to industry practices in remote or cross-cultural design environments, where verbal interaction may be constrained. Promoting structured sketching behavior in such settings can help maintain shared understanding despite limited verbal cues. At the national level, the findings support Malaysia's ongoing emphasis on strengthening industrial design capabilities. Integrating sketch fluency into professional development and design education programs can help accelerate early-phase innovation in local product development.

Alignment with Prior Research

These findings extend earlier work by van der Lugt (2003) and Goldschmidt (1995), who emphasized the role of link structures in design cognition. Although this study focused on communication rather than creativity, the patterns observed suggest that shared refinement via sketching promotes clearer alignment and more structured progress.

International Journal of Innovation and Industrial Revolution
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In contrast to previous studies that primarily relied on verbal protocols or focused on evaluating design outcomes, this research examined sketching as a standalone communication tool. It demonstrated that sketches serve as a sufficient medium for idea exchange, even in the absence of spoken dialogue. This expands current understanding of the communicative function of sketching, particularly in conceptual automotive design, where visual articulation is central to aligning perspectives and refining ideas.

Conclusion

This study examined whether sketching supports shared understanding among automotive designers working under silent and verbal communication conditions during the conceptual design phase. The findings confirm that sketching serves as a flexible and effective medium of communication, enabling both individual ideation and team alignment across varying interaction modalities.

Silent groups produced more self-contained and refined visual contributions during individual ideation, demonstrating that sketching alone can convey intent and support internal refinement. Verbal groups, while free to speak, also relied significantly on sketching to negotiate, align, and evolve their ideas. This reinforces the conclusion that sketching is not merely a support tool but a central mode of communication in design collaboration. Although statistical differences were not always significant, the consistent behavioral patterns highlight sketching's capacity to adapt cognitively, functioning either as a standalone reasoning tool or as a platform for group convergence.

These results validate the study's objective and reaffirm the dual role of sketching in design communication. It bridges cognitive perspectives and facilitates shared understanding, with or without verbal interaction. For design practitioners, combining silent sketching in early ideation with verbal sketching during group refinement can enhance both clarity and collaboration. Future research should continue to investigate sketching as a communication tool in design communication research, particularly in digital, cross-cultural, and remote collaboration contexts.

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