

Conversations Around Design Sketches: Use of communication channels for sharing mental models during concept generation

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In this paper, we present an exploratory protocol study on the use of different communication channels during design sketching. We focus on how individual designers share their mental models with other designers in a group, and analyse their use of graphical, textual, and verbal communications during concept generation.

Our findings suggest that verbal communication plays a role in the sharing of individual mental models during sketching, and complements graphical and textual communication channels. However, design teams can still function without verbal communication in that respect, and address design problems. They seem to compensate for the absence of the verbal communication channel by using the graphical and textual channels more, and by relying on a somewhat different communication structure. A natural and arguably more desirable interaction utilises all three channels in conjunction.

Our findings also suggest that, when working in groups, designers develop and share individual mental models not only about the design task at hand but also about the design process in order to manage the group interactions.

Key words

sketching, mental models, communication, design thinking

1. Introduction

Sketching is an essential thinking medium for designers (Ullman et al. 1990; Arnhem, 1993; Goel, 1995; McGown et al., 1998; van der Lugt, 2005; Menezes et al., 2006). Traditionally, it has been seen as a fundamental conceptual tool during the early stages of the design process (Fish & Scrivener, 1990). In design teams, it has been shown to facilitate design problem formulation and solution exploration in terms of functions and forms (Goldschmidt, 1991; van der Lugt, 2002).

When working in teams, designers need to communicate their mental models of problem and solution spaces to team members. However, such mental models are often not well formulated upstream in the design process, which can make them difficult to communicate. Naturally, this communication task is even more demanding in interdisciplinary teams, whose viewpoints are more diverse. Differences in goals, languages, and other cultural variables can lead to conflicting perspectives that need to be resolved (Smulders, 2008).

Moreover, when designers communicate in order to reach shared understanding, they support their verbal explanations by visual representations, and vice versa (Cikis & Ipek Ek, 2010). However, our understanding of the "dialog" between sketching and verbal communication is limited.

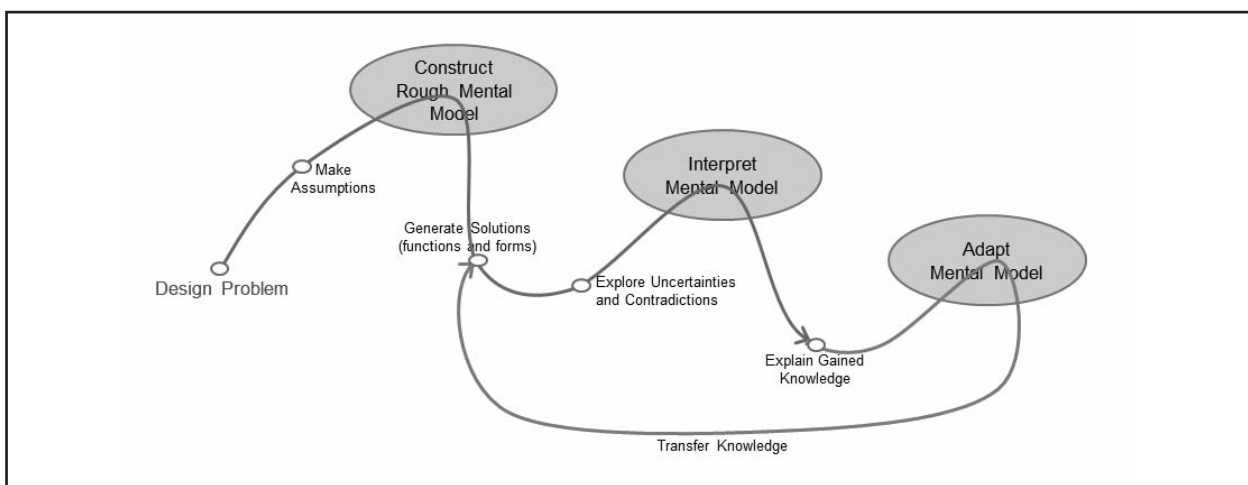


Figure 1. Postulated cognitive process employed during design sketching

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When exploring this knowledge gap, we first consider the cognitive process that is invoked during sketching. We postulate that while sketching, a designer first develops a “rough” mental model by making assumptions about the design problem based on the initial problem formulation, then interprets the design problem by exploring the uncertainties and contradictions presented by the design situation (Scrivener et al., 2000), and then refines that mental model by adapting it to the new knowledge that has been gained. We also postulate that the refined mental model will be much more “transferable” than the rough mental model, and thus forms the basis for effective design communication. This cognitive process is illustrated in figure 1.

More specifically, this cognitive process can be articulated on the following theoretical dimensions:

1. Exploration–Interpretation–Re-interpretation cycle

(see also Purcell & Gero, 1998): The cognitive process during sketching can be described as an exploration, interpretation and re-interpretation cycle. The mental model of the individual designers constitutes the cognitive structure that provides the basis for generating “questions,” “answers” and “instructions,” and shapes the exploration and interpretation of the design problem and the development of solutions.

The starting point is the knowledge and experience of the individual designer, which act as a template for mental model construction and shape the assumptions the designer makes about the problem.

2. Exploring uncertainties and contradictions: As figure 1 suggests, designing is not simply the application of knowledge and methods. Usually, the designer focuses on a specific aspect of the given problem, which he/she identifies and defines according to his/her knowledge and experience. This initial framing of the problem leads to further exploration of uncertainties and contradictions contained within the problem statement, and thus, a reframing of the design goal. The outcomes of these activities define the problem space, which is represented as a mental model, including uncertainties (knowledge gaps) and contradictions. Uncertainties can limit the completeness of the mental model, but they also serve as opportunities for creative interventions.

When designers start sketching, they rarely aim to visualise the entire problem. Instead, they focus on elements they prioritise based on criteria resulting from the exploration - interpretation – re-interpretation cycle,

such as unclear, complex, intertwined elements. In those types of situations creativity is a function of the extent to which uncertainties and contradictions can be exploited as generative elements to construct new solutions. Thus, sketching allows the designer to identify and focus on the elements that have the highest generative potential.

3. The knowledge gain – knowledge transfer cycle:

Sketching activities of individuals and teams are often accompanied by verbal explanations (Cikis & Ipek Ek, 2010). Design thinking and communication patterns alternate between gaining knowledge and transferring and exchanging knowledge (Badke-Schaub & Dörner, 2002). Switching between generating and exchanging knowledge can be seen as one of the sources of creativity (Dörner, 1998). This assumption suggests that verbalisation can be as important as visualisation.

Building on this theoretical discussion, this study aims to explore how different communication channels are used during sketching activity in design teams for sharing mental models. That intention can be translated to the following hypotheses:

H1: When verbal communication is blocked during sketching, designers will compensate by increasing their utilisation of graphical and textual communication to explain and transfer concepts.

The study also aims to examine if the specificity of initial problem framing affects that communication process. If the initial problem framing is constrained and the solution space is narrowed down, it is possible for designers to make more accurate initial assumptions, and to face fewer uncertainties and contradictions. In other words, their mental models might be more similar to begin with. That might result in less communication on mental models. This consideration led to our second hypothesis:

H2: When design problem framing is more specific, communication activities designers carry out with each other in order to share their mental models will be reduced.

2. Experimental Procedure and Study Design

We conducted our investigation in the form of a quasi-experiment in the laboratory. The participants were 18 Masters level industrial design engineering students at Delft University of Technology. They designed in groups of three.

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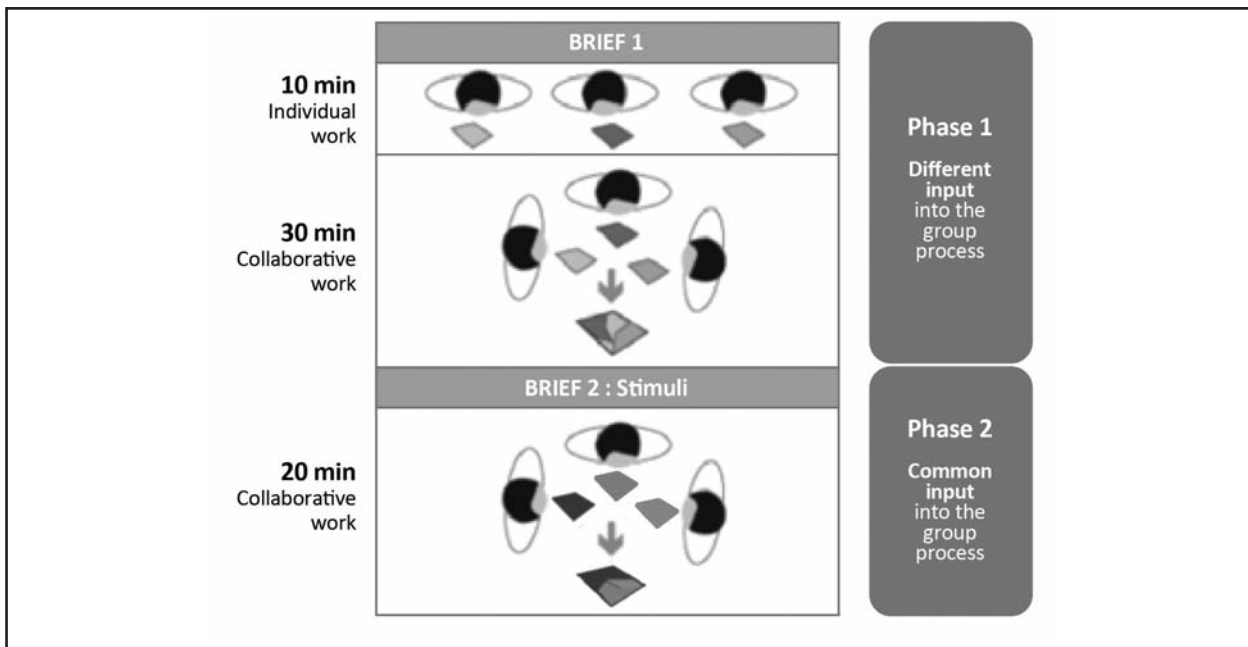


Figure 2. Overview of experiment procedure

There was a test and a control condition. Three groups were assigned to each condition. In the test condition, group members were not allowed to speak to one another while carrying out the task. Therefore, they were termed “silent” sketching groups. There were no constraints on verbal communication in the control condition; they were termed “non-silent” sketching groups.

The task was to design a product that helps blind people to cook. The design brief asked the groups to present a single concept at the end of the experiment. As shown in figure 2, the experiment had two phases. The first phase was 45 minutes long. During the first five minutes, the participants read the design brief, and in the next ten minutes, they worked individually to generate their own ideas without communicating with their group members. During the rest of Phase 1, they worked together as a group and developed a final concept.

After a ten minute break, the second phase started. A revised set of instructions were provided to the groups, which further specified the design goal by stating “camping” as the context in which cooking takes place. The revised instructions also contained pictures of existing outdoor cooking utensils as stimuli that were directly related to the revised (and more specific) use context. The groups were then given five minutes for reading the instructions and 20 minutes for design work.

After the second phase, groups presented their final idea for five minutes. A survey was administered to all

participants before the task in order to assess the communication medium preferences of the participants (graphical, textual, and verbal). All activities and the resulting sketches were video recorded, observed and analysed.

3. Data analysis

In this section, we discuss the analysis framework we used to interpret the sketches that were produced during the experiments. All sketches were decomposed into sketch elements. Each sketch element is seen as an outcome of a specific type of sketch activity. The sketch elements were then coded according to the following four sketching activity categories. The following four categories are data-driven, and are based on our qualitative observations during the experiments (see figure 3):

Generate: Introducing basic graphical form and function elements.

Detail: Articulating the sketch elements under the Generate category.

Explain: Communicating the meaning of sketch elements under the Generate or Detail categories with graphical and numerical annotations.

Transfer & Exchange: Communicating the meaning of sketch elements under the Generate or Detail categories with text annotations.

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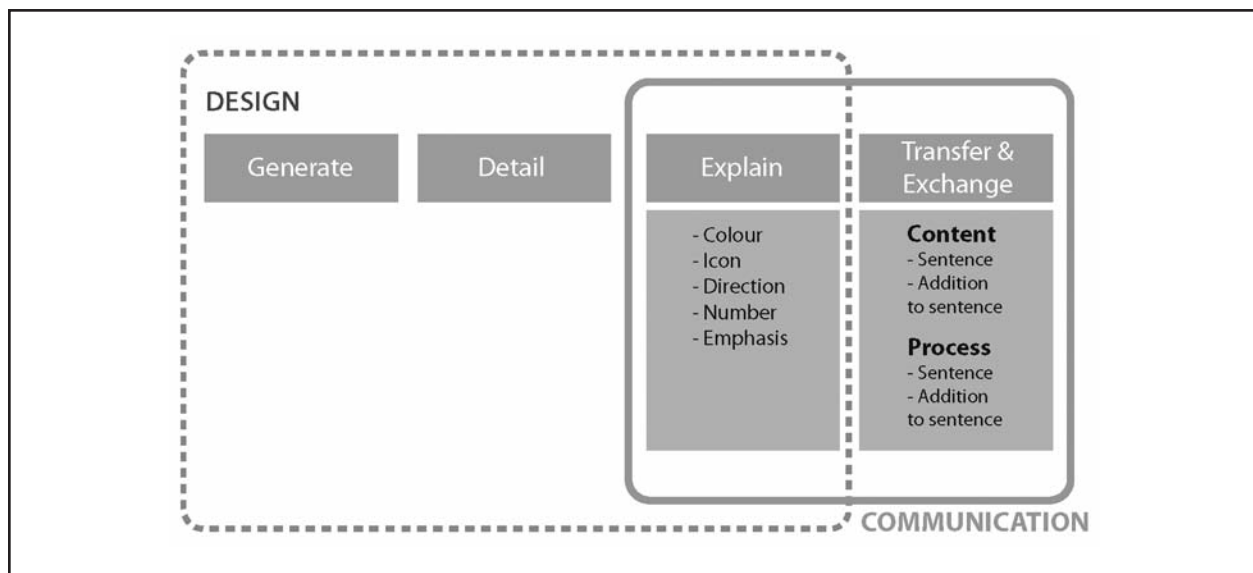


Figure 3. Sketching activity analysis framework

We see these four sketching activities (depicted in figure 1) as being essential to addressing the design problem across the three theoretical dimensions. Furthermore, as figure 3 illustrates, we make a distinction between designing and communicating during sketching. Generate and Detail actions are coupled with the emergence and refinement of the mental model an individual designer has of the design situation. Explain and Transfer & Exchange actions are coupled with the communication of the mental model an individual designer has at a specific point in time to other group members.

It is important to emphasise that this sketching activity framework is constructed from the perspective of the individual designer. Meaning, as the individual shares his/her mental model through communication actions, he/she will engage in dialog with others about the mental model and receive responses, which will lead to the negotiation and refinement of the mental model. The individual can then engage in a new series of Generate and Detail actions to reflect the revisions. We see that cycle as the basis for reaching sharing understanding during design sketching. In the context of the sketching activity framework illustrated in figure 3, the actor is always the individual as opposed to the group. The fact that multiple individuals might work on the same sketch/representation does not change this framing.

In this paper, we focus on the Communication dimension of the analysis framework, which consists of Explain and Transfer & Exchange activities. Each activity can result in the creation of several sketch elements, which are now described.

There are five sketch elements under the Explain category: Icon, colour, direction, number, and emphasis. They are illustrated with examples from the dataset in figure 4.

Icon is a graphical symbol that is commonly understood within the group, and used to identify or communicate more complex elements or interrelations in a single element. It can be generally accepted and familiar such as the summation symbol "+", or it can be locally constructed by the group such as the special icon a group created in the experiment to represent blind people.

Colour is often used to indicate meaning. For example, red stands for hot in many cultures.

Direction is a mark that shows path or route (such as an arrow) from one point/area to another point/area on a sketch.

Number is an arithmetical value, expressed by a word, symbol, or figure, that is used to calculate, order a series, specify, or to identify.

Emphasis is a special importance or prominence given to a sketch element such as underlining or boxing.

Figure 5 illustrates the sketch elements under the Transfer & Exchange category with examples from the dataset. These sketch elements are further broken down into two sub-categories: content-related and process-related.

Sentence is a full sentence written in text format on the sketch. In the content-related dimension, these elements

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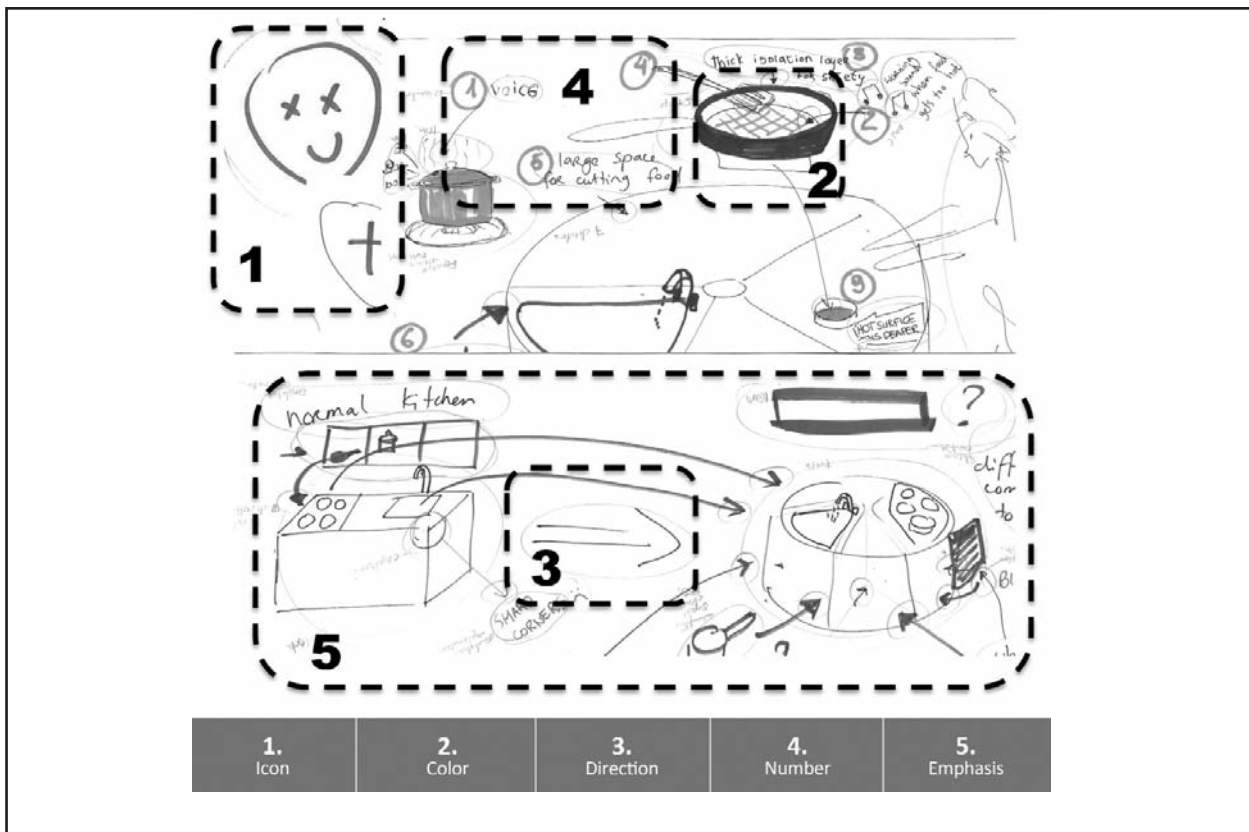


Figure 4. Examples of the five explain sketch elements from the dataset. Illustrated elements reside in two different sketches.

constitute the primary mechanism for written dialog during which existing sketch elements are discussed and negotiated. In the process-related dimension, they act as a medium for handling issues pertaining the design process.

Addition to sentence is an annotation to any such sentence element.

4. Results

In this section, we present the results of the data analysis. As mentioned before, in this paper, our emphasis is on the sketching activity categories that fall under the Communication dimension.

4.1. Communication Activities and Sketch Elements

A total of 60 A3 size paper sheets were collected during the experiment. The silent sketching groups used 37 sheets, and the non-silent groups used 23 sheets.

Each sketch was decomposed into its elements, and the elements were coded according to the categorisation scheme articulated in section 3. Sketching activities were counted and summed per test condition. Results are shown on Table 1.

Since this is an exploratory study that involves only three groups in each of the two conditions, testing the significance of group mean differences across conditions is not meaningful. However, when investigating patterns between the two phases of the experiment, a chi-squared test of independence was performed to check if the count differences across conditions constitute statistically significant deviations from expected values based on the overall occurrence probabilities of the sketch elements.

Figure 6 shows the cumulative Explain activity counts per experimental condition. There were a total of 669 Explain sketch elements. As indicated on Table 1, 73% of them occurred in the silent condition. Moreover, silent sketching groups made extensive use of icons and directions. *Direction* sketch elements were used the most in both experimental conditions, which suggests that *Direction* elements play a key role in explaining the meaning of other sketch elements.

For the entire experiment (Phases 1 and 2 combined), a chi-squared test of independence revealed that the observed element counts were significantly different than expected element counts overall between the two

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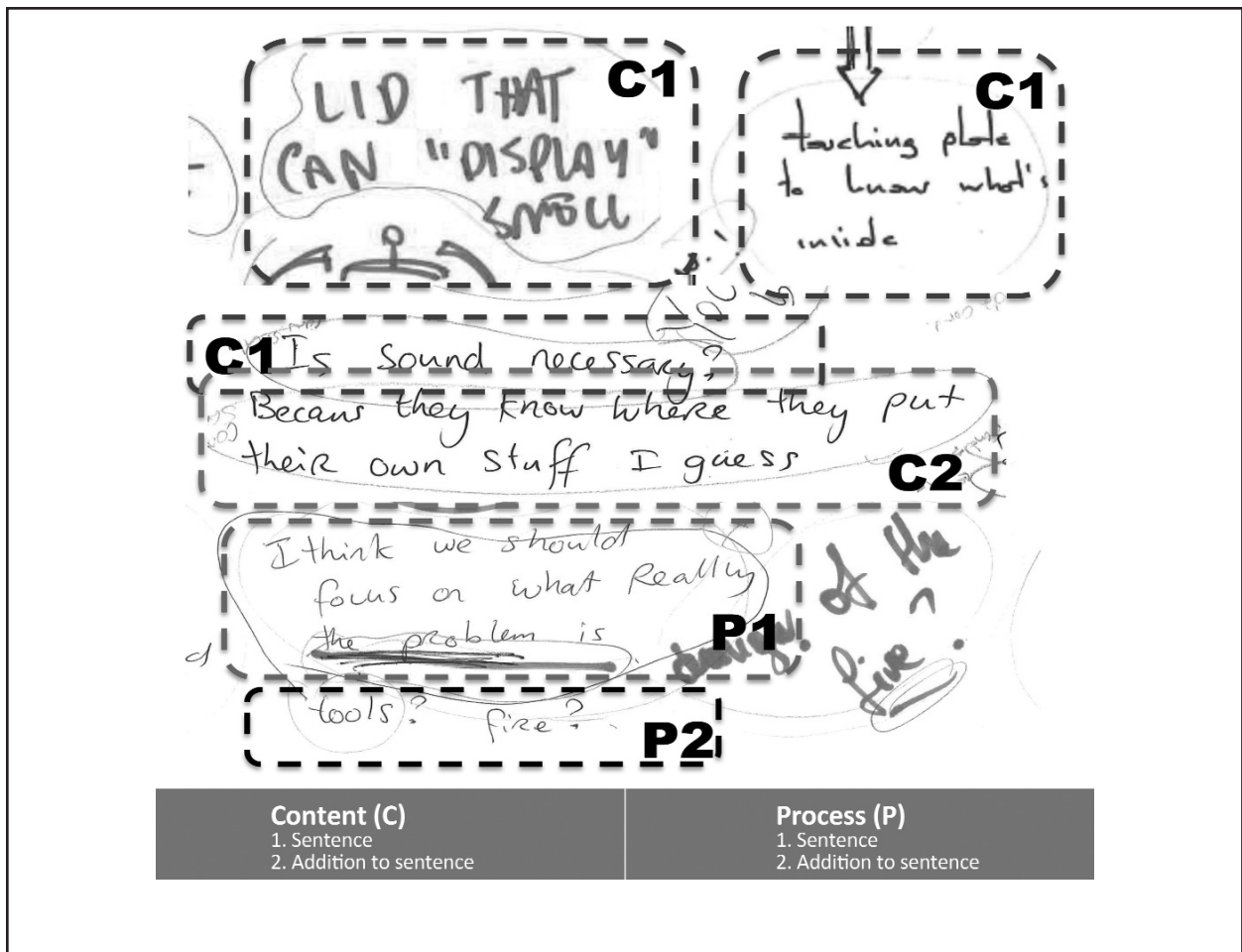


Figure 5. Examples of the four Transfer & Exchange sketch elements from the dataset. Illustrated elements reside in four different sketches.

experimental conditions in the Explain category, $X^2(4, 669) = 55.4, p < 0.001$. Analysis of the adjusted residuals revealed that the observed *Colour*, *Number*, and *Emphasis* element counts were significantly higher than expected in the non-silent condition ($p < 0.001$, two

tailed), whereas observed *Icon* and *Direction* element counts were significantly higher than expected in the silent condition ($p < 0.05$ for *Icon* and $p < 0.001$ for *Direction*, two tailed).

Sketching Activities	Experimental Condition	
	Silent	Non Silent
Explain	491	178
Transfer & Exchange	611	175

Table 1. Sketching activity counts per Explain and Transfer & Exchange categories for the silent and non-silent experimental conditions

We also further differentiated the results for the Explain activities in between the two phases of the experiment, and investigated if the probability of occurrence of the sketch elements differed between the experimental conditions by running two separate chi-squared analyses for the two phases of the experiment. Although trends for all of the five Explain elements were similar to the combined phase results stated above, deviations from expected counts of *Icon* and *Number* elements during Phase 1, and of *Emphasis* elements in Phase 2 were not significant at $\alpha = 0.05$.

Figure 7 shows the cumulative Transfer & Exchange activity counts per experimental condition. There were a total of

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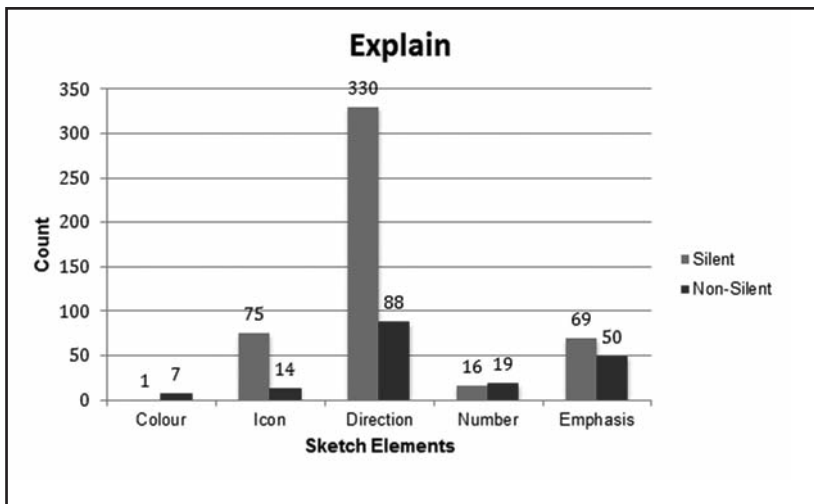


Figure 6. Explain sketch element cumulative counts per experimental condition

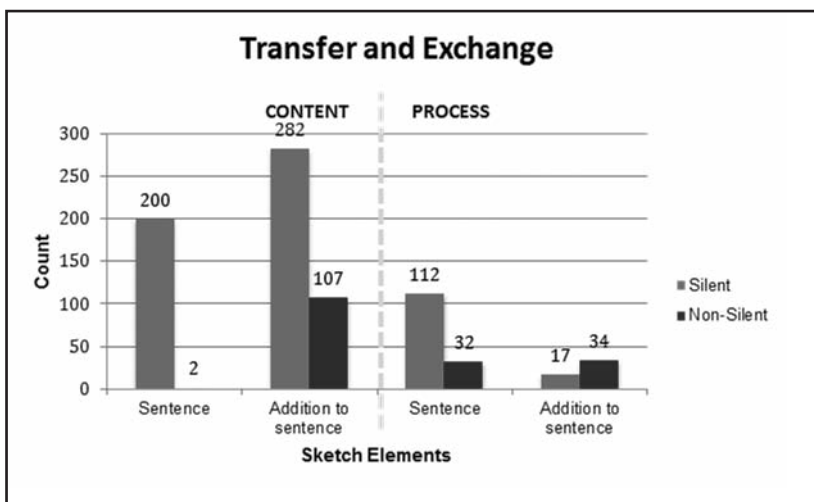


Figure 7. Transfer & Exchange sketch element cumulative counts per experimental condition

786 Transfer & Exchange sketch elements. As indicated on Table 1, 78% of them occurred in the silent condition. Content-related Sentence and Addition to Sentence counts are higher in the silent sketching condition than the non-silent condition. However, although Process-related Sentence counts are higher in the silent sketching condition, Process-related Addition to Sentence counts are higher in the non-silent condition.

For the entire experiment (Phases 1 and 2 combined), a chi-squared test of independence revealed that the observed element counts were significantly different than expected element counts overall between the two experimental conditions in the Transfer & Exchange

category, $X^2(3, 786) = 117.1$, $p < 0.001$. Analysis of the adjusted residuals revealed that the observed Content-related Addition to Sentence and Process-related Addition to Sentence elements counts were significantly higher than expected in the non-silent condition, whereas observed Content-related Sentence element counts were significantly higher than expected in the silent condition (all residuals $p < 0.001$, two tailed). Observed Process-related Sentence element counts were not significantly different than expected counts across the experimental conditions.

Two separate chi-squared analyses for the two phases yielded results for the Content-related Sentence, Content-related Sentence Addition, and Process-related Sentence Addition elements that are similar to the combined phase results stated above. However, the pattern was not similar for the Process-related Sentence elements: in Phase 1, observed Process-related Sentence element counts were significantly higher than expected in the non-silent condition, whereas that trend reversed in Phase 2 (both residuals $p < .05$, two tailed).

Furthermore, qualitative analysis revealed that the Sentence and Addition to Sentence sketch elements in the Transfer & Exchange activity category produced in the silent condition are more detailed than the ones produced in the non-silent condition.

When counts from the two experimental conditions are pooled, the number of sketch elements in the Explain activity category between Phase 1 and 2 are similar (330 vs. 339 respectively), whereas the number of sketch elements in the Transfer & Exchange activity category during Phase 2 was lower than Phase 1 (417 vs. 369 respectively). That decrease from Phase 1 to 2 is attributable to the decrease in process related elements (121 vs. 74 respectively) since content-related element counts across the phases were similar (296 vs. 295 respectively).

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4.2 Survey outcomes

In order to assess the communication preference (graphical, textual, and verbal) of the participants, we administered a survey before the task began. The questions investigated how comfortable each participant felt with each medium when conveying ideas. The survey utilised a 5-point response scale, where 1 represented "not comfortable at all," and 5 represented "very comfortable." The survey also contained an item that asked if the participants had received formal sketching training, with "Yes" or "No" response options.

The results revealed that all 18 participants had received formal sketching instruction. Responses to the communication medium preference items were analysed per study group. An ANOVA did not reveal any significant differences between the six groups, so we assume that communication medium preferences of the participants were not a factor in the experiment.

5. Discussion

The silent condition yielded the creation of a higher number of sketch elements in both communication activity categories (73% of all Explain and 78% of all Transfer & Exchange elements). Given the exploratory nature of this study and the small number of groups, we cannot meaningfully test the statistical significance of that difference. Therefore, these results suggest support for the first hypothesis.

However, there were differences in the distribution of sketch elements within each of those two communication activity categories in each condition, which suggests that certain types of elements were more important in each condition.

More specifically, in the Explain category, *Direction* and *Icon* elements occurred more than expected in the silent condition, and *Colour*, *Number*, and *Emphasis* elements occurred more than expected in the non-silent condition. In the Transfer & Exchange category, *Content-related Sentence* elements occurred more than expected in the silent condition, and *Content-related Addition to Sentence* and *Process-related Addition to Sentence* elements occurred more than expected in the non-silent condition.

Therefore, although silent groups seem to use more sketch elements to communicate their mental models than non-silent groups (as predicted), they do so discriminately with respect to the types of sketch elements we used to characterise such communication activities. Although these results suggest support for the first study hypothesis, the specifics of how designers compensate by

switching to graphical and textual communication channels when verbal communication is blocked seems to be nuanced.

Our comparison of communication activity between the two phases of the experiment show that the Explain and content-related Transfer & Exchange element counts were similar between the two phases. However, the second phase was shorter than the first, so if the results were to be normalised with respect to group collaboration time in each phase, it appears that the frequency of those sketch elements are actually higher in the second phase. This implies that groups communicated more intensely to share individual mental models during the second phase in the presence of a more specific design task framing, which is contrary to the second study hypothesis.

Moreover, the distribution of sketch elements within the Explain category in the two phases was similar for both conditions. The same was true within the Transfer & Exchange category for *Content-related Sentence*, *Content-related Sentence Addition*, and *Process-related Sentence Addition* sketch elements. However, *Process-related Sentence* broke the pattern and occurred more than expected in the non-silent condition during the first phase, and in the silent condition in the second phase.

These results suggest that participants actually communicated more intensely in order to share their mental models in the presence of a more specific problem framing, but displayed a similar sketch element usage structure when dealing with design task related information. There are many other process related variables at play, and it is not possible to attribute these observations solely to the intervention that led to a more specific problem framing in the second phase. For instance, this might be related to the overall task progression, and the intervention between the two phases might not have resulted in a significant effect at all. Regardless, if the observations are attributable to the intervention, the results counter the second study hypothesis.

In that case, one explanation might be that although the more specific problem framing led to more similarities in the mental models of individual designers, those similarities actually provided more common ground for them to engage in conversation (as in, people leaning toward speaking to what they perceive to be their similarities rather than differences).

Another limitation of the study is that we did not attempt to measure "how much" information a given sketch

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element contains. In other words, it is not possible to judge the “amount” of information that is being communicated by observing sketch element counts. Attempting to measure the information content in each sketch element would prove to be a challenging and most likely unreliable approach.

Finally, design students with some sketching training participated in study. Even though this was appropriate for the conceptual design task utilised in the study, experienced designers in real life settings might differ in their behaviour. For example, it has been argued that expert designers leverage sketches more than novices (Goldschmidt, 1991). Moreover, practicing designers were found to be more interpretive and displayed more fixation-resistance than novices (Tversky et al., 2007).

6. Conclusion

Verbal communication clearly plays a role in the sharing of individual mental models during sketching, and complements graphical and textual communication channels. However, based on the findings of this exploratory study, design teams can still function without verbal communication in that respect, and address design problems. They seem to compensate for the absence of the verbal communication channel by using the graphical and textual channels more, and by relying on a somewhat different communication structure. A natural and arguably more desirable interaction utilises all three channels in conjunction.

Findings also suggest that, when working in groups, designers develop and share individual mental models not only about the design task at hand but also about the design process in order to manage the group work flow. This understanding is congruent with one of our previous findings, which indicate that sketching in design teams can help to establish shared mental models about the process (Neumann et al., 2009).

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