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Exploring the role of sketching on shared understanding in design

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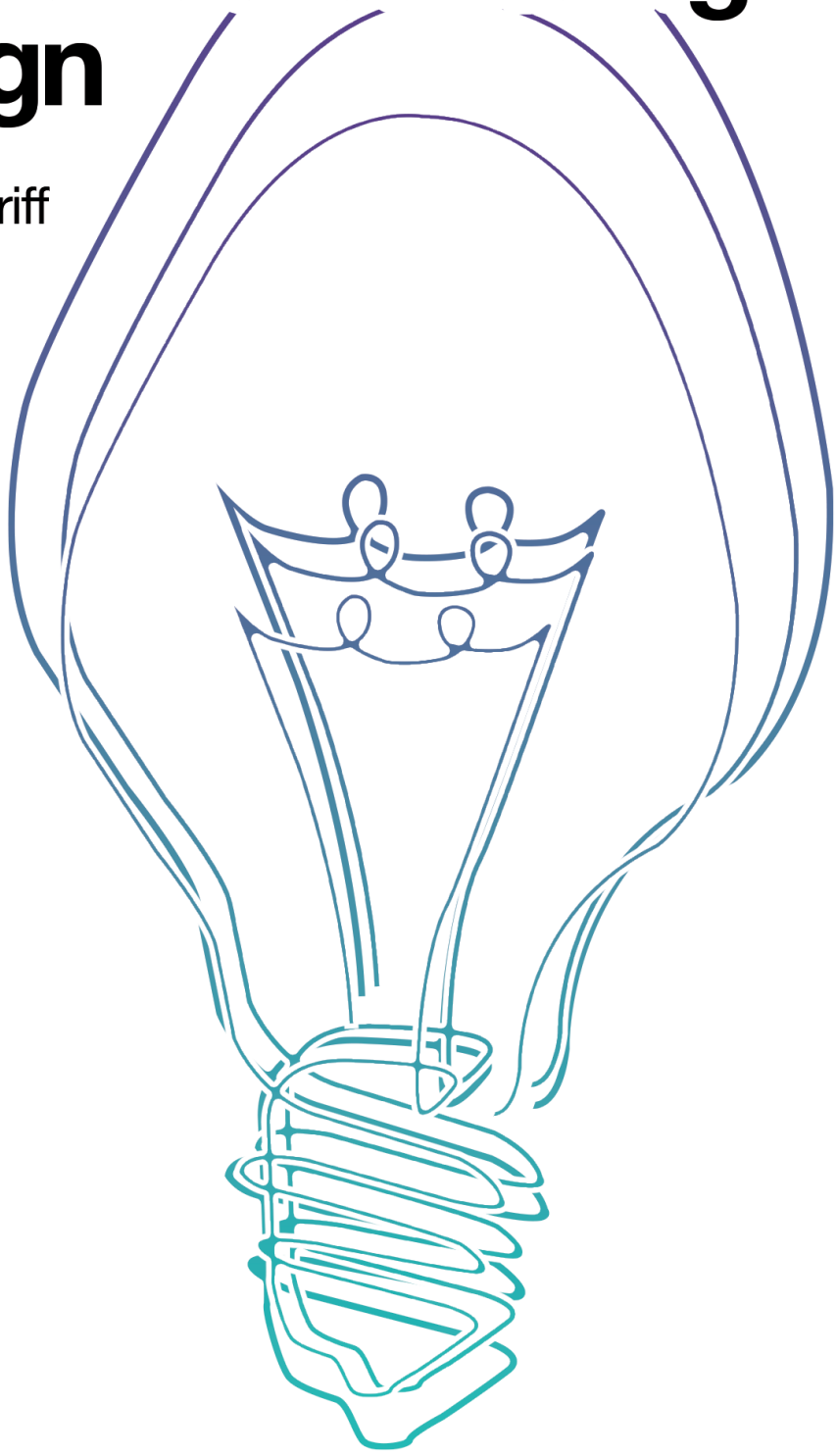
Nik Shahman Ariff



Exploring the role of sketching on shared understanding in design

Dissertation

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General Introduction

Chapter 1

General Introduction

1.1 Introduction

Sketching is an essential thinking tool for designers throughout the design process in individual and team settings (see for example Ullman, Wood, & Craig, 1990; Arnhem, 1993; Goel, 1995; McGown, Green & Rodgers, 1998; Van Der Lugt, 2005; Menezes, Gerais & Lawson, 2006). Sketching is traditionally viewed as a fundamental conceptual tool mainly during the early stages of the design process (Fish & Scrivener, 1990). Sketching can also act as a form of recording memories of a specific task for designers (Thoring, Desmet & Badke-Schaub, 2018). In design teams, sketching facilitates the formulation and framing of the design problem as well as the solution exploration in terms of function and form (Goldschmidt, 1991; Van Der Lugt, 2002).

Working in a team requires designers to articulate their mental models of problem and solution spaces. Nevertheless, these mental models are usually not formulated upstream in the design process, which contributes to difficulties in term of common understanding. This communication task is considerably demanding in interdisciplinary groups which demonstrate various perspectives. The distinction in languages, objectives, and other cultural elements can contribute to different perspectives that need to be addressed (Smulders, Lousberg & Dorst, 2008). Moreover, when designers communicate, their verbal explanations are supported by visual representations and vice versa (Cikis & Ipek Ek, 2010). Nevertheless, understanding of conversation between verbal communication and sketching is minimal.

The objective of this study is to understand and further explain how sketching influences team collaboration. The goal is to formulate a framework by studying the value-added contribution of sketching in design teams. The particular focus lies on how team collaboration is achieved over time, as previous methods mainly focus on sketching as a tool. Only few studies have investigated how sketching influences team collaboration. The following section elaborates on the concept of sketching as a communication tool.

1.2 Sketching as part of the design process

Designing is an activity that essentially consists phases of problems – framing and elaboration of concept development, and solution generation and evaluation. Moreover, designing is a complex process which it relates to consumptions, productions, material, innovation, markets and many more (Schoormans, 2018). During this activity, designers constantly adapt their processes to their environment as well as to their changing knowledge of the processes. Obviously, the adaptation due to new ideas, changing requirements, new information, or other external factors. Hence, designing needs to be understood as a process of external representation (Cross, 2006).

Although we know that we are in the age of digitalization (Eriksson, 2019), manual sketching is still used throughout the whole design process. In this case sketching is seen as an essential tool that is mainly used during the initial phases of the design process because it is quickly done and needs only a minimal amount of time for explanations in a team setting. It is essential to communicate design ideas while upholding uncertainty and allows design autonomy (Goel, V., 1995, Bao et. al., 2018). Sketching is significantly linked with creativity and design thinking (Suwa & Tversky, 1997, Tversky et. al, 2002). In design, sketching is a type of intelligence amplifier which is similar to writing. Intelligence amplifiers are employed to help in reasoning. Without writing or sketching, it is challenging for designers to investigate and determine their own thoughts (Cross, 2006). Designing of form is considered

an evolutionary process and the concepts of "default" and "surprise" are part of designer's problem and solution spaces (Dorst & Cross, 2001).

On a cognitive level, sketching can be described as dealing with the three different processes in an individual and/or team setting:

1. Exploration–Interpretation–Re-interpretation cycle (see also Purcell & Gero, 1979): Cognitive processes during sketching can be described as a process of exploration, interpretation, and re-interpreting cycle. The mental model is the cognitive structure, which provides 'questions', and 'answers', and 'instructions' on what to explore and how to gain a comprehensive mental model for the further development of situation at hand and may be also the potential development of the situation at hand. The starting point may be an observed inconsistency or a false assumption about the problem at hand, which requires special attention.

2. Definition of uncertainties and recognition of ambiguities: as mentioned earlier designing is search, analysis and transfer of information and the use of techniques. In general, the designer departs from his/her knowledge and picks a part of the given problem, which he/she analyses as indicated by his/her insight and experience. This underlying comprehension of the difficulties prompts further. Fuzziness and ambiguity can restrict the mental model's completeness, but they are also a chance for creative interventions. When designers start sketching, they seldom attempt to visualise the whole problem. They prefer to select elements that they prioritise due to criteria resulting from the exploration - interpretation – re-interpretation cycle such as vagueness, complicatedness, and unknown components. These are circumstances where solutions are required, and creativity is a function of the extent to which gaps and vagueness will be used to create novel solutions. Thus, sketching offers prospects to deal with obvious and less obvious constraints related to the problem at hand.

3. Knowledge gain – knowledge transfer cycle: the sketching procedure of individuals and teams is complemented by verbal communication. Individual thinking and communication in design teams rotate between acquiring knowledge and transferring and trading knowledge (Badke-Schaub & Doerner, 2002). The switching process between knowledge creation and knowledge exchange is observed as a primary creativity source (Badke-Schaub, 2007). This supposition advocates the assumption that verbalisation is as important as visualisation.

1.3 Research questions

Sketching can be described as external representation of internal thoughts. Thus the two following questions arise:

1. How does sketching influence the design process when working in design teams?

2. How does sketching influence the way of communication, especially the development of shared understanding in design teams?

The analysis of these processes will help to develop a framework that can contribute to understand how sketching in design teams helps to gain a shared understanding and thus a shared mental model in the team during the design process.

1.4 Thesis outline

This thesis is exploring the role of sketching on shared understanding in design. Figure 1 presents an overview of the thesis layout. The results of the literature review describe how sketching acts as a communication tool to reach a shared understanding during the concept generation phase in the design team(s). Previous findings on designing and sketching will be

discussed. Moreover, the role of sketching on shared understanding in design will be analysed in more detail.

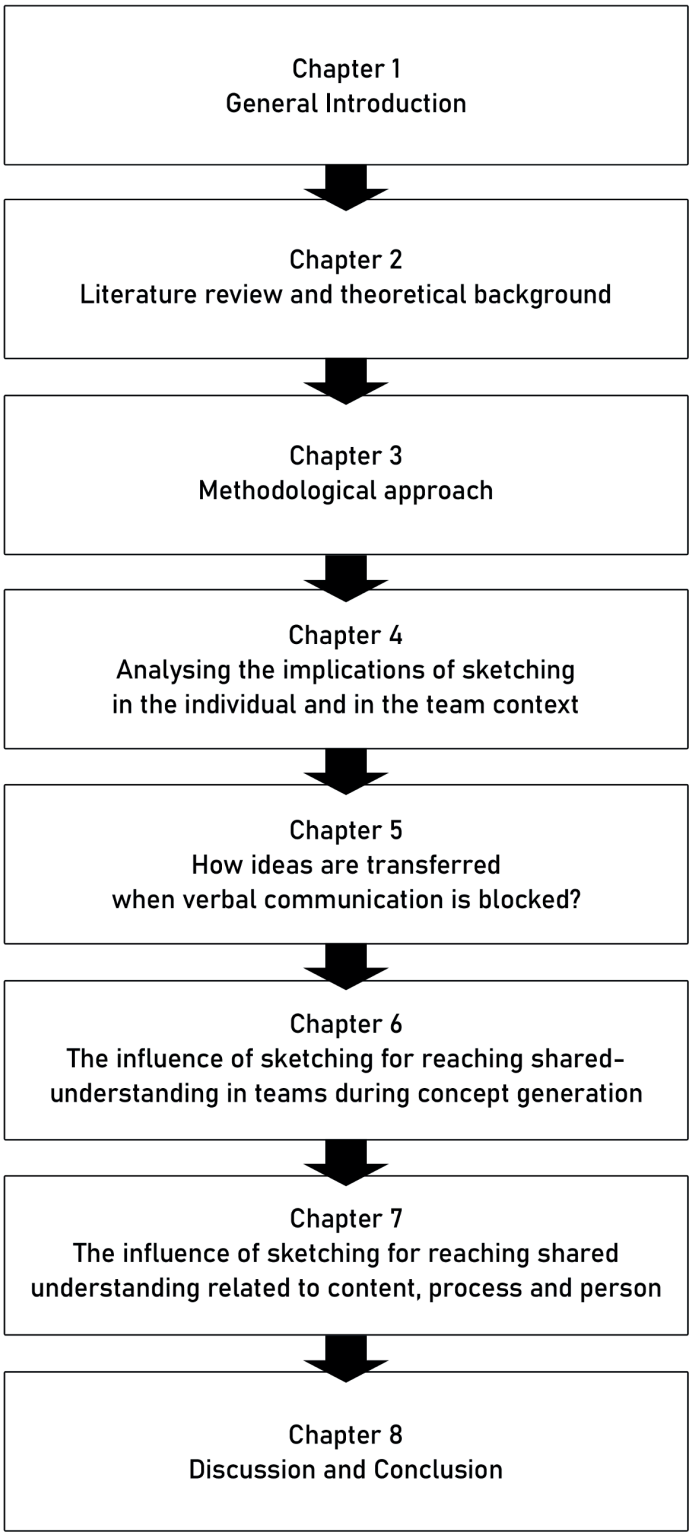


Figure 1: Overview of the thesis layout.

Chapter 2 presents a review of previous design research on design sketching, and teamwork in design. The chapter is sub-divided into three main topics, which together can be seen as the theoretical backbone of this thesis. The three main topics are (1) designing as a cognitive process (Badke-Schaub et al., 2010), (2) designing as a social process (Bucciarelli, 2002a), (3) sketching as communication tool for designers, reaching towards achieving shared understanding. The importance of understanding the implicit mechanisms that drive the usage of sketching among the designers is elaborated. Thus, an overview of sketching as a communication tool for designers is presented. Based on that, a theoretical model of sketching as a communication tool for shared understanding during concept generation in design teams is described. Next, the research questions for this study are derived.

Chapter 3 explains the research methodology and the empirical approach of this study. The design of this study is focused on examining sketching in the conceptual design phase and to identify suitable steps to enhance the positive impact of sketching. The outcomes of this investigation contribute to answering the research questions.

Chapter 4 analyses the relationship between sketching and communication in teams throughout the idea generation process in the early concept creation. This study employed a phase with quasi-experimental design from the Industrial Design Engineering postgraduate students at the Delft University of Technology, Netherlands who completed their Masters. There were six groups of three and they were given a stipulated time to provide a solution to a design problem. The experimental groups (n=3) were not permitted to verbally communicate during the process, while the control groups (n=3) were permitted. The experiments were logged, observed, and analysed. Communication was used by the two groups to move and bolster their individual thoughts. The written language was employed as the communication mechanism by the experimental group to specify the sketch information. These discoveries show that outlining is not solitary as the design teams need to utilize visual and verbal correspondence related

concurrently to deliver solid ideas and to move them into a common understanding in the group.

Chapter 5 examines the communication process throughout sketching in design teams. Two frameworks are proposed in this chapter. The first framework is the design-communication framework which segregates the categories of activities that happen during sketching and establishes the analysis structure of the empirical dimension of the work. The second framework is a framework to attain a shared understanding throughout sketching in design teams which represents the conclusions of the investigation. Our main finding is that although sketching activity itself forms the basis of team discourse during sketching, explaining, detailing, and transfer activities, sketching makes ideas more concrete, understandable, and transferrable within the team. Our findings also show that when verbal communication is blocked, the distinction between sketching activity, and explaining, detailing, and transfer activities becomes clearer.

Chapter 6 reports the results of the exploratory study on the usage of diverse communication channels during sketching. This chapter concentrates on how individual designers allocate and transfer their mental models among other designers in the group. Their usage of textual, verbal, graphical communication was analysed during concept generation. The findings propose that verbal communication contributes during the mental model sketching sharing process and supplements textual and graphical communication channels. However, design teams can still function without verbal communication and address design problems. They seem to compensate for the absence of the verbal communication channel by using graphical and textual channels more, and relying on a somewhat different communication structure. A natural and arguably more desirable interaction utilises all three channels simultaneously.

Chapter 7 further expands the analysis of the role of verbal communication in reaching shared understanding during idea generation in design teams. Specifically, the study aims to investigate specific

communication actions that designers take in different communication modalities that lead to shared understanding. In order to realise this goal, a quasi-experimental study was conducted with 18 participants, who were separated into groups of 3. The experimental groups were not permitted to employ verbal communication while the control group did not experience the same restrictions. Communication actions that represent agreement were identified and analysed in four different modalities which are gestural, verbal, graphical, and textual communication. The results suggest that when verbalisation is allowed, groups rely on concepts that are generated primarily by individuals and do not negotiate the type of shared understanding that leads to the co-creation of new concepts. When verbalisation is not allowed, they are more likely to build on and advance concepts that are generated by individuals to construct that type of shared understanding and conceptualise collectively.

Chapter 8 entails the integration of the results of the three studies which contribute to the discussion. Finally, Chapter 8 elaborates the implications and limitations of this study. Finally, recommendations for future research are suggested.

2

Literature Review And Theoretical Background

Chapter 2

Literature Review And Theoretical Background

Chapter 2 integrates two perspectives - designing as cognitive process and designing as social process.

2.1 Designing as cognitive processes

Designing is a compelling example of how only moderately complex problems require multidisciplinary approaches referenced to context-specific knowledge and cognitive skill. Understanding design is a preeminent contemporary concern in a variety of complex domains including industrial design, engineering, programming, algorithm design, mechanical engineering and engineering design, architecture and environmental design, design of policies and social protocols, and other domestic artifacts

2.1.1 Cognitive processes

According to the Cambridge dictionary, cognitive is an adjective and is connected with thinking and conscious mental processes. Moreover, it also brings the meaning of relating to or involving the processes of thinking and reasoning. For instance, cognition occurs through information exchange that enables the advent of cognitive difference among designers. Moreover, cognition refers to "the mental action or process of acquiring knowledge and understanding through thought, experience, and the senses" (lexico.com, 2020). It envelops numerous parts of scholarly capacities and procedures, for example, consideration, the development of information, memory and working memory, judgment and assessment, thinking and

"calculation", critical thinking and dynamic, understanding and creation of language. Psychological procedures utilize existing information and create new information. Intellectual procedures are broken down from alternate points of view inside various settings, strikingly in the fields of phonetics, sedation, neuroscience, psychiatry, brain science, instruction, reasoning, human studies, science, systemics, rationale, and software engineering (von Eckardt, 1996). These and other various ways to deal with the examination of cognition are combined in the emerging field of cognitive science.

2.1.2 The development of mental models

The possibility that human beings create mental ‘duplicates’ of objects of the present situation in our mind can be traced back in philosophy history to the old Greeks. It was not until 1943 that Kenneth Craik expounded upon this thought by applying it to examine cognitive parts of human behaviour. In his view, the brain makes little scope models of the real world (Craik, 1943). Every novel matter we see in reality is displayed in a comparative yet balanced portrayal. We reason, clarify, and envision occasions according to those models. In spite of the fact that his thought had influenced the developing field of cognitive science, scholars did not immediately employ mental models as a research paradigm until much later. Johnson-Laird (1980) reintroduced the term “mental models” to the cognitive science literature in the early 1980s by two books, brought this idea once more into the focal point of consideration. Johnson-Laird (1983) proposed mental models as the fundamental structure of cognition, which he used to depict how individuals reason about reference per syllogistic thinking (see additionally Lave, 1988; Oakhill & Garnham 1996). In another significant distribution from that year, Gentner and Stevens (1983) acquainted mental models with the ergonomic network to examine the collaboration among systems and in other people. Interacting with the other individuals, the environment, and technological artefacts, mental models are and the matter they are collaborating to address. These models give explanatory and predictive value to comprehend these relationships. (Norman 1983).The two distinct conceptualisations by Johnson-Laird

(1983); Gentner & Stevens (1983), show that the idea of mental models appears to be relevant to different orders with their unique attentions. Hence, a survey of the definitions and utilisation of mental models in various areas (Rouse & Morris 1986) uncovered a wide range of understanding of the idea of mental models. Rouse and Morris contend that so as to maintain a strategic distance from simply rethinking information as mental models, the specific kind of information on which they are made, and the reason for what they are utilised, ought to be thought of. They propose that examination on mental models ought not be viewed as conventional yet investigated explicitly for every area.

Johnson-Laird (1983) recommended three categories of mental representations. The first mental representation is "propositional representations which refer to strings of symbols that correspond to natural language, mental models, which are structural analogues of the world, and images, which are the perceptual correlates of models from a particular point of view" (p. 165). He contended that both mental images and propositional representation are subject to mental models. Contingent upon the errand the mental models are identified with, they are differently actualised, taking different structures with various degrees of precision. They may incorporate ideas, suggestions, contents, mental images, outlines (Bainbridge 1992). This highlights that mental models are not just proportional to (declarative) knowledge. In spite of the fact that they are put away in memory, mental models are explicit to a task at a specific timeframe and progressively change. A fundamental issue in the conceptualisation of mental models is the connection among representations. It is progressively about how information is organised and related than whether explicit information is available. In this manner, mental models mirror our inclination to sort what we know and how this information is composed (Klimoski & Mohammed 1994).

Summing up the hypothetical suppositions, this study postulates that the fundamental thought of mental models is that people build interior working models of the world. These models permit coordinating new data

and to put forth forecasts with minimal mental effort. These working models are fundamentally improvements of the world (Smyth et al.1994). For instance, not every feature of a scene (e.g. a pilot taking off) is incorporated in the corresponding mental model (or 'script' or 'schema') of that scene. Hence, mental models do not necessarily portray precise representations of the world. It is definitely their simplicity that makes them so helpful since they empower an individual to rapidly comprehend and act even in new and obscure circumstances (Oakhill & Garnham 1996). It is obvious that simplification has its disadvantages. Particularly when completing an assignment, for example, working on a complicated technical system, erroneous models can have negative impacts. For instance, improvements, for example, confusing incidental co-events with causal impacts are a common reason for failure models (Besnard, Greathead & Baxter, 2004). As the instance of the smashed plane epitomises, a mistaken mental model prompting the error of a notice signal, can have disastrous results.

Then again, the term mental model has been utilised as an informative mechanism in different papers throughout the years (see Wilson & Rutherford, 1989). Basically, mental models are composed information structures that allow people to communicate with their environment. In particular, mental models permit individuals to foresee and clarify the conduct of their general surroundings, to perceive and recall connections among segments of the environment, and to build desires for what is probably going to happen (see Rouse and Morris, 1986). Moreover, mental models allow individuals to make conclusions and forecast, comprehend a phenomenon, choose which moves to make, and experience occasions vicariously (Johnson-Laird, 1983). Hence, this study characterises mental model in accordance with Rouse and Morris (1986), as a "mechanism whereby humans generate descriptions of system purpose and form, explanations of system functioning and observed system states, and predictions of future system states" (p. 360). Moreover, the externalisation of a mental model may lead to changes in how it is internalised (Eris, Martelaro & Badke-Schaub, 2014) Hence, mental

models serve three crucial purposes: They help people to describe, explain, and predict events in their environment.

Mental models cannot be observed, they are hypothetical constructs, and the following general characteristics are to be mentioned:

1. A mental model is a portrayal of some space or circumstances that support comprehension, thinking, and forecasting. Mental models encourage thinking about circumstances that are not directly experienced. They allow individuals to mimic or simulate the conduct of a framework. Numerous mental models depend on hypotheses and analogies. These hypotheses are not generally precise and so are mental models; scientists have distinguished striking instances of inaccurate mental models. A comprehension of common mental models—both right and wrong—is significant to create tools that individuals will utilise accurately and to make viable instructional materials.

2. Mental models are cognitive constructs utilised for language related procedures. A focal research area is the development of mental models for spatial thinking (see for example Held et. al. 2006, Vandierendonck et. al. 1996). However, even in its most focal region of utilisation, it is not completely clear mental model truly should be. For instance, in the first structure of mental model hypotheses (Johnson-Laird, 1983), mental models are a vehicle for mental representation. They are an instrument to control mental items to design solution. This analysis alludes to the modelling as processing part of mental models. However, mental models are managed as intangible mental items that can be controlled. Based on this point of view, they signify to the result of the modelling process. It is for the most part that this last view is incorporated in the philosophies of human language processing. When referred to language processing, mental models are very often defined as mental constructs describing the knowledge a person has about a

particular domain of the world (see e.g. Gernsbacher, 1991). This definition is more or less equivalent to a general concept of background knowledge and rarely more specified than that. Experimental evidence showing that "mental models" exert an influence on language processing amounts more or less to evidence on the general relevance of world knowledge. This is surely the most general, least debatable, and thus least helpful definition. What a theory of mental models should really give us, is a tool to represent or even formalise the way background knowledge is applied in human language processing. A more text-oriented version of this definition is proposed by Garnham (1985), who considers text comprehension as a process of constructing a model of the situation the text is about (real or imaginary). The construction of this model serves the linking of information in different parts of the text. This definition is similar to the description of a discourse model as it is described in more linguistic theories (e.g. Kamp, 1981; Kamp & Reyle 1990; Heim, 1982). The situation models are, however, enriched with background knowledge that is not explicitly mentioned in the text (see also Van Dijk & Kintsch, 1983). A central point here is that the mental model contains objects and relations referred to in the text, but not the linguistic structure (words and sentences) of the text itself. The linguistic representation, however, is available as a separate representation which is known as the so-called text basis.

3. There are research results that indicate mental models are processed in the areas of the brain that are related to visuo-spatial information processing. Therefore, reasoning with multiple mental models should lead to an increase of blood flow in these areas as compared to reasoning with single mental models. However, another study (Tanenhaus et. al, 1995) states that different linguistic representations of the premises are kept in memory while constructing different possible models. In this case, multiple mental models would lead to an additional activation in linguistic

areas. In addition to the behavioural studies conducted so far, Goel et. al. (2007) explores the differences in brain activation during reasoning with determinate and indeterminate problems. The difference between determinate and indeterminate problems consists in the activation in both the left superior parietal cortex and the left frontal and temporal cortex. Since the first region can be related to spatial processing whereas the second region is involved in language processing, these data clearly support the second hypothesis. They conclude that any mental models are augmented with linguistic representations as soon as the reasoning problem becomes difficult.

2.2 Designing as social processes

Recent years have witnessed an increased attention to examining design as a social process. This is initiated from the acknowledgement that design is not viewed as an activity of an excluded mind, the designer. As Domeshek, Kolodner, Billington & Zimring (1994) note: "The lone design genius, if not mythical or completely extinct, is surely on the endangered species list. Nowadays, significant design projects require teams of designers coordinating their varied expertise to arrive at effective design solutions" (p. 143). But, it is not only the coordination of different experts that is instrumental in design. Design requires the management of resources, knowledge, requirements, and objectives that are derived from other identically critical agents such as clients, users, and stakeholders. Design, in all its manifestations (web and graphic design, product design, architectural and urban design, organisational design, policy design, etc.), is increasingly becoming an activity that involves multiple agents with different needs, knowledge, and goals. To the human agents that participate in the process, one should add the computational agents—computational tools in general—which inform and support design decision-making. But, design is an intrinsically social process in another important respect. Design products (from buildings to policies) are motivated by and realised within a social environment. The agents (individuals or social structures) that

constitute the context or environment of design, provide both the requirements and the final evaluations of the design products. Hence, they should be considered as essential parts of it.

Most publications in the field of design consider design to be a cognitive activity and narrow their point of interest to the individual cognitive activities. However, designers do seldom work individually. They work within different teams often with contradictory information, in groups on a similar task. Collaborative work suggests that they need to communicate with one another on numerous events during the design procedure. An individual cannot segment an artefact-to-be into subsystem, tackle the relevant sub-design issues, and afterward fit every all solution into one intelligible entirety. The (mid-term) consequences of individual cognitive processes must be imparted with characters from different areas to recognise and examine their complementary impacts. Because of the different perspectives that exist among engineering disciplines, this sharing of information is not just a matter of sender and receiver. In view of the alternate points of view that exist in engineering disciplines, knowledge sharing is not an issue of just the receiver and sender. An actor in design is unable to submit fragmented information to another actor without communicating. Hence, design is nowadays observed as a social process that necessitates many (social) interactions among the participants and conversations (Bucciarelli, 1988; Bucciarelli, 2002a; Bucciarelli, 2002b; Lloyd & Deasley, 1998; Boujut & Tiger, 2002; Love, 2003; Smulders, 2007; Sauer et. al. 2006). To create an approach to examine the distinctions among the various actors, Bucciarelli (1988) presents the idea of "object worlds" as the most significant component of the mental world belonging to the various actors. He characterises such a world as follows: "a world of technical specialisation, with its own dialect, system of symbols, metaphors and models, instruments and craft sensitivities" (Bucciarelli, 1988, p. 163). He applied this idea to designing on-screen characters from various designing areas, to clarify that the diverse world perspectives bring about the way that they do not share a typical arrangement of potential outcomes and requirements (Bucciarelli, 1988), and that they utilise internally

predictable yet distinctive language; they represent "structures", "electronics" and "aesthetics" (Bucciarelli, 2002b). The distinctive issue – solution spaces belonging to the diverse objects universes commonly influence, implying that decisions made in electronic design may have repercussions on the conceivable issue – solution space of a mechanical design. For actors within design teams to have effective communication among one another, they need to reach at a form of “shared understanding” that assists them to act within the same overall frame (Valkenburg, 2000; Kleinsmann, 2006; Sonnenwald, 1996). Clark & Brennan (1991) postulate that shared comprehension signifies a circumstance of “mutual knowledge, mutual beliefs and mutual assumptions" related to the object of conversation. The probability for shared comprehension to happen among designers from various disciplinary foundations is expanded on the off chance that they are acting simultaneously inside a similar design process.

As per Cambridge dictionary, social is connected exercises in which you meet and invest time with others and that occur during when you are not working. Furthermore, social brings the implication that identifying with society and living in organized manners. Social is an adjective that identified with practices in which you acquaint and spend time with others.

Social processes can be characterised as any procedure or action that incorporates the demonstration of social association between individuals nearby different exercises (Love, 2003). For social constructivists, for example, Berger & Luckman (1987) as cited in (Bechky, 2003), all information creation is a social procedure. Thus, all actions that rely upon the “body of human knowledge” somehow or another is additionally part of a social procedure, whether or not the action is attempted by an individual alone. This viewpoint requires caution since it is critical to stay away from over broadening the idea of 'social process’ with the goal that everything is social process (for example thinking, feeling, imagining, choosing, and behaving) and, similar to 'design', losing the diagnostic exploratory intensity of the idea of social process since everything is incorporated.

2.2.1 Shared mental models and shared understanding in teams

The idea of shared mental models in groups has been utilised to help clarify how a team can come up with a good decision making procedure. As per Cannon-Bowers, Salas & Converse (1993), shared mental models help clarify how groups can adapt to complex and changing assignment conditions. Indeed, scientists have recommended that the capacity to adjust is a significant aptitude in superior groups (Cannon-Bowers, Tannenbaum, Salas & Volpe, 1995; Mclntyre & Salas, 1995; Badke-Schaub et. al., 2007). The shared mental model hypothesis offers a description of what the instruments of flexibility may be—that is, the manner by which groups can rapidly and proficiently modify their technique "on the fly." The next sections give more insights about shared mental models hypothesis and its relationship to viable collaboration.

Cannon-Bowers et al. (1993) proposed that groups that must adjust rapidly to changing assignment may be sketching on shared or individual mental models. The reason for Cannon-Bowers et. al. affirmation was that so as to adjust successfully, colleagues must foresee what their partners will do and what they are going to require so as to do it. Henceforth, the capacity of shared mental models is to permit colleagues to draw on their own well-developed knowledge as a reason for choosing activities that are synchronized with those of their partners.

To refine the idea of shared mental models much further Stout, Cannon-Bowers & Salas (1996) recommended that the way how shared mental models work is linked with the demands of a task. In particular, these researchers contended that under conditions that permit colleagues to unreservedly speak with each other—to plan—shared mental models would not be significant. This is based on the grounds that the group can talk about its best courses of action and does not have to depend on prior knowledge. Nevertheless, under conditions in which communication is troublesome—as a result of exorbitant workload, tight deadlines, or some other environmental elements—groups that cannot participate in essential planning. For this situation, shared mental models become pivotal to group

working since they permit individuals to foresee the data and asset prerequisites of their group members. Thus, individuals can follow up based on their comprehension of the assignment demands and how these will influence their group reaction. It is this capability to adjust rapidly that empowers groups in vibrant conditions to be effective.

Research has stated that sharedness of mental models is important for tasks with the following characteristics:

1. Shared mental models are significant for tasks that require exceptionally planned activities between various members. In such groups, individuals need to act according to their predictions of each other's' comprehension of the task demands and their conduct. This coordination contributes improved organisation and improves group dynamics and execution (Stout, Cannon-Bowers, Salas & Milanovich, 1999).

2. Shared mental models are significant for adapting to tasks with complex interaction. Team performance can be improved by imparting mental models in circumstances to a serious need of knowledge sharing in the group. In circumstances where restricted correspondence is conceivable, because of overwhelming remaining burden and time pressure, shared mental models were discovered to be generally significant (Mathieu, Heffner, Goodwin, Salas & Cannon-Bowers, 2000). But in any event, when task demands where there are no tight deadlines or when tasks are acted in groups that don't share all important data, shared mental models improve communication and performance.

Most early examination on mental models concentrated on the examination of individual mental models, and it took an additional 10 years until the idea of mental models was acquainted with group settings. Common or team mental models (TMM) are described as information or conviction structures that are shared by individuals from a group, which

empower them to frame precise clarifications and assumptions regarding the undertaking, and to arrange their activities and adjust their practices to the demands of the tasks and other colleagues (Cannon-Bowers et. al., 1993; Klimoski & Mohammed 1994). “The term team mental model is not meant to only refer to multiple levels or sets of shared knowledge or just to an aggregate of the individual mental models, but also to a synergistic functional aggregation of the teams mental functioning representing similarity, overlap, and complementarity.” (Langan-Foxet, Anglim & Wilson, 2004.). As group mental models portray both individual mental models and how they are shared or conveyed inside a group, this idea appears to be truly appropriate to research how complex issues are explained inside groups. Design issues can be characterised as an explicit type of complex critical thinking (Hacker, Sachse and Schroda 1998; Badke-Schaub and Frankenberger 2004). Utilising team mental model studies to examine structure issues that may assist with seeing how the arrangement discovering develops and how it is conveyed and (implicitly) planned in a group. (Cannon-Bowers et. al., 1993). In addition, a principle normal for group mental models is that they can assist with organising and adjust activities and practices as mentioned by the design circumstance (Cannon-Bowers et. al., 1993).

Likewise, team mental models are characterised as organised mental portrayals, which group members share about key components in their condition (for a review see Mohammed et. al., 2010). These mental representations allude to task-related substance (i.e., which tasks should be finished) just as group-related content (i.e., how task fulfilment is best accomplished through collaboration). Two significant viewpoints further describe team mental models: (1) their comparability among group members and (2) their precision. Elevated levels of closeness infer that group members hold perfect mental models, which thus brings about regular desires for task consummation and interpersonal collaboration. Precision of group mental models is characterised by how much shared information and conviction structures reflect existing conditions in the authoritative condition. Group mental models have been examined

prevalently under the presumption that they add to organisational performance. Nevertheless, excessively shared information and conviction structures may bring about wonders tantamount to groupthink (see Groupthink) when group members argue reconsidering obsolete or wrong mental models in light of the fact that the team shares them.

Empirical research has indicated that high sharedness of mental models in teams positively affect performance. However, most studies focused on different aspects of teamwork that led to this performance benefit. Results from the different empirical studies are summarised as:

1. Shared mental models improve communication and coordination by using a common language (Eccles & Tenenbaum, 2004).

2. Shared mental models result in better planning, thereby improving coordinated team decision-making and performance (Stout et. al., 1999).

3. Shared mental models are most valuable when only limited communication is possible for example in situations of heavy workload and time pressure (Matthieu, et. al., 2000).

4. Successful teams share more similar concepts than unsuccessful teams (Carley, 1997).

5. People with more experience of working in teams have more elaborated mental models about teamwork, and higher experience results in more similar mental models among team members (Smith-Jentsch, Ampbell, Milanovich, & Reynolds, 2001).

6. Shared beliefs about failures, as part of a shared mental model, are influenced by leadership coaching and direction and positively affect performance (Cannon & Edmondson, 2001).

7. Shared mental models on knowledge about the task have a positive influence on strategy coordination, which in turns facilitates performance (Espinosa et. al., 2002).

8. Team processes and performance are better among teams sharing higher quality shared mental models than among teams with low-quality models or less sharing (Mathieu, Heffner, Goodwin, Cannon-Bowers & Salas, 2005).

2.2.2 Communication as tool to reach shared mental models in teams

Communication is another bottleneck when working in teams. More communication is needed when the more complex and less clarified information facing by the team at the beginning of the design process in order to coordinate the team and the task (Casakin & Badke-Schaub, 2015). Effective communication is required in order to exchange ideas about the problem and the solution. However, the communication among members from different disciplines is often hindered by different understandings of terminologies, concepts and processes (e.g. Kleinsmann & Valkenburg, 2008; Kratzer, Leenders, & van Engelen, 2004; Stempfle & Badke-Schaub, 2002). In order to overcome this problem, there is a need to better understand how individual representations are getting shared within a team.

Ineffective teamwork can also arise from insufficient clarity of the used terminology, probably due to differences in background knowledge (MacGregor, Thomson, & Juster, 2001). The need of a shared understanding of the task is important to identify critical situations and react appropriately (Badke-Schaub & Frankenberger, 1999; Badke-Schaub & Frankenberger, 2002). It is an acknowledged phenomenon that the responsibilities and understanding of a task are usually not fairly distributed. Communication across different topics can be challenging given the functional differences that create boundaries. Boundary objects are objects that are shared by different groups within an organisation but used differently by each of them. Boundary objects can help to overcome

these boundaries by serving as a shared ground (Carlile, 2002; Star & Griesemer, 1989). Such boundary objects can be a shared terminology or practice, but also shared representations like sketches. These boundary objects help to represent knowledge and transfer it to other team members, thereby creating and maintaining cohesion (Bechky, 2003). This results in enhanced shared understanding within the team. Valkenburg (2000) assumes that design team members need a shared understanding of the task. In her study, she referred to shared understanding as shared frames related to the definition and understanding of a problem. Badke-Schaub and Frankenberger (2002) state that much can be learned about communication among members and the used strategies from the analysis of the information transfer within design teams.

Previously, mental models have been introduced as mental representations about the design task at hand. Within a team, designers have to exchange and adapt their individual models to reach an agreement. When working together, designers start with individual mental models about the task. Within a team setting, the designers also have a representation of the other team member, thereby also having a representation of the team. Finally, they also have a mental model about the process, which is how they work and structure the design process. In time, team members exchange their mental models, which lead their individual models to change and converge. When they agree on aspects such as the problem definition, their mental models become more similar. Eventually, teams that have achieved mutual agreements and shared understanding continue to employ the same cognitive processes, leading to similar mental modes.

Given the research presented above, it becomes clear that research in design collaboration has provided insights into the factors that influence such. However, attempts to study the psychological processes that drive design collaboration are rarely taken. Many design research missed the opportunity to embrace knowledge about teamwork that is already present in the mature field of social sciences. Theoretical models, concepts and measurement techniques are waiting to be selected and adapted to design

research. Incorporating those into design research is the main aim of this work. In the next sub-topic, I will present a model of sketching as a communication tool for reaching shared understanding during concept generation in design teams, which is the main finding of this study.

2.3 Sketching as a communication tool for designers

Sketching and drawing are the fundamental parts of communication; words are worked around them. Moreover, manual sketching fortifies reasoning (Jobst, Thoring, & Badke-Schaub, 2020; Goldschimdt, 2017). However, the drawings are integral to such an extent that individuals wait for visuals or sketches on white boards to be communicated. Coordination and struggle occur over, on, and through the drawings. These visual portrayals shape the structure of the work, who may take an interest in the work, and the outcome of designing. They are a segment of the social association of aggregate cognition and the locus for practice-situated and practice-generated knowledge. Engineering sketches and drawings are the fundamental structure of technological design and production. Besides, since they are created and utilised through communication, these visual portrayals are a method for arranging the structure to creation process, subsequently connecting people and team members. The drawings and sketches structure the work procedure and the products.

2.3.1 Visualisation as a means of information transfer

Drawings and sketches serve the social association of disseminated cognition in a way that was depicted by Suchman (1988) for white boards. The overwhelming distinction between the designers' authentic practice and that of the psychological researchers is that architects depend all the more vigorously on the simply visual configuration. The difference is noteworthy due the connection between visual data and nonverbal tacit information. Representational practice in science has lately developed as a strong motivation to assess the construction of scientific understanding.

Research in this discipline concentrates on what Latour & Woolgar (1986) have designated "inscriptions," which are articulated as visual or verbal devices such as purposely prepared, pruned, and strained samples; cautiously cropped photographic archives; and edited chart tracings. (Latour, 1986; Lynch, 1985; Gilbert & Mulkay, 1984; Knorr-Cetina and Amann, 1990; Pinch, 1985; Rudwick, 1976). The perspective on technological stance comparatively shows that innovation as a social procedure, concurrently socially formed and society molding.

This goes past current investigations of visual portrayals in science, in any case, in that it uncovers the job of building representations and drawings as gadgets that socially compose the laborers, the work procedure, and the ideas laborers control in designing structure.

A few scholars have proposed that the way toward making drawings might be as imperative to structure as the drawings themselves (Bly, 1988; Tang & Leifer, 1988). The researcher’s assessment of visual communication exercise in the realm of mechanical advancement depends on a contextual analysis of the visual interchanges that structure the way toward planning a modern applications motor bundle and spotlights on what befalls the structure of the association of artifacts and actors when computer-aided design is incorporated into the procedure. In this case study, the presentation of a Computer Aided Design (CAD) / Computer Aided Manufacturing (CAM) framework into the visual culture of designing drawings dampens the adaptability that is significant to their capacity, especially in light of the fact that the computer-generated drawings that are connected to a few other information bases, overextending the limit of drawings to go about as limit objects. This happens in light of the fact that they become less adaptable yet additionally due to the suspicions of the direct procedures of configuration work incorporated with the projects themselves. The social exercises rebuilt most fundamentally by the presentation of CAD/CAM are the procedures of sketching and designing plans. Computer aided design/CAM is intended to

permit specialists to plan on computers. This implies they should revamp the system for visual presentations.

Sketches are the essence of visual communication. They are presumably the most significant transporters of visual information since they serve both as an intelligent specialized instrument and as an individual reasoning instrument. According to Henderson (1991), the adaptability of sketches to function in both capacities permits these two capacities to intersect when designers work together, with the goal that sketches become a thinking instrument of dispersed cognition. For instance Selco management was persuaded by the design of Mark IV by a model created from exchanges between Cap, a senior engineer known as "the guru of piping," and a hobbyist model builder in management who became project engineer for the enterprise. The new design combined some of the best aspects of previous designs along with new ideas. The new plan consolidated the absolute best parts of past structures alongside new thoughts. Before the model could be manufactured, these thoughts must be passed on through rough sketches and supplemented by a discussion. In their initial draft stages, sketching additionally are utilized by designers as an interactive instrument, in that they might be modified or revised by somebody other than the individual who drew them. Sketching is associated with considerations that are in visual configuration. As an intelligent device, sketches are the most immediate route for a designer to help structure an idea in the brain of an associate by offering structure to ideas imagined in her or his own brain.

The significance of sketches as individual reasoning instrument is outlined by a design engineer – Sharon, who said that when she was elevated from drafter to designer, they took her sketching board away. She requested it back, expressing "I can't think without my drafting board." As a reasoning instrument, the version of the visual picture onto paper is similar to the achievements of the composed work in the authentic advancement of education (Henderson, 1998, p.83). A physical picture, such as composing, is a transporter for an idea, permitting it to navigate in

time and space unrelated to the author. The substantial shape or type of the idea rendered onto paper disables critical analysis as it is impossible to analyse a representation in another's brain. Sharon states, "As soon as you start sketching it, you have ideas and changes. You're erasing it and improving it." And later, "But when you start laying it out, that's where, you know, 80% of the problems come out." the beginning phases this is a fast procedure during which the sketch fills in as notes or the blueprint for a composition. Sharon notes, "They say the best designers start sketching right from the beginning." Similar to note taking, speedy sketching gets short-lived thoughts down before they vanish from memory (Henderson, 1998, p.84). The sketch catches them in a solid form and structure. This shapes a potential that is a first estimation of the genuine structure items will take.

Sketching also helps to comprehend the constraints of a project; "You're just trying to get a size, trying to understand it ... to get an understanding of the system, almost building up your self-confidence so you know the task you've been assigned." Sharon delineates the sketch's utilisation both as an individual reasoning device and as an enrolment instrument, demonstrating its adaptability from one to the next in her statement: "As soon as you have something, you can take it to someone else and say, "Look this is what I have, how can I improve on it?' or 'Did you have a problem in this area too?". At the intuitive level, sketches fill in as limit items and promote communication to refine thoughts further. As stated in the book of Henderson (1998, p.83), sketches catch relevant information from numerous sources as it an object that helps in the development of shared cognition related to the packaging of a turbine engine. Cap, a senior designer on the Mark IV, highlights that these conscription instruments are used not only among design engineers but also to encourage consultation among designers and those in the production phase. He deliberates his ideas early in the design procedure with individuals in "structures," the division that completes welding. He states: "I usually take my layouts right after I've started, after I do my initial layouts, before they're ever dimensioned." This permits him to strategise a

design that is the most effective to develop: "It's just a matter of 'is this the best possible way to do this particular thing' and usually it's peripheral, but a lot of times they'll say, ah, 'Well, gee, if you did this, over here, this would save one weld.' ", (Henderson, 1991, p. 460).

A sample of sketches as limit objects-strongly organised in a singular site utilise but is a feebly organised for use as depicted in Cap's reliance on sketches after the design is completed and the venture moves to creation. Comprehensive visual data is at first given uniquely in a design position-”top-down” views that shows the arrangement of parts like a guide. A comprehensive description of how the last task should "look" or how parts fit together are not accessible on the shop floor during the gathering of a first package. At the point when the project goes into standard creation, a form book, produced out of the procedure of the main gathering and incorporated with get together guidelines from parts merchants will be accessible for the shop.) Due to his experience, Cap is aware that the conscription can be misconstrued, hence, Cap is on the shop floor during the primary assembly of his plans and gives extra visual data when required. He recognises that for laborers, working from the two-dimensional designs, "they still may not make as much sense in one area, so you circle a line on it and make a little hand sketch off to one side there to clarify the thing." Referring to an ambiguous area in a layout, he mentions:

> *For instance, like where it's black here in this area, they see a dotted line coming down and say "what's really going on there?" I'm liable to just go off with the pencil and go and just make a little hand sketch off to one side just to make it clearer to the guys doing it at the time but it wouldn't be as a permanent anything.*

While not all designers finish as systematically as Cap does, his utilisation of visual correspondence through hand sketches encourages both the early structure process during its reasonable states and the actual realisation of the structure during its last creation. He moves from the

fragile structure of the format attracting to the quality of its structure squares, outlines, to fill in the site-explicit detail. The casual visual correspondence of sketching is fundamental to conveying ideas; Sharon states you never "get two designers who just sit down and just talk," adding, "Everybody draws sketches to each other." Cap highlights that a discussion with people in structures, where the package is essentially developed "works wrong if you can't communicate." He takes his drawings to "sit and talk," so others are able to comprehend what he is attempting to do. Similarly, he draws outlines for laborers so they can comprehend what they should do to make what he has in his mind that may not be clear in their brains from viewing the design drawings. This intuitive utilisation of conscription devices as limit objects weaves together the contribution of individuals with skill from industrial experience, for example, the welders in the "structures" division with the joint knowledge from different planners. It taps singular mastery in funnelling, electrical hardware, oil frameworks, etc. to socially build a machine worked through composed and disseminated cognition (Henderson, 1991).

2.3.2 Verbalisation as a means of information transfer

There are numerous perspectives on creativity. Amabile (1988) contends that creativity is displayed when a service or product is created that is both novel and helpful concerning the firm. Woodman et. al. (1993, p. 293) brought up that innovativeness alludes to 'the making of a significant, helpful new item, administration, thought, strategy, or procedure by people cooperating in an unpredictable social framework. King & Anderson (1990, p. 82) suggested that creativity at the group level unequivocally consolidates the relational conversation among colleagues. Through viable correspondence, expanding on the information on the different colleagues, groups encourage knowledge sharing and make new information. To accomplish development, there must be thoughts, and these initially emerge from the team members. A novel idea perishes unless it discovers a breeding place. Creating, refining, testing, choosing, and executing these thoughts further depends on communication among the

colleagues. Creativity does not occur inside individuals' heads, but through communication (Csikszentmihalyi, 1996). An expanded degree of communication makes the cross-preparation of idea conceptualisation more likely. Consequently, collaboration is required to prompt more and better new thoughts (West, 1990). Furthermore, Allen (1977) has contended that, to trade data designers and technologists need to converse with one another. The designer can obviously find out about new advancements, explicit economic situations, or serious turns of events. Nevertheless, to have the option to comprehend and process this data, engineers needs to comprehend the setting of the data. This setting is understood through ccommunicating with others (Allen, 1977; DeMeyer, 1991).

Groups are data preparing units like people, groups process data: they encode, store, and recover it (Brauner & Scholl, 2000). Communication among its individuals should encourage groups to be more productive concerning their creative outcomes. This is because they profit from both the 'exposed' contribution of colleagues and the group's ability to process and upgrade these information sources.

Communication is fundamental to the suitable accessibility of data required by the different individuals from the various capacities and background present in the group. Due to its conspicuous potential benefits and significance, the recurrence of communication inside groups has become the most logical variable of group performance in the literature, irrespective of the sort of group or performance.

2.4 Model of function of sketching in the design process

In this section, I will further elaborate on the integration and relationship of shared mental model and sketching within the design teams. Moreover, a model of sketching as communication tool for reaching shared understanding during concept generation in design teams is presented.

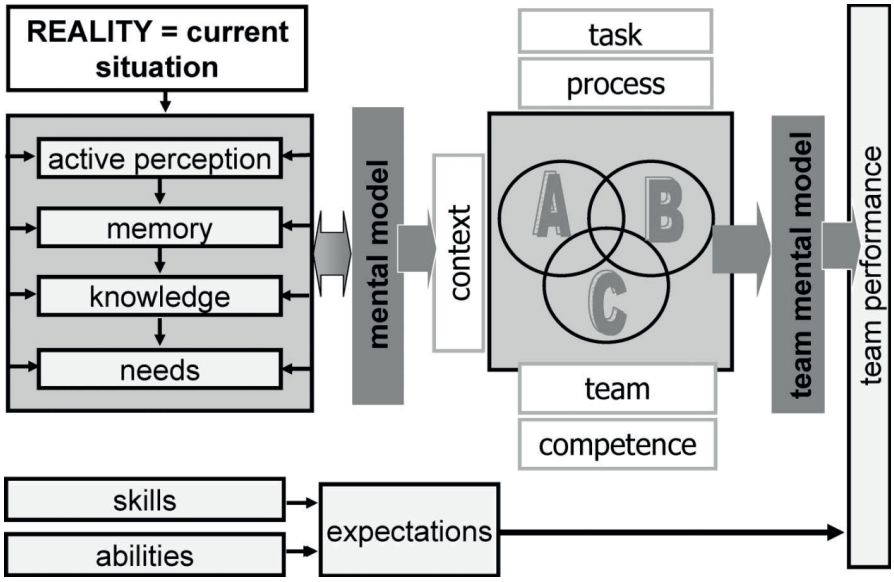


Figure 2: Mental model after Badke-Schaub et. al. 2007

Figure 2 shows general model of the main factors and the interplay of these factors as have been studied in the last more than 20 years of research on shared mental models. Starting from the left part the model shows that individual cognitive processes are actively involved when individual mental models are built. Each team member A, B and C perceives reality due to his/her memory built on prior knowledge and experience and structures the world around him. At this early moment, the individual team members work already together based on their own subjective representations and expectations.

Thus, the individual mental models need to be accessed and communicated in the team. Based on the need for adaptations the quality of team performance will be changing.

However, these parameters are still very general and need to be better clarified for design teams. But of course the team performance is also dependent on the individual skills and abilities which determine the expectations of the performance. The situation is matched with the current context and continuously checked which is the team situation and needs referring to their own background knowledge, experiences, expertise, or aims. Hence, these features cause the development of the mental models in

individual. The exchange of the individual models in communication among the team members built up a team mental models. Thus, this cycle relates to one of the five content aspects: the task, the process, the team, the competence, or the context resulted towards team performance.

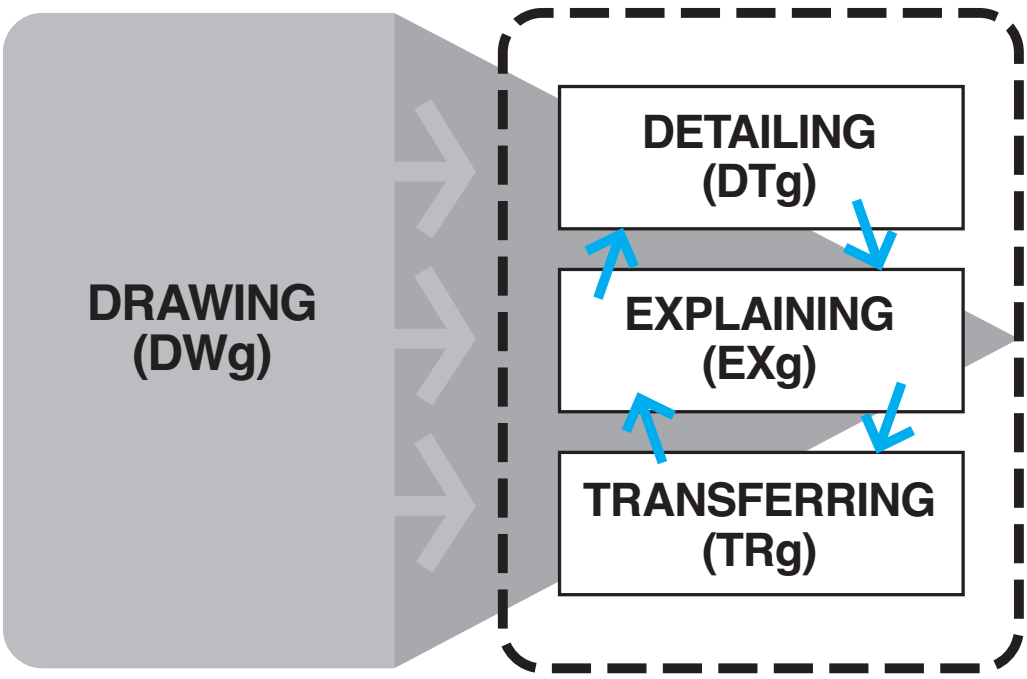


Figure 3. Model of sketching as communication tool for reaching shared understanding during concept generation in design teams

Figure 3 depicts the sketching and verbal activities which are part of the development of the shared mental model. The communication relates to four different activities – drawing (DTg), detailing (DTg), explaining (EXg), and transferring (TRg). Drawing appears to be a continuous activity throughout the design task, whereas detailing, explaining, and transferring built on drawing elements in order to negotiate and develop the idea(s) ensured that the ideas were transferrable to the team. Transferring activities can be considered effective when a common understanding of a given idea is established across the team.

Therefore Figure 3 depicts a cycle (the grey arrows) that builds on and revolves around drawing activities (the blue arrows). It can be argued that as the team executing that cycle in an iterative way, ambiguity will decrease and the shared understanding in the team will increase.

Now we know that, sketching plays an important role for designers in term of individual thinking and visualising process as well as for collaboration among the team members. Details on these are described in the following chapters.

3

Methodological Approach

Chapter 3

Methodological Approach

In this chapter, the research methodology will be elaborated. A quasi experiment study is chosen to be the setup for all studies that were conducted during this research journey. In the next sub chapters, each study setup is described and elaborated.

3.1 Research questions

As mentioned in the previous chapter, the main research questions are as below:

1. How does sketching influence the design process when working in design teams?

2. How does sketching influence the way of collaboration in design teams?

In order to answer these two main research questions, several sub-questions are developed which later were executed in five studies of this research. The overview as in Table 1.

Table 1. Overview of Research questions, sub-research question, chapters and studies

Main Research Question	Sub-Research Question	Chapter	Study
1. How does sketching influence the design process when working in design teams?	How will the sketching process be changed if verbalisation during sketching activity is limited?	4	3
	How are ideas transferred within a design team when verbal communication is blocked?	5	2
	Are the agreements reached while constructing shared understanding expressed through multimodal communication? If so, what is the interplay among the different communication channels that are involved? Is there a dominant one?	7	5
2. How does sketching influence the way of collaboration in design teams?	What role does verbal communication play for sketching activity?	4	3
	How does information and knowledge transfer change during sketching if verbal communication is blocked?	5	2
	How different communication channels that were used during sketching activity in design teams for sharing mental models?	6	4
	What strategies are used by design teams to build a shared understanding while sketching?	7	5

3.2 Experimental setup

A quasi-experiment is conducted to explore the research questions, with 18 participants responded to a design brief in groups of 3. Their age

ranged from 23 to 36 years old. They were randomly assigned to the control and experimental condition. In the experimental condition termed as ‘silent sketching’, participants were not allowed to talk during the design task. In the control condition termed as ‘verbal sketching’, communication was not restricted. Before participating, they were informed about the experiment procedures. Their background information and other details were kept anonymous. All participants were masters and doctoral students at the Industrial Design Engineering faculty of Delft University of Technology in the Netherlands.

The experiment consisted of two phases. In the first phase, participants responded to the design brief individually. In the second phase, they continued to work on the same design brief collaboratively, and established one final concept.

Finally, they were asked to fill in a survey about their self-perceived ability to communicate using different media. All activities were audio-visual recorded by using multiple cameras located at three locations – two side views and one top view of the experiment table in the laboratory setting. GoPro Hero® 3 camera was placed on top of the experiment table for all experiments (see Figure 22 & 23). All activities were observed and analysed.

The records related to the behaviour of the participants, conversations as well as the sketching process during the designing task were analysed. After Phase 1, sketches produced by individuals were captured digitally to record their outcomes before continuing Phase 2 if they might extend further development according to the task. After the experiment is completed, all sketches and survey forms were collected and digitally captured for coding purposes using Microsoft Excel software and graphically generated using Adobe Illustrator and Adobe Photoshop software. The conversations during the design task were transcribed. Furthermore, the Statistical Package for the Social Sciences (SPSS)

software was used for the statistical analyses of sketching categorizations of verbal and silent sketching groups.

3.3 Description of studies

In order to answer two main research questions as described in chapter 1, and sub-research questions for each studies as in Table 1, five studies have been setup, recorded and analysed. The main experiment setup for all studies remain the same. Each consist of 2 phases. For phase 1 participants underwent individual idea generation process and in phase 2, they teamed up with other team members for collaborative design task and finally the teams came out with one solution agreed by all. The details of each study are described in the following sub chapters. All studies started with the same design brief with improvements have been applied to one study and another. Hence, the designing tasks were looking at five different lenses. Results from each improvement are the findings for the specific sub-research questions. These findings support to answering two main research questions of this research work. An overview of all studies can be seen in Table 2.

Table 2. Overview of study setup

Study	Setup	
Study 1	**Number of participants**	6
	Experiment time	Total: 85 minutes Phase 1: 45 minutes, Phase 2: 30 minutes Break between phases : 10 minutes
	Design task	To design products that help blind people to develop cooking experience with stimuli in phase 2 of collaborative design task
Study 2	**Number of participants**	6
	Experiment time	Total: 85 minutes Phase 1: 45 minutes, Phase 2: 30 minutes Break between phases : 10 minutes
	Design task	To design products that help blind people to develop cooking experience with stimuli in phase 2 of collaborative design task
	Improvement	1. A survey after the designing task.
Study 3	**Number of participants**	18
	Experiment time	Total: 85 minutes Phase 1: 45 minutes, Phase 2: 30 minutes Break between phases : 10 minutes
	Design task	To design products that help blind people to develop cooking experience with stimuli in phase 2 of collaborative design task
	Improvement	1. Number of participants 2. A survey before the designing task
Study 4	**Number of participants**	18
	Experiment time	Total: 80 minutes, Phase 1: 45 minutes, Phase 2: 20 minutes, Break between phases: 10 minutes Fill in survey: 5 minutes
	Design task	To design products that help blind people to develop cooking experience with stimuli in phase 2 of collaborative design task
	Improvement	1. Time of experiment 2. A survey after the designing task
Study 5	**Number of participants**	18
	Experiment time	Total: 90 minutes, Phase 1: 20 minutes, Phase 2: 50 minutes, Break between phases: 3 minutes, Fill in survey: 12 minutes with 5 minutes transition allocated after completed the designing in phase 2.
	Design task	To design products that help blind people to develop cooking experience without stimuli in phase 2 of collaborative design task
	Improvement	1. No stimuli 2. Time of experiment

3.3.1 Study 1

Study 1 is aiming at investigating the sketching in the conceptual design stage and to explore what measures and procedure might be appropriate to improve the positive influence of sketching during the design process. This is the kick start of this research work. We started with two research questions:

1. Does the initial idea change or maintain throughout the design process through sketching? And if so, how?

2. How does the team situation affect the sketching process and idea development?

Findings from this study were used to further developed what and how are the added value in sketching on shared understanding in design team. Thus, 2 groups of 3 participants were gathered. They were divided equally in control and experimental condition. The task was to design products that help blind people to develop cooking experience (see Appendix A). The design process took 85 minutes in total. They were given 45 minutes for phase 1, 10 minutes breaks and another 30 minutes for phase 2.

3.3.2 Study 2

Study 2 investigates the communication process during sketching in design teams on theoretical and empirical levels and proposes two frameworks. The task was to design a product that helps blind people to cook. This experiment was the continuation of study 1 with an improvement has been made in the last part. The participants were asked to fill in a survey to assess the communication medium preferences. The total time for the experiment was 85 minutes.

3.3.3 Study 3

Study 3 investigates the relation between sketching and communication in teams during the idea generation process in early concept generation–analysis of sketching in design teams. In this study, it was continued with the same setting of the design task as in study 1 and study 2. On the contrary, different sub-research questions have been applied. In the last 5 minutes of the experiment, groups presented their final idea. Two improvements have been done to the whole setup. Firstly, participants were given a survey to assess their communication medium preference (sketch, written, and verbal) before the designing task started. Secondly the number of participants were increased to 18 masters students and divided equally into 3 groups for both - control and experimental condition.

3.3.4 Study 4

Study 4 was conducted as an exploratory protocol study on the use of different communication channels during design sketching. The analyses of how individual designers shared their mental models with other designers in a group, and their use of graphical, textual, and verbal communications during concept generation. 18 participants of masters and doctoral students at Delft University of Technology were randomly assigned into six groups of three participants for two conditions – control and experimental. The design process took 80 minutes in total with 10 minutes break after phase 1. Two improvements have been made from previous study. Firstly, a survey was administered to all participants after completing the designing and secondly, the total time of experiment was accumulated.

3.3.5 Study 5

Study 5 investigates specific communication actions designer takes in different communication modalities that lead to shared understanding. A total numbers of 18 participants were grouped in six groups of three and

were randomly assigned equally for both – control and experimental condition. In this final study, the setup has been enhanced in term of total time and the design process activities. The design process required 90 minutes to complete. Time allocated for phase 1 had been shortened to 20 minutes and the participants were given a break for 3 minutes before the phase 2 started. In phase 2, the participants spent a total of 62 minutes. The first 50 minutes were allocated for collaborative design task and ended with 12 minutes of filling in a survey about their self-perceived ability to communicate using different media (see Appendix C).

4

Analysing The Implications Of Sketching In The Individual And In The Team Context

Chapter 4

Analysing The Implications Of Sketching In The Individual And In The Team Context

This chapter is based on; Nik Ahmad Ariff, Badke-Schaub & Eris (2012b). "Does Sketching Stand Alone as a Communication Tool during Sketching in Design Teams?", Proceedings of the Design Research Society Conference DRS 2012, Research: Uncertainty, Contradiction and Value.

In this chapter the implications of sketching on the individual and on the team context is investigated.

In Chapter 4 the relationship between sketching and communication in teams throughout the idea generation process in the early concept creation are described and analysed. This study employed a quasi-experimental design and observed participation from the Industrial Design Engineering postgraduate students at Delft University of Technology, Netherlands who were completing their Masters. There were six groups, each group consisted of three members and they were given 3) a stipulated time to provide a solution to a design problem. The experimental groups (n=3) were not allowed to communicate during the design process, while the control groups (n=3) did not receive any restrictions. The experiments were logged, observed, and analysed. Communication was utilised by the two groups to move and bolster their individual thoughts. The written language was employed as the communication by the experimental group to specify the sketch information. These discoveries show that outlining is not solitary as the design teams' need to utilize visual and verbal

correspondence related concurrently to deliver solid ideas and to move them into a common understanding in the group.

4.1 Introduction

Sketching is an important thinking means in design. This is valid for individual and group design processes. Sketching has generally been viewed as an essential instrument for conceptualization in the beginning phase of the individual design process (Fish & Scrivener, 1990). Research has indicated that sketching is also utilised for an examination of solutions concerning functions or/and forms, and for resolving the design problem in teams (Goldschmidt, 1991; Van Der Lugt, 2002).

Many design practices are occurring in groups and require the individual designer to impart his/her own perspectives about the issue and solution spaces to other group members. Nevertheless, these thoughts are not well-established and fuzzy upstream in the design procedure, and require more refinement to improve its transferability. Normally, this undertaking is more challenging in interdisciplinary groups. Distinctions in objectives, dialects, and other social factors produce clashing perspectives which should be synchronised (Smulders et. al., 2008) to agree on design decisions. Designers are prepared to help their verbal clarifications by visual portrayals to encourage correspondence and common comprehension, or vice versa. In any case, our comprehension of the "discourse" between sketching and verbal correspondence is constrained.

When resolving this matter, we initially ask what psychological procedures are included during the drawing procedure. The accompanying model (Figure 4) delineates the most important stages from the presentation of the issue until its re-evaluation by the designer and the communication of the updated mental model.

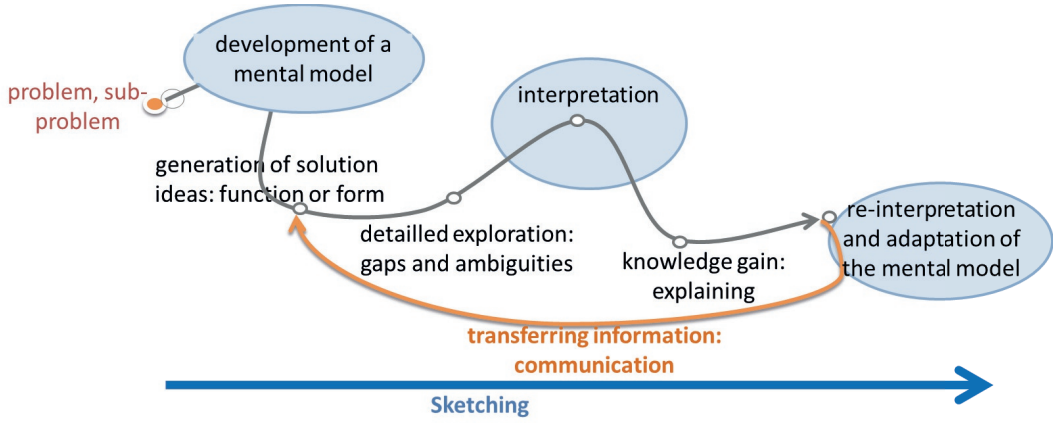


Figure 4: Cognitive activities during the sketching process in a team

The introduction of the design problem will lead to a premature understanding of the problem, and thus, a rough mental model will be built from each of the group members. Initial ideas about possible solutions are generated on the basis of that rough mental model. The processes depicted by the blue bubbles are internal activities such as mental models, which cannot be directly observed. These constructs need to be characterised by criteria which can be inferred through observations. Moreover, these constructs should be treated as elements of the whole process.

At the level of individual and team activities, sketching can be described as processing three cognitive patterns:

1. Exploration–Interpretation–Re-interpretation cycle (see also Purcell & Gero, 1979): Cognitive processes during sketching can be described as a process of exploration, interpretation, and re-interpreting cycles. The mental model is the cognitive structure, which provides ‘questions’ and ‘answers’ and ‘instructions’ on what to explore and how to build a comprehensive model for the further development of solutions. The starting point may be inconsistencies or the main assumptions about the problem at hand seem to contradict own experiences.

2. Defining uncertainties and ambiguities: As Figure 4 suggests, designing is not simply the implementation of knowledge and

application of methods. Usually, the designer chooses a partial aspect of the given problem, which he/she defines according to his/her knowledge and experience. This initial understanding of the problem leads to further exploration of goals and ambiguities. The results of these activities define the problem space, which is represented as a mental model, including gaps and ambiguities. Ambiguity and fuzziness can limit the completeness of the mental model, but they also are an opportunity for creative interventions. When designers start sketching, they rarely try to visualise the whole problem but choose those elements which they give priority due to criteria resulting from the exploration – interpretation – re-interpretation cycle such as unclear, complex, intertwined elements. These are situations where solutions are needed, and creativity is a function of to what extent gaps and ambiguities will be exploited to construct new solutions. Thus, sketching provides opportunities to select relevant parameters with respect to creativity.

3. Knowledge gain – knowledge transfer cycle: the sketching process of individuals as well as of teams is accompanied by verbal explanations. Individual thinking processes and communication patterns in design teams alternate between gaining knowledge and transferring and exchanging knowledge (Badke-Schaub & Doerner, 2002). The process of switching between generating and exchanging of knowledge is observed as a main source of creativity (Paulus & Yang, 2000). This assumption suggests that verbalisation can be as important as visualisation. Building on that inference, this study hypothesises that if designers in a team are not be allowed to talk while sketching, they would be severely hindered from producing well-developed design solutions. This study presents empirical results on the relationship between verbal communication and sketching in the context of the design process.

4.2 Research questions

This study intends to answer the research questions as follows:

1. How will the sketching process be changed if verbalisation during sketching activity is limited?

2. What role does verbal communication play in sketching activity?

4.3 Experimental design

4.3.1 Data collection

Quasi-experimental research design was employed for this. The participants of this study were 18 design students who are completing their Masters in the Faculty of Industrial Design Engineering, Delft University of Technology. Participants were assigned into six groups of three and requested to react to a design brief. Three groups were given two conditions: experimental and control. The experimental groups were not permitted to verbally communicate with each other during designing, hence, these groups were termed as “silent” sketching groups. The control groups completed the same design task without any restrictions and are designated as “non-silent” sketching groups.

4.3.2 Data assessment

As presented in figure 5a and figure 5b, the experiment was split into two stages. In the first stage, 45 minutes were provided to the groups to create ideas. The assigned task requires the groups to develop a product that aids blind people to cook. The teams were provided 5 minutes to read the design brief and in the subsequent 10 minutes, each participant had to work individually to produce his/her ideas without communicating with other group members. This restriction was consistent for both the

experimental and control groups. Then, the group members collaborated and developed a final concept.

After a 10-minute break, the second phase began, which was envisioned as the "stimuli phase." A different set of instructions were offered to the groups, which additionally detailed the goal by indicating "camping" as the setting in which the cooking is conducted. The new instructions also provided pictures of outdoor cooking devices as stimuli. The intention of the stimuli was to restrict the solution space and to enable the process of reaching a mutual covenant. This phase requires the groups to finish the design task in 25 minutes, with 5 minutes for reading the instructions and 20 minutes for group work. In the last 5 minutes of the experiment, the groups presented their final idea. A survey to evaluate the communication medium preference (sketch, written, and verbal) was administered to all participants before the task. All activities and the resulting sketches were digitally logged, witnessed, and analysed.

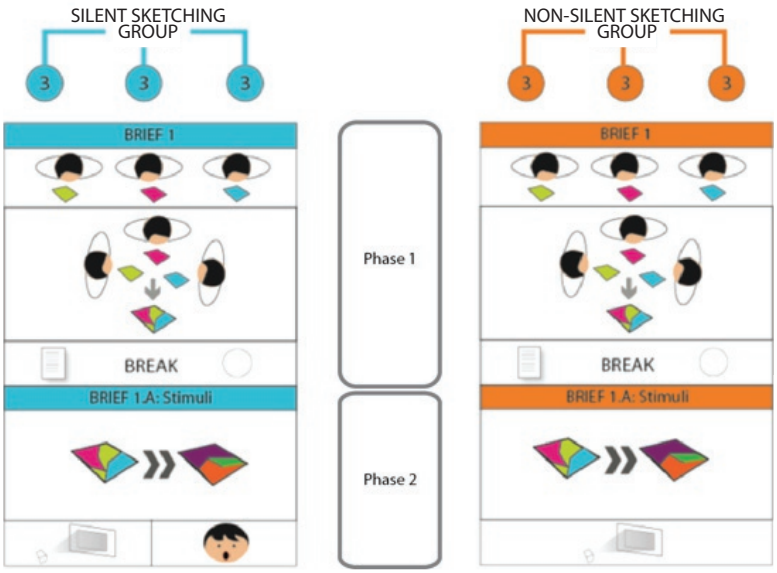


Figure 5a. Overview of experiment

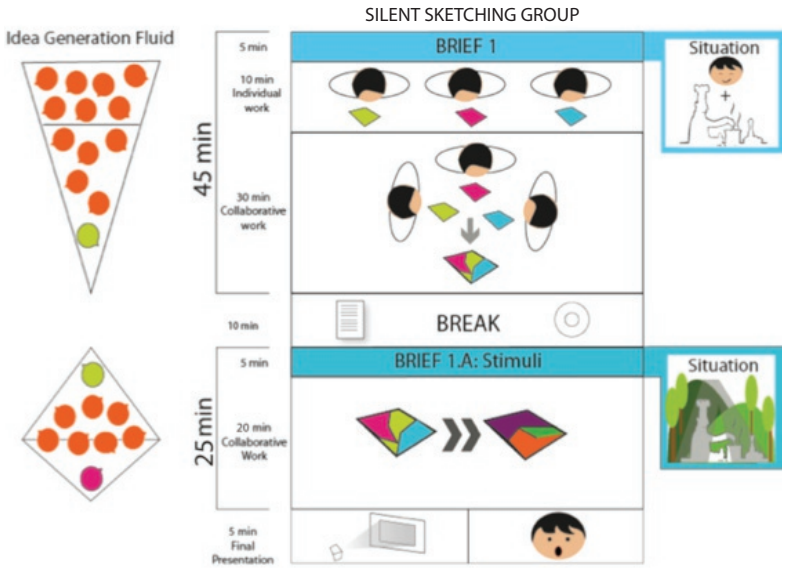


Figure 5b. Overview of sketching task

4.4 Data analysis

This section elaborates on the examination of the sketches and the design process. All sketches were disintegrated into sketch elements, and the sketch elements were linked with (seen as the outcome of) four activity classifications that were constructed based on the observation during the experiments (see figure 6):

1. ***Generate:*** Introduction of basic form and function elements in a sketch.

2. ***Detail:*** Extension of the sketch through the Exploration–Interpretation–Re-interpretation cycle (as discussed earlier).

3. ***Explain:*** Clarifying the meaning of sketch elements with annotations.

4. ***Transfer and Exchange:*** Negotiating the meaning of sketch elements through information sharing and dialogue.

As mentioned before, we assume that these four activities are indispensable to satisfying the two central necessities for handling with the particular situation: addressing the design problem (design, refer figure 6) comprehending and ensuring that the team members possess a similar comprehension (communication, refer figure 6). This study focuses on the function of the communication activities, which were further categorised into explanation, and transfer and exchange actions.

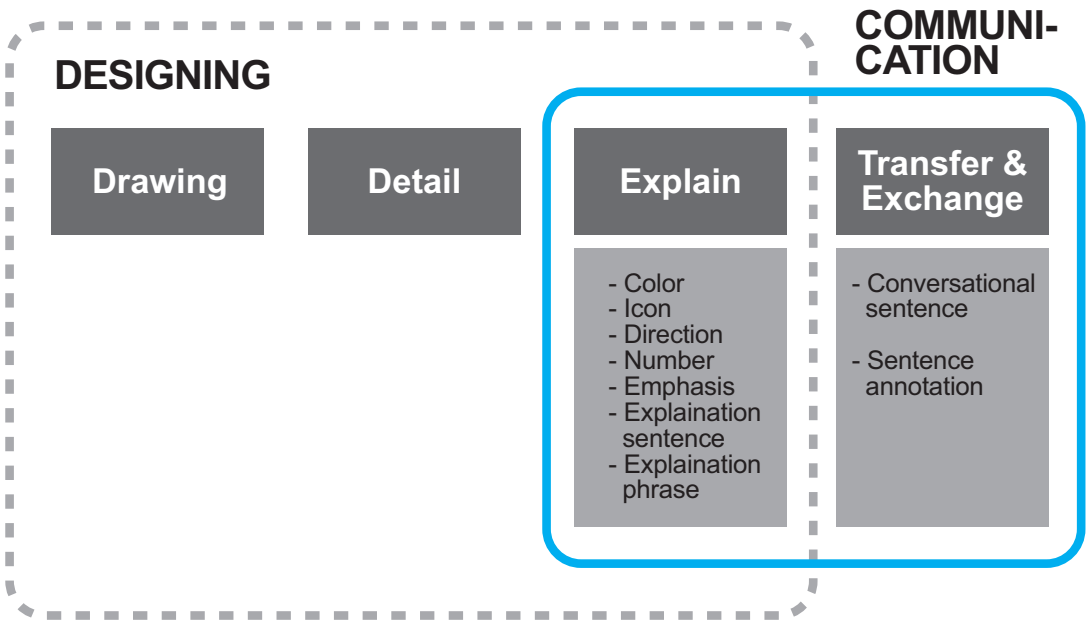


Figure 6. Sketching activity categorisation framework

The explanation category identified seven explanation elements which consist of (1) colour, (2) icon, (3) direction, (4) number, (5) emphasis, (6) explanation sentence, and (7) explanation phrase.

Colour is frequently utilised to specify meaning. For instance, red represents hot. An Icon is a graphical representation and is normally assumed within the group to be utilise to classify or transfer meaning. *Icon* can be very broad such as the addition symbol "+", or can be exclusive to a group such as the group generating an icon to embody blind people. *Direction* is a mark that specifies direction (such as an arrow) from one point/area to another point/area on the sketch. *Number* refers to an

arithmetical value, articulated by a word, symbol, or figure, that is utilised to compute, order in a sequence, or to classify. *Emphasis* refers to special significance given to a sketch element to highlights its important such as underlining. *Explanation sentence* are notes inscribed in a sentence form to further elucidate a sketch component. The *explanation phrase* is a succinct textual annotation utilised to clarify a sketch element.

Two transfer and exchange elements were determined which were *conversational sentence* and *sentence annotation.* They denote to the written conversation that took place in a sketch without openly referring to any sketch elements.

Conversational sentence is a note penned in a sentence form to describe a sketch element. *Sentence annotation* is a concise textual annotation utilised to elucidate a conversational sentence.

4.5 Results

4.5.1 Design and communication activities

A total of 60 A3 size paper sheets with sketches were gathered during the experiment. 23 sheets were collected from the non-silent sketching group, while 37 sheets were collected from the silent sketching sketches.

The core assessment of the sketches was conducted by classifying the components in the sketches and categorising the components into the categories as explained in Section 4.5. Sketching activities were assessed and summarized according to the experimental condition. Table 3 details the results from the assessment.

Table 3. Cumulative sketching activity counts for the silent and non-silent experimental conditions

Sketching Activities		**Experimental Condition**	
		Silent	**Non-Silent**
Generate	Count	40	40
	% of total	3.4%	9.8%
Detail	Count	43	16
	% of total	3.6%	3.9%
Explain	Count	973	287
	% of total	82.1%	70.2%
Transfer & Exchange	Count	129	66
	% of total	10.9%	16.1%
Total	**Count**	**1185**	**409**
	% of total	**100%**	**100%**

A chi-squared test of independence was performed to examine the relation between sketching activities in detail, explain and transfer & exchange and the assigned conditions during the design process. The chi-squared test revealed that the observed total counts were significantly different in these three activities, which for detail, $X2$ (1, N=18) = 28.72, $p<0.001$, for explain, $X2$ (1, N=18) = 613.4, $p<0.001$ and for transfer & exchange, $X2$ (1, N=18) = 94.93, $p<0.001$.

4.5.2 Communication activities

Figure 7 illustrates the explanation activity counts according to experimental condition. Icons, directions, sentence annotations, explanation sentences were comprehensively used by the silent sketching groups. Their amplified utlisation of explanation sentences and sentence annotations compared with non-silent groups is particularly interesting. This is because when speech is not a choice, sketch elements are clarified using written communication. These results uphold our assumption that

sketching and verbal communication must be employed concurrently to construct well-developed ideas.

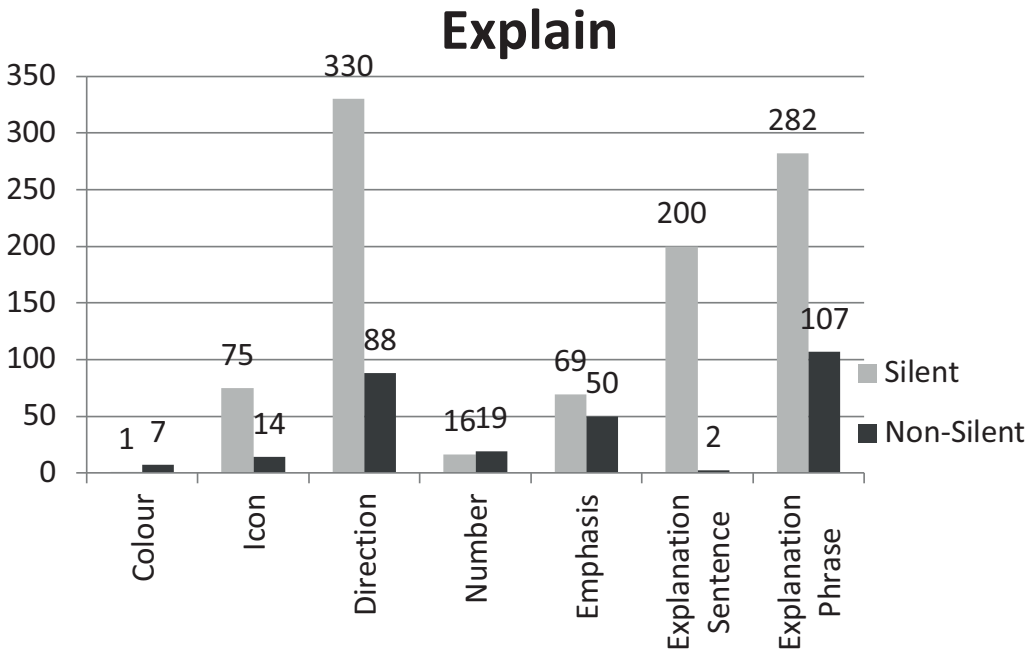


Figure 7. Explanation element counts

Figure 8 illustrates the transfer and exchange activity counts according to experimental condition. The silent groups widely employed conversation sentence while the non-silent groups utilized more sentence annotations. This can be attributed to annotation being a quicker way to attract attention to current conversational sentences to be discussed when one has admission to speech to conduct the negotiation itself.

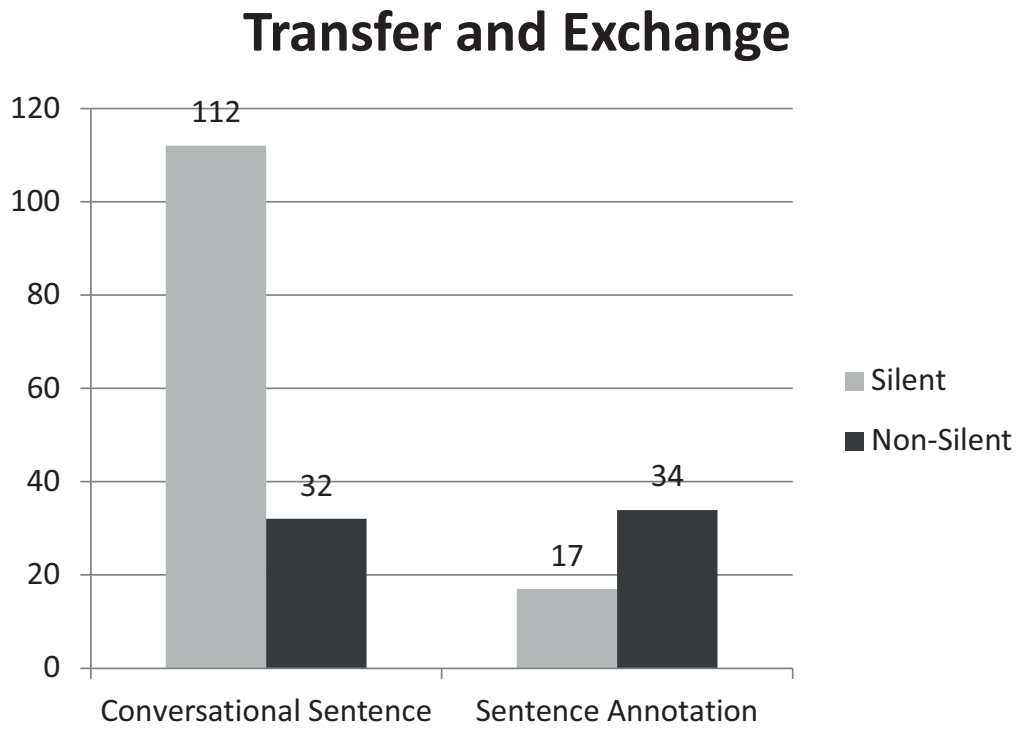


Figure 8. Data collection in the communication category

To summarise:

> *Written explanation sentences, explanation phrases and conversation sentences replace verbal discussions when verbal communication is not possible.*

Restriction of verbal description promoted the substitution of utilising explanation sentences, conversation sentences, and explanation phrases to clarify ideas and confer their definitions. Moreover, the explanation sentences, conversation sentences, and explanation phrases constructed by the silent groups are more comprehensive than the ones formed by the non-silent group.

4.5.3 Survey outcomes

A survey was conducted to gauge the communication medium inclination (sketch, written, and verbal) of all participants prior to the task. More specifically, participants were asked on their level of comfort with

each medium to convey their ideas. The instrument utilised a 5-point response scale, where 1 represented "not comfortable at all," and 5 represented "very comfortable." The survey also contained an item which inquired if the participants had received formal sketching training, with "Yes" or "No" options.

The survey revealed that all 18 participants have formal sketching experience. Responses to the communication medium preference items were analysed according to study groups. ANOVA was conducted to identify to identity any significant differences between the groups. The test revealed no significant differences among the six study groups.

4.6 Discussion

Sketching is an influential instrument for designers to idea visualisation and transfer. However, to ensure that the ideas are more transferrable and clearer to the other designers in a team, verbal communication is necessary. Language is a necessity to transfer details. Furthermore, this study displays that the detailing process during sketching primarily signifies to elements of explanation, and conversation to transfer, and share ideas within the team when speaking is not permitted. The inclusion of these elements in the drawings creates more concrete, transferrable, understandable ideas within the team. This aligns with the previous finding where sketches were acknowledged to contribute to a more cohesive group process (Van Der Lugt, 2005). However, those elements are also part of the "normal" designing setting (non-silent sketching) since they are required to transfer the ideas in a more concrete manner.

Hence, team members do not only advance shared mental models about the current, but also about the procedure and the team as they must lead their group process appropriately. Thus, a solid comprehension of each other's viewpoints and what they are currently working on is required. This finding is in accordance with a previous finding that reported that the

common sketching and usage of sketches in a team as a common ground can assist in the creation of shared mental models (Neumann, Badke-Schaub & Lauche, 2009).

Design postgraduate students with sketching experience participated in study. Although this was suitable for the simple conceptual design task utilised, experienced designers in real-life environments might vary in their behaviour. For instance, expert designers are expected to control sketches more than novices (Goldschmidt, 1991). Furthermore, practising designers were identified to be more explanatory and exhibited more fixation-resistance as compared with novices (Tversky et. al., 2007). Examining the differences between novice and expert designers on how they utilise sketches to communicate during the idea stage generation in teams would be a thought-provoking follow-up study. The research design of the experiment and the framework are planned to be further refined.

4.7 Conclusions

Despite studies have examined sketching during the design process have been done in the past, there is a still poor understanding of the extent of sketching to be utilised as a communication medium. These findings recap the role sketching plays as a reliable instrument for designers to connect within oneself and in teams. The findings also established that, in a team context, verbal communication is necessary to clarify ideas in a more detail manner. This enables the sketches to be more concrete, visualisable, and transferrable.

5

How Ideas Are Transferred When Verbal Communication Is Blocked?

Chapter 5

How Ideas Are Transferred When Verbal Communication Is Blocked?

This chapter are based on; Nik Ahmad Ariff N. S., Badke-Schaub P., Eris O., Suib S. S. S. (2012). "A Framework for Reaching Common Understanding during Sketching in Design Teams", Proceedings of the 12th International Design Conference DESIGN 2012, pp. 1525-1534.

This chapter studies the communication processes during sketching in design teams based on theoretical and empirical perspective. This has led to the development of two frameworks. The first framework is the design-communication block framework which segregates the categories of activities that took place during sketching and establishes the analysis structure for the empirical dimension of the work. The second framework is a framework to attain a shared understanding during sketching in the design teams which influences the outcomes of the analysis.

Our main finding is that although drawing activity itself forms the basis of team discourse during sketching, the actions of explaining, detailing, and transfer activities make ideas more concrete, understandable, and transferrable within a team. Our findings also show that when verbal communication is blocked, the distinction between drawing activity, and explaining, detailing, and transfer activities become more apparent.

5.1 Introduction

Freehand sketching has conventionally been employed as a main conceptual instrument in the initial phases of a design process (Fish & Scrivener, 1990). It is commonly leveraged to structure problems, generate

and explore solutions, investigate functions or/and forms, and assist designers to develop and analyse ideas. This cognitive facet has been emphasised by Cross, who refers to the memory saving aspect of sketching, when he indicated “sketches enable designers to handle different levels of abstraction simultaneously” (Cross, 2006).

Currently, most design activities are conducted in teams, and necessitate individual designers to articulate his/her views about the issue and solution spaces to other team members. Nevertheless, these ideas are usually not clearly described and fuzzy upstream in the design process and require more handling to ensure that the idea is transferable. This task is more difficult when done in a team that has members from different backgrounds. Distinctions in objectives, vernaculars, and other cultural variables contribute to diverse perspectives which need to be aligned to (Smulders et. al., 2008) to ensure a good decision-making process. Generally, designers are educated to sustained their verbal descriptions by visual representations to expedite communication and mutual understanding.

During the embodiment and detail design phases, sketching does not have the same relevance. However, it can still be useful to resolve details which cannot be addressed by verbal description communication only. Moreover, sketches play a critical role in communicating with an external audience such as during presentations.

Pipes refer to three essential functions of sketching—“a designer’s drawing”—in information transfer situations as follows:

1. It is a means of externalising and analysing thoughts and simplifying multi-faceted problems to make them more understandable,
2. It is a persuasion medium that sells an idea to clients, and reassures them that their brief will be understood correctly,

3. It is a method for communicating complete and unambiguous information to those responsible for the product's manufacture, assembly, and marketing (Pipes, 2007, p.15).

Design concepts, even while being created, often constitute artefacts that resemble objects in the real world. Designers hold mental images of these artefacts that assist them during their thinking process (Athavankar, 1997). These mental images have to be manipulated and altered constantly during the design process. Although the preconditions and circumstances in which sketching is required are not yet fully understood, there seems to be an unproven assumption that designers often use sketches to facilitate thinking. It has been shown that sketching does not necessarily lead to better results (Bilda, Gero & Purcell, 2006).

However, in summary, most empirical studies reveal that sketching is a necessary part of the design process (Ullman et. al., 1990). In addition to the functions referenced above (as identified by Pipes), this study also postulates that:

1. The use of visual representations by sketching provides a memory extension which lowers the cognitive load (Purcell & Gero, 1998). Therefore, designers who sketch during the design process perceive problems as less difficult and can infer more relations among components of complex concepts (Sachse, Hacker & Leinert, 2004). These results support the idea that sketches contribute to a better and deeper understanding of one's own ideas.

2. During design collaboration, the use of shared sketches within the design team facilitates communication by providing a common ground that contributes to a shared focus of attention and understanding (Heiser, Tversky & Silverman, 2004).

5.2 Research questions

This study aims to investigate the following questions:

1. How are ideas transferred within a design team when verbal communication is blocked?

2. How does information transfer during sketching change if verbal communication is blocked?

5.3 Experimental design

5.3.1 Data collection

Both groups were assigned to 2 phases of the design task. The participants of this study were 18 design students who are completing their Masters in the Faculty of Industrial Design Engineering, Delft University of Technology were assigned to six groups of three. They were requested to react to a design brief. Three groups were given two conditions: experimental and control. The experimental groups were not permitted to verbally communicate with each other during designing, hence, these groups were termed as "silent" sketching groups. The control groups completed the same design task without any restrictions and are designated as "non-silent" sketching groups.

5.3.2 Data assessment

As presented in Figure 9 and Figure 10, the experiment was split into two stages. In the first stage, 45 minutes were provided to the groups to create ideas. The assigned task requires the groups to develop a product that aids blind people to cook. The teams were provided 5 minutes to read the design brief and in the subsequent 10 minutes, each participant had to work individually to produce his/her ideas without communicating with other group members. This restriction was consistent for both the

experimental and control groups. then, the group members collaborated and developed a final concept.

After a 10-minute break, the second phase began, which was envisioned as the "stimuli phase." A different set of instructions were offered to the groups, which additionally detailed the goal by indicating "camping" as the setting in which the cooking is conducted. The new instructions also provided pictures of outdoor cooking devices as stimuli. The intention of the stimuli was to restrict the solution space and to enable the process of reaching a common shared mental model. This phase requires the groups to finish the design task in 25 minutes, with 5 minutes for reading the instructions and 20 minutes for group work. In the last 5 minutes of the experiment, the groups presented their final idea. A survey to evaluate the communication medium preference (sketch, written, and verbal) was administered to all participants before the task. All activities and the resulting sketches were digitally logged, witnessed, and analysed.

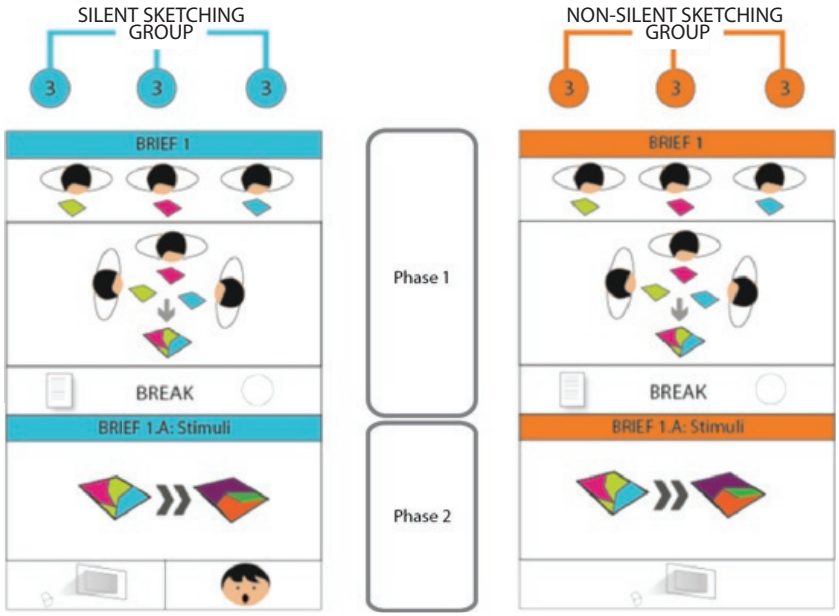


Figure 9. Overview of experiment

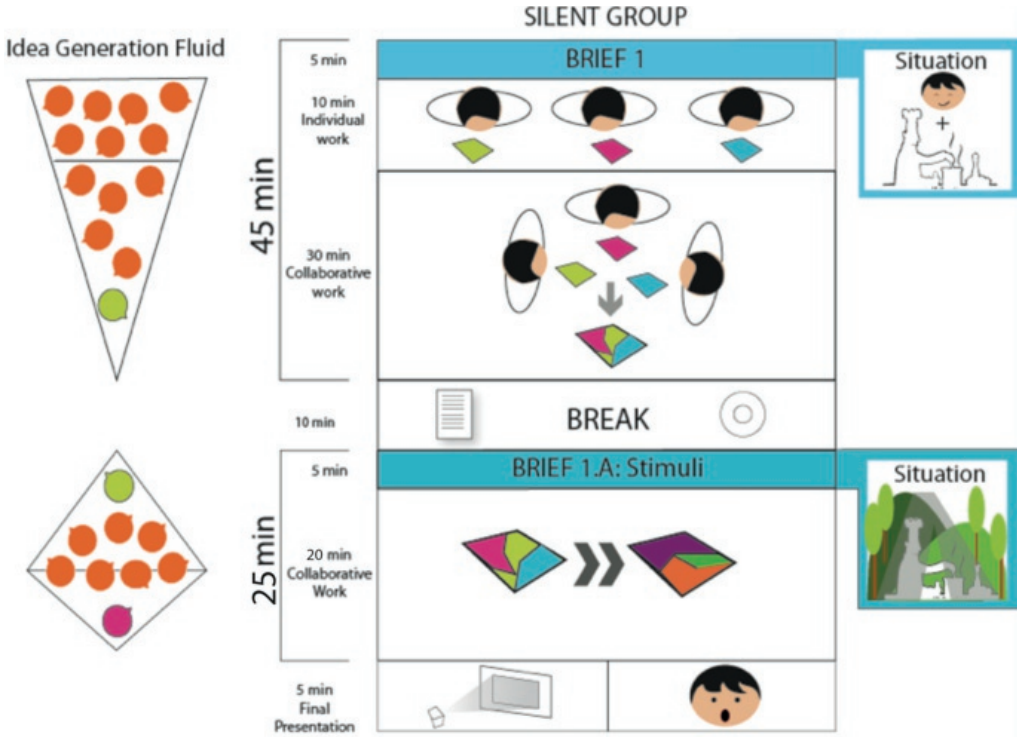


Figure 10. Overview of sketching task

5.4 Data analysis

Sketches were analysed according to the following four activity categories:

1. Drawing (DWg)
2. Detailing (DTg)
3. Explaining (EXg)
4. Transferring (TRg)

There are two types of sketch elements. The first type of element is 'support notation' which includes textual notes, list dimensions (leaders and arrows), and calculation. The second type of element is 'graphic representation', which includes drawing of objects and their functions, plots, and charts (Ullman et. al., 1990).

Based on this understanding and our own analysis of sketches generated during the design activity, a new framework was developed for

categorising sketch elements and expressed them in the form of a design-communication block (Figure 11). The element categories are drawing, supporting, technical, explanation, and conversation.

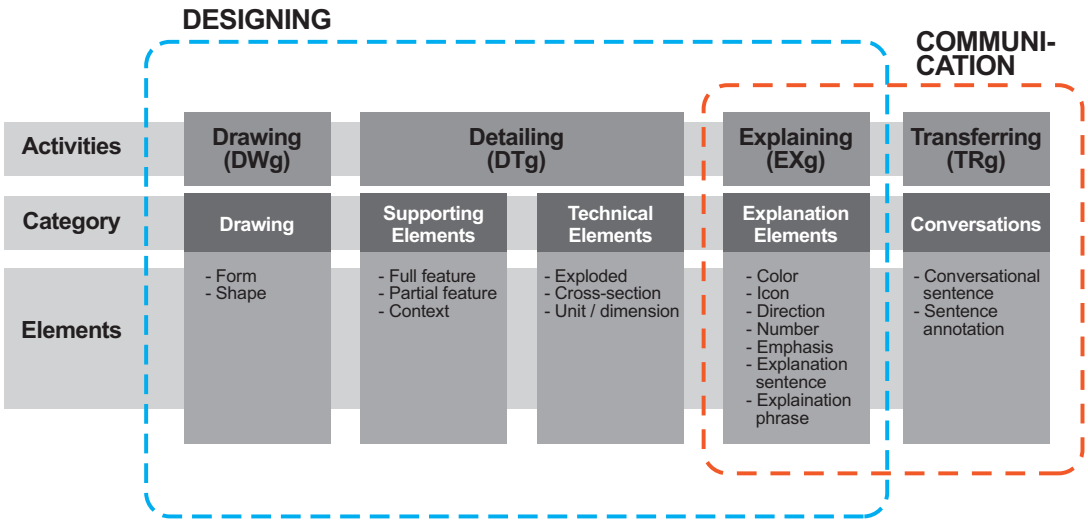


Figure 11. The Design-Communication block framework

The Design-Communication block framework dimensions and sketch elements are defined in Table 4. These definitions were used as guidelines to code and calculate the sketch elements that were produced during the experiments. Although the entire Design-Communication block framework is discussed, this study is focused on the activities associated with the design block only.

Table 4. Categorisation system of the sketching activities

Activities	Element of Categorisations	Elements
Drawing (DWg) Drawing / sketching on paper.	**Drawing elements:** Elements of a drawing that communicate functionality at the level of a product and have distinct physical forms. (e.g. stove, pot, sink)	**Sketch :** Sketch elements with low level of detail and high level of ambiguity. **Form :** Sketch elements with high level of detail and low level of ambiguity.
Detailing (DTg) Extending/ refining a drawing element through the use of supplemental drawing or technical elements.	**Supporting elements:** Drawing elements that re-visualise and existing drawing element in additional detail.	**Full feature :** An additional and more detailed drawing of an entire existing drawing element. **Partial feature :** An additional and more detailed drawing of a part of an existing drawing element. **Context :** An additional drawing of an entire existing drawing element in a specific context - often to visualize a usage scenario.
	Technical elements: Technical elements that convey a technically detailed understanding of existing drawing elements.	**Exploded :** Exploded view of an assembly that further specifies its geometry. **Cross-section :** Cross sectional view of a part that further specifies its geometry. **Unit / dimension :** Value and/or units of technical parameters such as length (mm) or 10mm.
Explaining (EXg) Annotating existing drawing elements with graphical, numerical or textual information to clarify their meaning.	**Explanation elements:** Elements that clarify the meaning of existing drawing elements in the form of annotations.	**Color :** Use of color to indicate meaning (e.g. Red is hot). **Icon :** A graphical symbol commonly understood within the group that is used to identify or communicate meaning. Can be very general such as the addition symbol "+", or can be internal to the group such as creating an icon to represent *blind people*. **Direction :** Lines that indicate direction (e.g. Arrow) from one point/area to another point/area on the drawing. **Number :** An arithmetical value, expressed by a word, symbol, or figure that is used to calculate, order in a series, or to identify. **Emphasis :** Special importance or prominence given to a drawing element such as underlining. **Explanation Sentence :** A note written in a form of a sentence to further explain a drawing element. **Explanation Phrase :** A brief textual annotation used to explain a drawing element.
Transferring (TRg) Carrying out a conversation to establish common understanding within the group around the drawing elements.	**Conversation elements:** Elements enable written communication on the meaning of existing drawing elements.	**Conversational Sentence :** A note written in the form of a sentence to further explain a drawing element. **Sentence Annotation :** A brief textual annotation used to explain a conversational sentence.

In order to understand how ideas were transferred within the group through visual communication, this study analysed how drawing elements that were created during the individual part of the experiment were connected with the drawing elements that were created during the collaborative part. Sketches created after the stimuli were not a part of this analysis because the relationships between the sketch elements could not

be reliably tracked that far into the design process. Figure 12 graphically illustrates the outcome of that analysis for one of the silent groups.

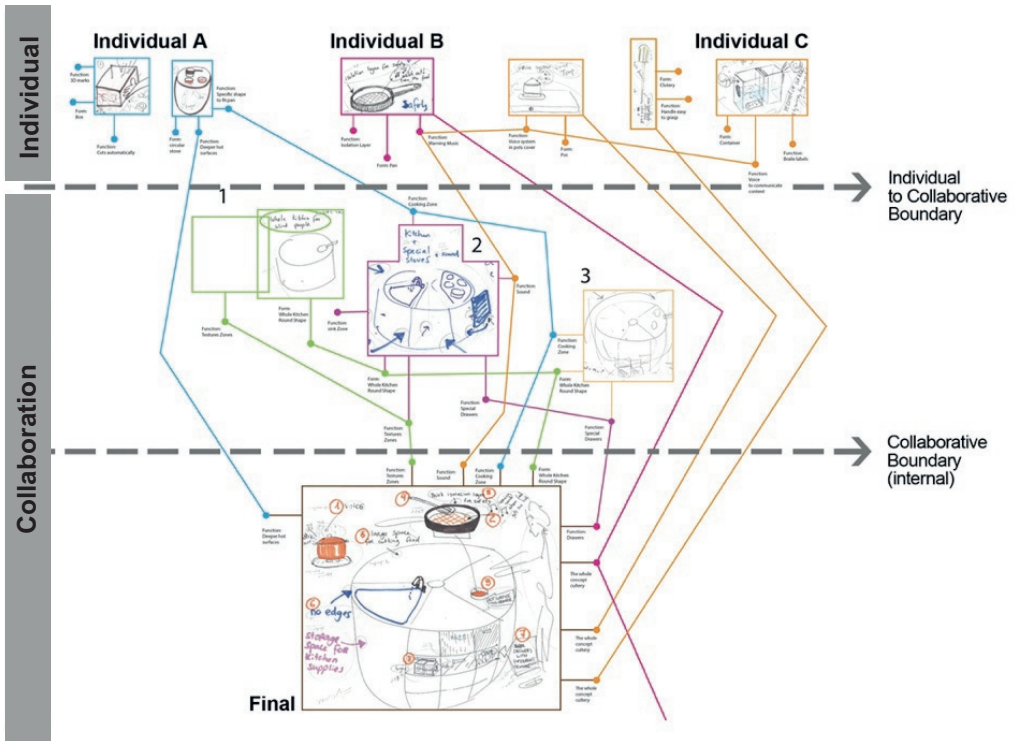


Figure 12. Outcome of the visual connectivity analysis for one of the silent groups. Lines indicate links that show either a form or function relationship between two sketch elements.

The lines represent "visual links." Each sketch element was associated with a form (graphic), and one or more functions (to the extent that it/they are revealed by the graphics). Sketch elements in the different parts of the design process sharing the same form or function were assumed to be "connected," and lines across the sketch elements depict such connections. We paid specific attention to how the sketch elements were connected across two boundaries; 1) individual to collaborative boundary and 2) collaborative boundary (internal of the collaborative activity). The collaborative boundary is established between the drawings that appear in the final proposal and the group activity that preceded it. These distinctions allowed us to investigate the effects of blocking verbal communication on how ideas were shared within the team.

5.5 Results

This section presents the results of the three types of analysis outlined in Section 5.4, categorisation of the sketching activities, visual connectivity analysis, qualitative observations on the design-communication block activities, and the communication methods preference survey. Statistical analysis to test for the significance of the differences that exist between the silent and non-silent groups was conducted.

5.5.1 Categorisation of sketching activities

A total of 60 A3 size paper sheets with sketches were gathered during the experiment. 23 sheets were collected from the non-silent sketching group, while 37 sheets were collected from the silent sketching group.

The core assessment of the sketches was conducted by classifying the components in the sketches and categorising the components into the categories as explained in Section 5.4. Sketching activities were assessed and summarized according to the experimental condition. Table 5 displays the results from the assessment.

Table 5. Differences between silent and non-silent group according to four main activities

Activities		**Group**	
		Silent	**Non Silent**
Drawing	Count	40	40
	% of total	4.3%	17.8%
Explaining	Count	716	150
	% of total	77.3%	66.7%
Detailing	Count	43	16
	% of total	4.6%	7.1%
Transferring	Count	127	19
	% of total	13.7%	8.4%
Total	**Count**	**926**	**225**
	% of total	**100%**	**100%**

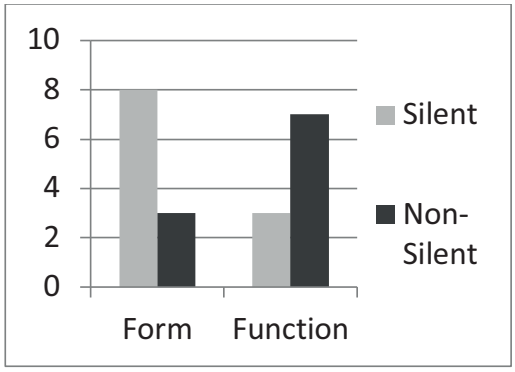
As can be seen on Table 5, although both conditions yielded the same number of drawing elements, the silent conditions yielded much higher explanation, detailing, and transferring elements.

A chi-squared test of independence was performed to examine the relation between sketching activities in explaining, detailing and transferring and the assigned conditions during the design process. The chi-squared test revealed that the observed total counts were significantly different in these three activities, which for explaining, $X2$ (1, $N=18$) = 527.42, $p<0.001$, for detailing, $X2$ (1,$N=18$) = 35.93, $p<0.001$ and for transferring, $X2$ (1, $N=18$) = 88.92, $p<0.001$.

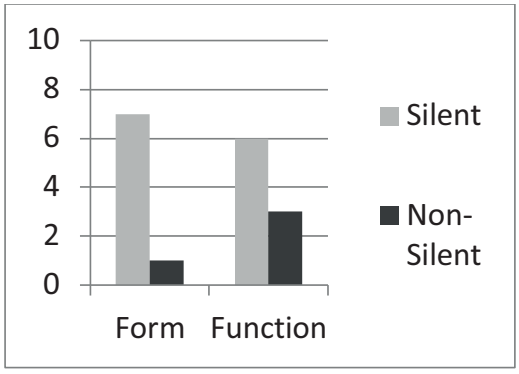
5.5.2 Visual connectivity

The link counts that cross the individual to collaborative boundary are indicated on the graph on the left in Figure 13. The link counts that cross within the collaborative boundary are indicated on the graph on the right in Figure 13. As defined in Section 5.4, each link was further categorised into

a form or function link. Links that went from the individual activity directly to the final product were not included in this analysis.



Individual to collaborative link counts



Collaborative links (internal) counts

Figure 13. Results of visual connectivity analysis for the silent and non-silent sketching groups

Link counts from the individual to collaborative boundary suggest an interesting trend. The trend illustrates silent groups made more form connections whereas non-silent groups made more function connections. This suggests that when verbal communication was blocked, form elements were the more tangible elements for describing the drawing, thus, were used for transfer within the group. Furthermore, form elements can visualise the idea(s) more effectively, which later seed the graphical dialogue within the team. For the non-silent sketching groups, function elements seemed to be a mechanism for describing the drawing in order to bring the idea(s) forward into the collaborative activity. Therefore, verbal language plays a role in allowing the team to explore and leverage the semantics of the sketch elements.

However, a different pattern appeared within the collaborative activity when the links across the collaborative boundary were analysed. Silent groups made more both form and function connections. This might be because of the increased relevance of exploring function while trying to converge on a final solution, which applies to either group. And since the non-silent groups cannot use verbal language to attain a final solution, it is

possible that they use the only communication medium that is available to them. In other words, even when verbal communication is blocked, function elements were used in conjunction with form elements during the collaborative activity when the need to establish a common understanding was critical.

5.5.3 Qualitative observations on the design-communication block activities

During the first part of the experiment, designers were asked to generate and sketch solution ideas individually in response to the design brief. These sketches were then brought into the group. The teams paid special attention to the drawing elements (form and shape), which were initially fairly abstract for the purposes of transferring individual ideas to other group members and moving toward a decision about the proposed solution. The need to produce a final concept by the end of the session drove the detailing of the form and shape of drawing elements in order to anchor the description of the ideas under consideration. Therefore, as more elements were gathered and sketched, the proposed concept became more concrete until it was finalised.

Figure 14. Framework for reaching a common understanding during sketching in design teams

Figure 14 illustrated the process that relates the four activity categories – drawing (DTg), detailing (DTg), explaining (EXg), and transferring (TRg). Drawing appeared to be a continuous activity throughout the design task while detailing, explaining, and transferring activities were built on drawing elements in order to negotiate and develop the idea(s). They ensured that the ideas were transferrable to the team. Transferring activities can be considered effective when a common understanding of a given idea is established across the team.

Therefore, Figure 14 depicts a cycle (the green arrows) that builds on and revolves around drawing activity (the orange arrows). It can be argued that as the team executed that cycle in an iterative fashion, the level of ambiguity in the drawing elements decreased and the ideas became more concrete. In producing the final concept, these four activities were performed in both experimental conditions – silent and non-silent groups. However, as shown in Table 5, it is noteworthy that both groups created a similar number of drawing elements. Therefore, the difference was in what was happening around the drawing activity.

5.5.4 Communication preference survey

A survey was conducted to gauge the communication medium inclination (sketch, written, and verbal) of all participants prior to the task. More specifically, participants were asked on their level of comfort with each medium to convey their ideas. The instrument utilised a 5-point response scale, where 1 represented "not comfortable at all," and 5 represented "very comfortable." The survey also contained an item which inquired if the participants had received formal sketching training, with "Yes" or "No" options.

The survey revealed that all 18 participants have formal sketching experience. Responses to the communication medium preference items were analysed according to study groups. ANOVA was conducted to

identify to identity any significant differences between the groups. The test revealed no significant differences among the six study groups.

5.6 Conclusions

Sketching is an influential instrument for designers to idea visualisation and transfer. However, to ensure that the ideas are more transferrable and clearer to the other designers in a team, verbal communication is necessary. Language is a necessity to transfer details. Furthermore, this study displays that the detailing process during sketching primarily signifies to elements of explanation, and conversation to transfer, and share ideas within the team when speaking is not permitted. The inclusion of these elements in the drawings creates more concrete, transferrable, understandable ideas within the team. This aligns with the previous finding where sketches were acknowledged to contribute to a more cohesive group process (Van Der Lugt, 2005). The distinction between drawing and explaining, detailing, and transfer activities becomes more apparent when verbal communication is blocked and is supported by our findings.

Thus, team members do not only cultivate collective mental models about the task at hand, but also the process and the team since they must lead their group process appropriately. In order to do this, a strong comprehension of each other's viewpoints and current works. These findings are in accordance with preceding findings which indicated that common sketching and use of sketches in a team as a common ground could assist in the creation of shared mental models (Neumann et al., 2009). These outcomes have assisted in the development of a framework that defines the process of attaining a common understanding during the sketching process in design teams (Figure 14).

6

The Influence Of Sketching For Reaching Shared Understanding In Teams During Concept Generation

Chapter 6

The Influence Of Sketching For Reaching Shared Understanding In Teams During Concept Generation

This chapter is based on; Nik Ahmad Ariff N. S., Badke-Schaub P., Eris. O. (2012a). "Conversations Around Design Sketches: Use of Communication Channels for Sharing Mental Models during Concept Generation", Journal of Design and Technology Education, Volume 17, No. 3, 2012, pp 27 – 36.

This chapter demonstrates the influence of sketching as a communication tool for shared understanding during the concept generation stage in design teams. Firstly, the discussion deliberates on communication channels in reaching a shared understanding in the design process. Then, its role in communicating agreement and reaching a shared understanding during the conceptual design stage is deliberated.

Furthermore, this chapter demonstrates an exploratory protocol study on employing various communication channels during design sketching. This study examines how individual designers share their mental models with other designers in a group, and analyse their use of graphical, verbal, and textual communications during concept generation. Our findings suggest that verbal communication is responsible in the sharing of individual mental models during sketching, and supplements textual and graphical communication media. However, design teams can still function without verbal communication and address design problems. They seem to compensate the absence of verbal communication by using 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 simultaneously. 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 to manage the group interactions.

6.1 Introduction

In design teams, sketching has been shown to facilitate design problem formulation and solution exploration in terms of functions and forms (Goldschmidt, 1991; Van Der Lugt, 2002). Therefore, sketching is an important instrument for conceptualization in the early phases of the design process (Fish & Scrivener, 1990). On the other hand, 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).

Individual designers to articulate his/her mental models about the issue and solution spaces to other team members. Nevertheless, these models are usually not clearly described and fuzzy upstream in the design process and require more handling to ensure that the idea is transferable. This task is more difficult when done in a team that has members from different backgrounds. Language, aims, and cultural differences which can contribute to overlapping viewpoints that need to be aligned (Smulders et. al., 2008).

Moreover, when designers communicate in order to reach shared understanding, their verbal explanations are supported by visual representations, and vice versa (Cikis & Ipek Ek, 2010). Nevertheless, our comprehension of the “dialogue” between verbal communication and sketching is limited.

This study first considered the cognitive process that is invoked during sketching when examining this knowledge gap. This study

postulated 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, Ball & Tseng, 2000), and then refines that mental model by adapting it to the new knowledge that has been obtained. We also postulate that the refined mental model will be much more "transferrable" than the rough mental model which forms the foundation for effective design communication.

More specifically, this cognitive process can be articulated according to 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:** Designing is not simply the application of knowledge and methods. Usually, the designer focuses on a specific aspect of a given problem, which he/she identifies and defines according to his/her knowledge and experience. The initial framing of the problem leads to further exploration of uncertainties and contradictions contained within the problem statement, and thus, 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 begin sketching, they seldom intend to visualise the entire issue. Instead, they emphasis on components they highlight according to criteria resulting from the *exploration - interpretation – re-interpretation cycle* such as vague, multifaceted, and entwined components. In these types of situations, creativity is a function that measures 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. **Knowledge gain – knowledge transfer cycle:** Sketching activities of individuals and teams are often accompanied by verbal explanations (Cikis & Ipek Ek, 2010). Communication patterns and design thinking switch between gaining knowledge exchange and transfer (Badke-Schaub & Doerner, 2002). Alternating between knowledge generations and sharing is observed as a primary source of creativity. This supposition proposes that verbalisation is equally as important as visualisation.

6.2 Research questions

Building on this theoretical discussion, this study aims to explore on:

How different communication channels that were used during sketching activity in design teams for sharing mental models?

This aim can be translated to the following hypothesis:

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 the communication process. If the initial problem framing is constrained and the solution spaced 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 the 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.

6.3 Experimental design

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

There were test and control conditions. 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 given task was to create a product that assists blind people to experience cooking. The design brief asked the groups to present a single concept at the end of the experiment. As shown in Figure 15, the experiment had two phases. The first phase was 45 minutes long. The first 5 minutes observed the participants reading the design brief, and in the subsequent 10

minutes, they worked individually to generate their ideas without interacting with their group members. They collaborated as a group and established a final concept during the remaining Phase 1.

After a 10-minute break, the second phase began, which was envisioned as the "stimuli phase." A different set of instructions were offered to the groups, which additionally detailed the goal by indicating "camping" as the setting in which the cooking is conducted. The new instructions also provided pictures of outdoor cooking devices as stimuli. The intention of the stimuli was to restrict the solution space and to enable the process of reaching a mutual covenant. This phase requires the groups to finish the design task in 25 minutes, with 5 minutes for reading the instructions, and 20 minutes for collaborative work.

After the second phase, the groups presented their final idea for 5 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 exercise and the drawn sketches were observed, recorded, and analysed.

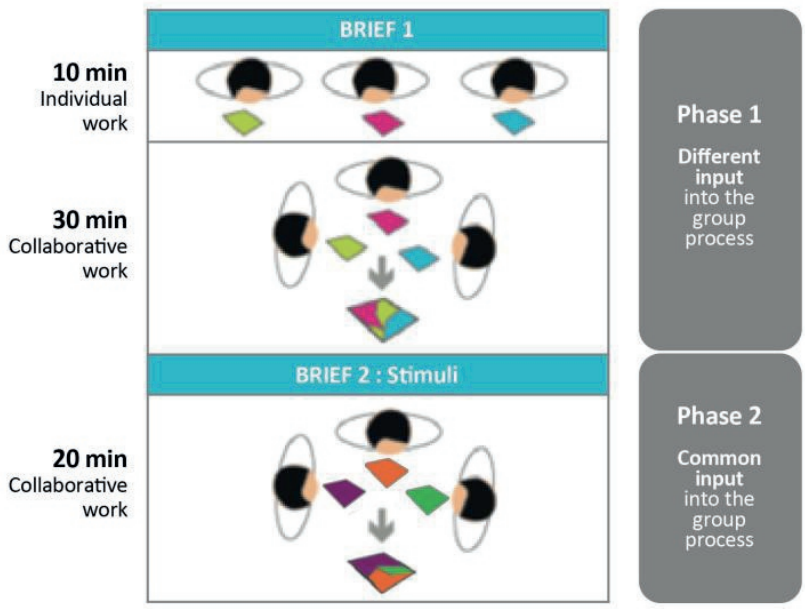


Figure 15. Overview of experiment procedure

6.4 Data analysis

This section discusses the analysis framework used to interpret the sketches that were produced during the experiments. The sketch elements in all sketches were categorised. Each sketch element is viewed as an outcome of a specific type of a sketching 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 16):

1. **Generate:** Introducing basic graphical form and function elements.
2. **Detail:** Articulating the sketch elements under the Generate category.
3. **Explain:** Communicating the meaning of sketch elements under the Generate or Detail categories with graphical and numerical annotations.
4. **Transfer & Exchange:** Communicating the meaning of sketch elements under the Generate or Detail categories with text annotations.

Four sketching activities (Figure 16) were determined to be essential to address the design problem across three theoretical dimensions. Furthermore, as Figure 16 illustrates, a distinction between designing and communicating during sketching was made. Generate and Detail actions were 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.

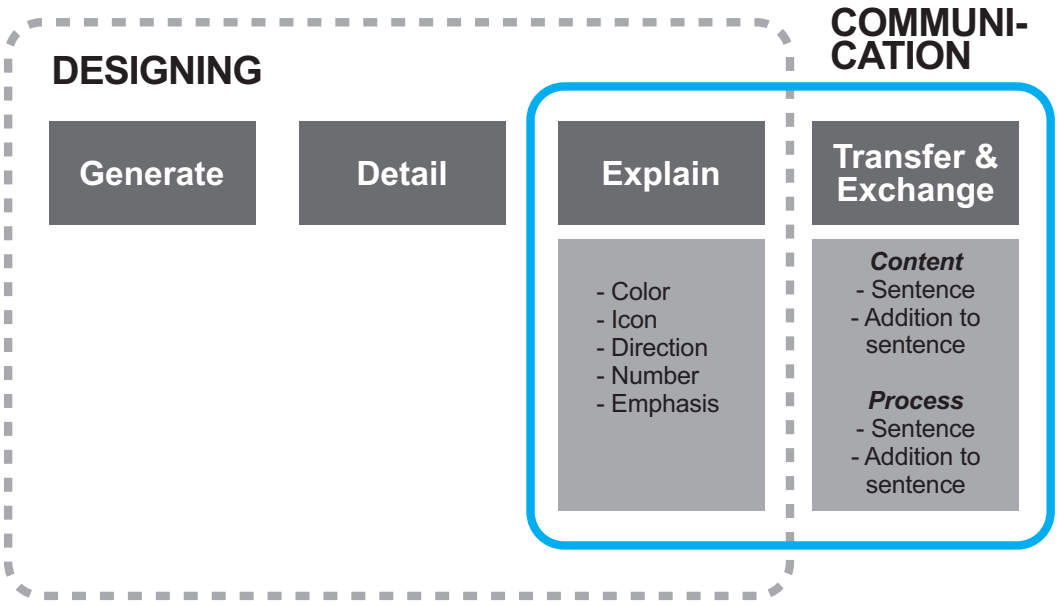


Figure 16. Sketching activity analysis framework

It is important to emphasise that this sketching activity framework is constructed from the perspective of the individual designer. This means that as the individual shares his/her mental model through communication actions, he/she will engage in dialogue 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 a shared understanding during design sketching. In the context of the sketching activity framework illustrated in Figure 16, 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.

This chapter focuses on the Communication dimension of the analysis framework. The dimension consists of Explain and Transfer & Exchange activities. Each activity can result in the creation of several sketch elements.

There are five sketch elements under the Explain category (figure 17): (1) icon, (2) colour, (3) direction, (4) number, and (5) emphasis. They are illustrated with examples from the dataset in Figure 17.

Icon is a graphical symbol that is frequently comprehended within the group. This symbol is employed to determine and articulate complicated elements or relationship in a single element. It can be generally accepted and familiar such as the summation symbol "+", or it can be locally constructed by a group such as a special icon a group created in an experiment to represent blind people.

Colour is frequently utilised to specify meaning. For instance, red represents heat in many different cultures. Direction is a mark that specifies direction (such as an arrow) from one point/area to another point/area on the sketch

Number refers to an arithmetical value, articulated by a word, symbol, or figure, that is utilised to compute, order in a sequence, or to classify.

Emphasis refers to special significance given to a sketch element to highlights its important such as underlining.

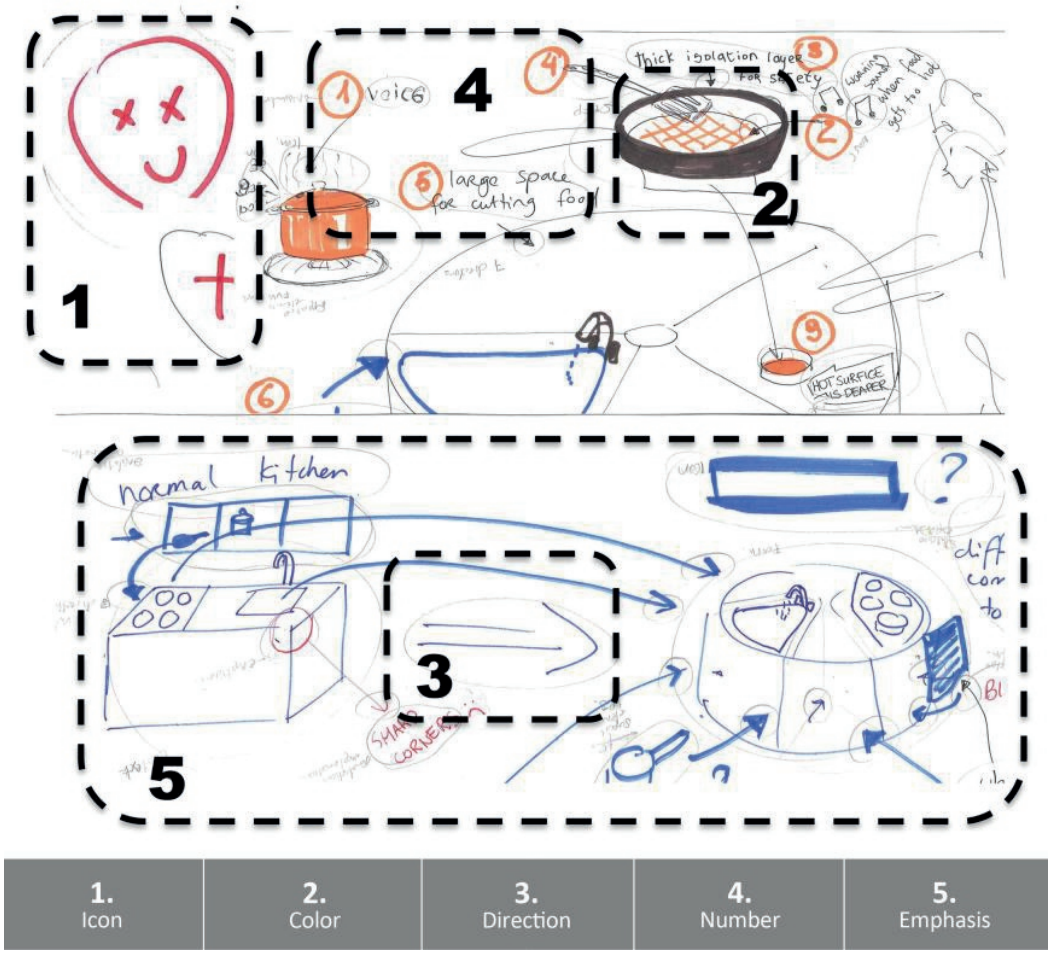


Figure 17. Examples of the five Explain sketch elements from the dataset. Illustrated elements reside in two different sketches.

Figure 18 illustrates the sketch elements under the Transfer & Exchange category with examples from the dataset. These sketch elements are further segregated into two sub-categories: content-related and process-related.

Sentence is a full sentence written in a text format on the sketch. In the content-related dimension, these elements constitute the primary mechanism for written dialogue during which existing sketch elements are discussed and negotiated. In the process-related dimension, they act as a medium for handling issues pertaining to the design process.

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

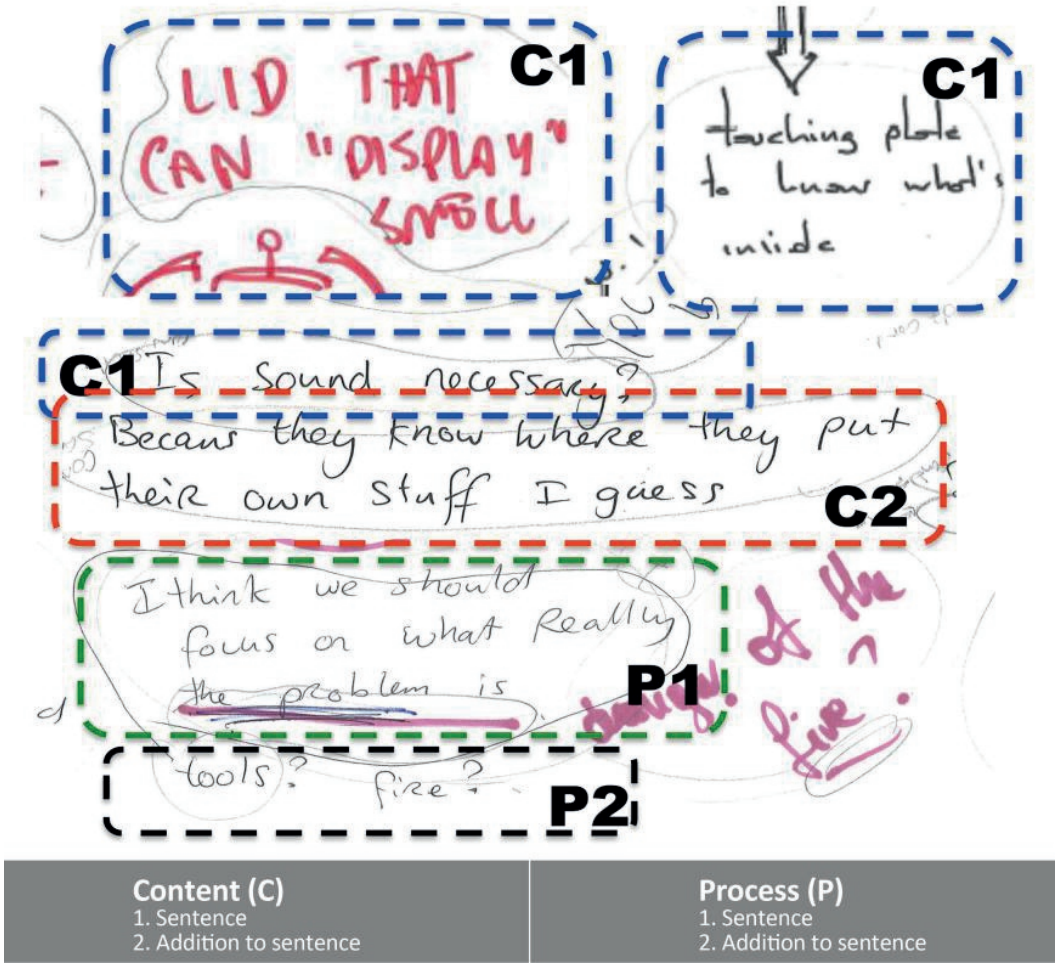


Figure 18. Examples of the four Transfer and Exchange sketch elements from the dataset. Illustrated elements reside in four different sketches.

6.5 Results

This section explains the data analysis results. As previously mentioned, this study emphasises on the sketching activity categories that fall under the Communication dimension.

6.5.1 Communication activities and sketch elements

The researcher collected 60 A3 size paper sheets throughout the experiment. The silent sketching groups used 37 sheets, while the non-silent groups used 23 sheets.

Each element in the sketch was categorized. The elements were coded according to the categorisation scheme presented in Section 6.3. Sketching activities were tallied and summed up per test condition. Table 6 demonstrates the results.

Table 6. Sketching activity counts per Explain and Transfer & Exchange categories for the silent and non-silent experimental conditions

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

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. Nevertheless, when examining patterns between the two phases of the experiment, a chi-squared test of independence was executed to determine if the count differences across conditions constitute statistically significant deviations from the expected values according to the overall occurrence probabilities of the sketch elements.

Figure 19 shows the cumulative Explain activity counts per experimental condition. There were a total of 669 Explain sketch elements. As indicated in Table 6, 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. The frequent use of this element suggests that Direction elements play a key role in explaining the meaning of other sketch elements.

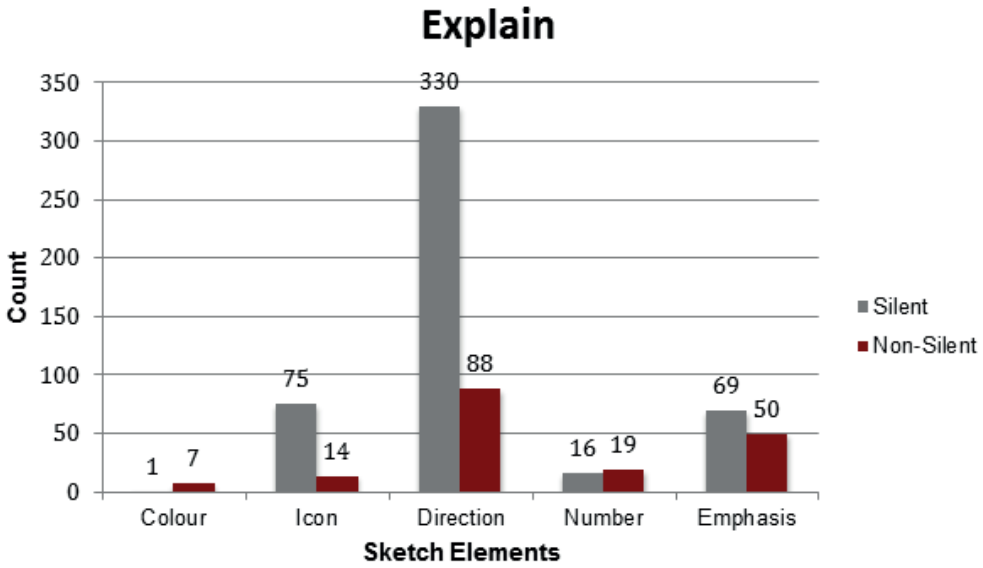


Figure 19. Explain sketch element cumulative counts per experimental condition

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 Explain category, $X2\ (4, 669) = 55.4$, $p<0.001$. 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).

This study also further differentiated the results for the Explain activities 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, deviations from the 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 20 shows the cumulative Transfer & Exchange activity counts per experimental condition. There were 786 *Transfer & Exchange* sketch elements. As indicated in Table 6, 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.

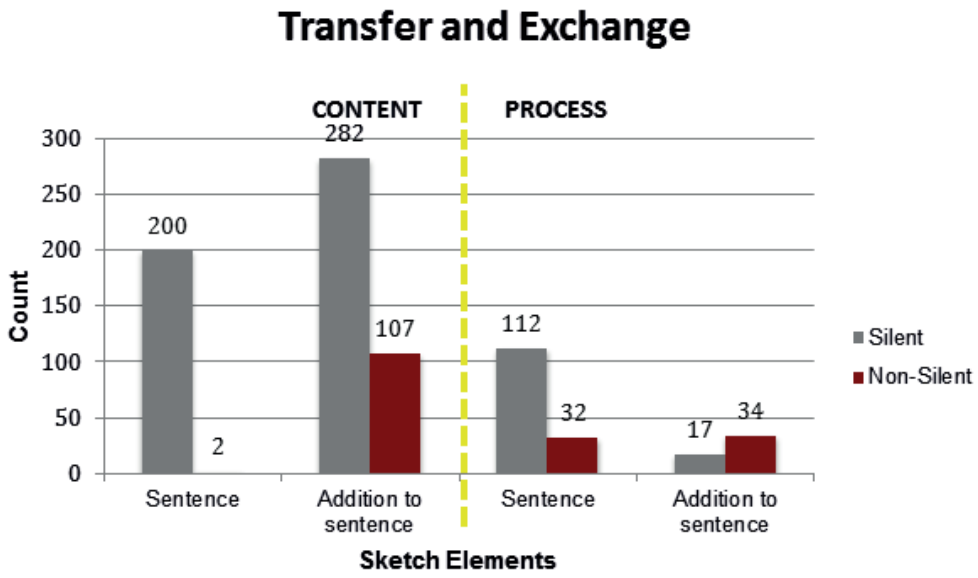


Figure 20. Transfer & Exchange sketch element cumulative counts per experimental condition

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, $X2\ (3, 786) = 117.1$, $p<0.001$. 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. This is because Phase 1,observed *Process-related Sentence* element counts that were significantly higher than expected in the non-silent condition, whereas that trend reversed in Phase 2 (both residuals $p<.05$, two-tailed).

Furthermore, a 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 the *content-related* element counts across the phases were similar (296 vs. 295 respectively).

6.5.2 Survey outcomes

A survey was conducted to gauge the communication medium inclination (graphical, textual, and verbal) of all participants prior to the task. The survey inquired other participants' level of comfort with each medium to convey their ideas. The instrument utilised a 5-point response scale, where 1 represented "not comfortable at all," and 5 represented "very comfortable." The survey also contained an item which inquired if the

participants had received formal sketching training, with “Yes” or “No” options.

The results revealed that all 18 participants had received formal sketching instruction. The survey divulged that all 18 participants have formal experience of learning to sketch. Responses to the communication medium preference items were analysed according to study groups. ANOVA was conducted to identify to identity any significant differences between the groups. The test revealed no significant differences among the six study groups. Hence, this study postulates that communication medium preferences of the participants do not influence the experiment.

6.6 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, this study was unable to test the statistical significance of the difference. Therefore, these results suggest support for the first hypothesis.

However, there were differences in the distribution of sketch elements within the two communication activity categories in each condition. This 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), the groups communicate discriminately with respect to the types of sketch elements used to characterise such communication activities. Although these results suggest support for the first hypothesis, this specifics 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 showed 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. Therefore, if the results were to be normalised with respect to group collaboration time in each phase, 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 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 contributed any significance. Regardless, if the observations are attributable to the intervention, the results counter the second 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 (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 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.

Design students who possess sketching training were involved in this study. Even though this was suitable for the conceptual design task utilised in the study, experienced designers in real-life situations might have varying behaviour. For instance, it has been argued that expert designers maximise sketches more than novices (Goldschmidt, 1991). Moreover, practising designers were identified to be more informative and demonstrated more fixation-resistance compared with novices (Tversky et. al., 2007).

6.7 Conclusions

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 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 concurrently.

The 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 workflow. This understanding is congruent with a previous finding which indicates that sketching in design teams can help to establish shared mental models about the process (Neumann et. al., 2009).

7

The Influence Of Sketching For Reaching Shared Understanding Related To Content, Process And Person

Chapter 7

The Influence Of Sketching For Reaching Shared Understanding Related To Content, Process And Person

This chapter is based on Nik Ahmad Ariff, N.S., Eris, O., & Badke-Schaub (2013). "How Designers Express Agreement: The role of multimodal communication in communicating agreement and reaching shared understanding during conceptual design", Proceeding of IASDR 2013, International Association Society of Design Research, August 26 – 30, 2013, Tokyo, Japan.

This chapter presents a study on the role of verbal communication in reaching a shared understanding during idea generation in design teams. More specifically, our goal is to investigate specific communication actions that designers take in different communication modalities that lead to shared understanding. In order to realise this goal, a quasi-experimental study was conducted with 18 participants, who were in groups of 3. The control groups communicated freely, while the experimental groups were not allowed to use verbal communication. Communication actions that represent agreement were identified and analysed in four different modalities: gestural, verbal, graphical and textual communication. The results suggest that when verbalisation is allowed, groups rely on concepts that are generated primarily by individuals, and do not negotiate the type of shared understanding that leads to the co-creation of new concepts. When verbalisation is not allowed, they are more likely to build on and advance

concepts that are generated by individuals to construct that type of shared understanding and conceptualise collectively.

7.1 Introduction

Designing is a cognitive activity (Thomas & Carroll, 1979; Visser, 2006). Starting with the first step of the design process which is problem framing, designers construct and negotiate mental representations of the problem and its potential solutions. These representations are dependent on the designers' knowledge and expertise. However, since existing knowledge is usually not sufficient for generating a solution, further information must be acquired and integrated into representations. New and often contradicting information must be integrated into the problem-solving process, which requires designers to analyse and adapt their mental representations constantly. The problem and solution representations are interrelated and have direct consequences on the outcome, the product. A variety of complex and uncertain decisions characterise that rich dialogue (Neumann, 2012).

When solving complex design problems, designers engage in several activities. A key activity is framing the problem they are facing. This involves analysing the problem and searching for possible solutions—these two activities are often interlaced (Roozenburg & Eeekels, 1995; Pahl et. al., 2007). Once a satisfactory problem frame has been established, a decision has to be made to select the most appropriate solution among the possible solutions that have been generated. Sketching can play an important role for designers as a representation medium during these activities.

Designers and sketches are always in dialogue as sketching is a central activity while designing (Athavankar, 1997; Heiser et. al., 2004). Sketches are often the designer's medium for visualising, verbalising, and transferring their thinking to oneself and to the team members [Nik Ahmad Ariff et. al, 2012; Nik Ahmad Ariff, Badke-Schaub, Eris, 2012a; Nik Ahmad Ariff, Badke-Schaub, Eris, 2012b]. Sketching also plays a

role in content sharing and specific information processing at both the individual and team levels (Badke-Schaub et. al., 2007).

Sketches are viewed to possess three functions. Firstly, they are an externalisation and analysis mechanism and simplify multi-faceted problems. Secondly, they are mediums of persuasion to "sell" ideas to stakeholders and reassure them that their "situation" is being correctly interpreted. The third function is that it is a communication method to articulate clear information to those involved in the manufacturing, assembly, and marketing of a product (Pipes, 2007).

The literature indicates that sketching is an essential component of the design process (Ullman et. al., 1990). It can also be argued that the use of visual representations provides memory extension, which lowers the cognitive load of designers (Purcell & Gero, 1988). Therefore, designers who sketch during the design process perceive problems as more workable and can infer more relations between components of complex concepts (Sachse et. al., 2004). These findings suggest that sketches support the designer in reaching a better and deeper understanding of his/her own ideas.

Moreover, when sketching as a part of a group, designers use multimodal communication to transfer, communicate, and visualise their thoughts. For instance, sketches themselves consist of graphical and textual information (McGown et. al., 1998; Nik Ahmad Ariff et. al, 2012; Nik Ahmad Ariff, Badke-Schaub, Eris, 2012a; Nik Ahmad Ariff, Badke-Schaub, Eris, 2012b; Ullman et. al., 1990). In addition, gesturing has been identified as an influential activity during collaborative design sketching (Bly, 1988; Tang & Leifer, 1988).

Finally, in group settings, sketching provides a common ground. This leads to a shared focus of attention and contributes to enhanced design collaboration and product performance (Heiser et. al., 2004). Shared sketches serve as a common object of communication and facilitate the interaction among team members.

7.2 Research questions

In this chapter, the following research questions are explored:

1. Are the agreements reached while constructing shared understanding expressed through multimodal communication? If so, what is the interplay among the different communication channels that are involved? Is there a dominant one?

2. What strategies are used by design teams to reach shared understanding while sketching?

Moreover, this study hypothesised that when verbal communication is blocked, other communication channels will be utilised more extensively to express agreement.

7.3 Experimental design

7.3.1 Data collection

Quasi-experimental research was employed to explore the research questions in which 18 participants responded to a design brief group of 3. There were 3 teams in each of the control and test conditions.

In the test condition, which was termed “silent sketching”, participants were not allowed to talk during the design task. In the control condition, which we termed “verbal sketching”, communication was not restricted. The participants were Masters and doctoral students from the Industrial Design Engineering faculty of Delft University of Technology in the Netherlands.

7.3.2 Data assessment

As shown in Figure 21, the experiment consisted of two phases. In the first phase, participants responded to the design brief individually, without any collaboration with other group members for 20 minutes. In the second phase, they continued to work on the same design brief in a team and arrived at one final concept after 50 minutes.

The task was to design a product that will enhance the cooking experience of blind people. At the beginning of Phase 1, they were asked to develop solutions that are novel and different from existing cooking products. At the beginning of Phase 2, they were asked to collaboratively work toward one final concept by the end of the experiment. In Phase 1, they were provided with A3 size paper sheets and coloured markers. In Phase 2, they were provided with A1 size paper sheets, which were meant to facilitate collaborative sketching. Also, they were asked to use the same colour pen throughout the whole exercise. Finally, they were asked to complete a survey about their self-perceived ability to communicate using different media.

All activities were audio and visually recorded using multiple cameras (Figures 22 & 23), observed, and analysed. During the break after Phase 1, the sketches produced by individuals were captured digitally to document their state before Phase 2 in case they might be developed or modified during collaboration.

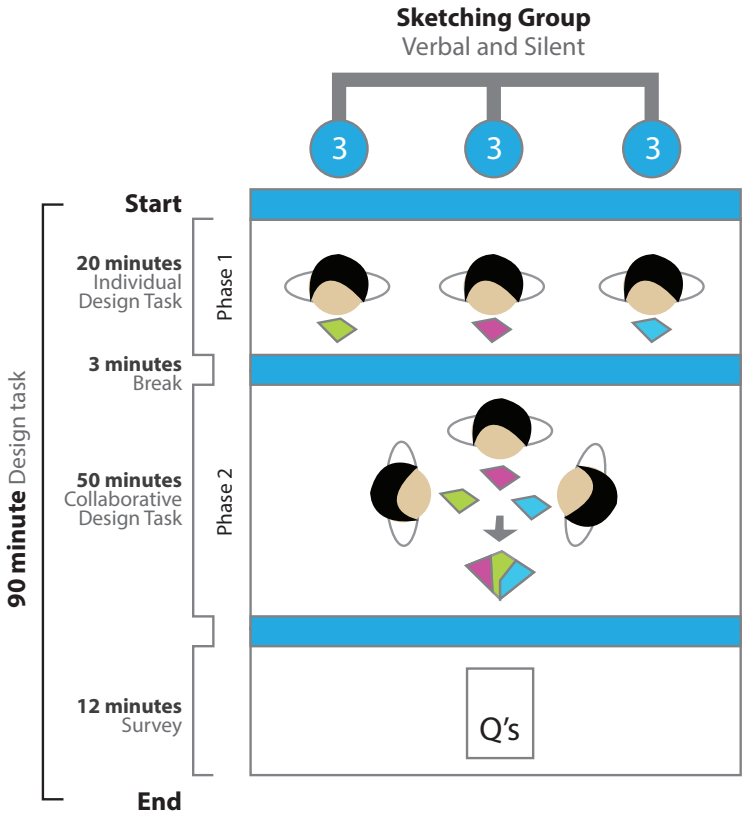


Figure 21. Overview and timeline of the experiment.

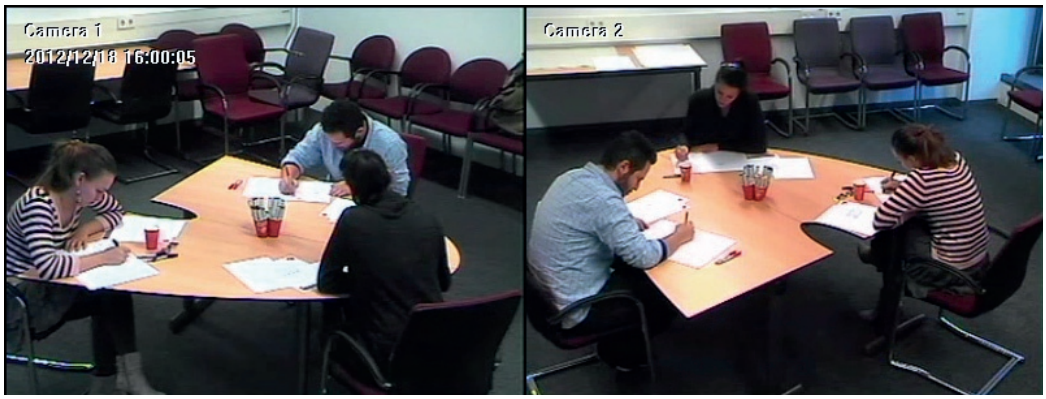


Figure 22. Representative still image from the side cameras

Figure 23. Representative still image from the top camera

7.4 Data analysis: Communication activity categorisation

In order to understand if agreements reached while constructing shared understanding are expressed through multimodal communication, the agreement actions that occurred in the following communication modalities were classified and analysed:

1. Gestural
2. Verbal
3. Graphical
4. Textual

Gestural agreement entails the act of *pointing at sketch elements or at the person who communicated an idea, giving thumbs up, clapping, hugging* or *smiling,* after which no further changes were made to the sketch element under consideration.

Verbal agreement entails saying *yes, yeah, okay, sure, exactly,* or *true,* after which no further changes were made to the sketch element under consideration.

Textual agreement entails writing *okay, yes, true, cool!, done, you are right* on the sketch.

Finally, graphic agreement entails drawing *checkmarks* on the sketch. The specific agreement actions defined above were the outcome of an analysis of all agreement actions that were made during the sessions, constituting an emergent coding scheme. Also, in order to analyse temporal relationships, all observed agreement actions were time-stamped.

7.5 Results

Phase 1 was excluded from the analysis because the study is focused on how design teams reach shared understanding and how agreements are communicated during design collaboration. Statistical analysis was not employed to examine the significant differences between the experimental and control groups. This is attributed to the small number of groups (n=3) in each condition at this stage of the research.

7.5.1 Agreement actions by communication modality

Each agreement was coded according to the communication channel in which it was expressed and was assigned to a time interval based on when it occurred during the collaborative phase – the 50-minute session was divided into five 10-minute intervals.

Table 7 demonstrates the cumulative counts of agreement actions for the verbal and silent sketching groups. The total number of agreement actions was higher in the verbal sketching groups as these groups achieved 669 actions while the silent sketching groups had 114 actions.

Table 7. Cumulative agreement actions by communication modality for verbal and silent sketching groups (Verbal =V; Silent = S)

Time (minute)	Type of agreements							
	Gestural		Verbal		Textual		Graphical	
	V	***S***	***V***	***S***	***V***	***S***	***V***	***S***
10	6	12	52	0	0	0	0	2
20	12	21	148	0	0	2	0	6
30	3	14	111	0	0	4	0	7
40	1	25	204	0	0	2	0	3
50	0	13	132	0	0	1	0	2

This information plotted in Figure 24 illustrates the average of agreement actions per group for each communication modality. When verbal communication was possible, verbal agreement actions were dominant. When verbal communication was blocked, agreement actions were much lower as a whole. This drastic drop in agreement actions in the silent condition suggests that agreement was achieved either more efficiently through non-verbal actions, or to a much lesser extent. Another observation is that verbal groups did not use textual or graphical information to express agreement, whereas silent groups used all available communication modalities (gestural, textual, and graphical).

These results offer preliminary support for our hypothesis which postulated that when verbal communication channel was blocked, other communication modalities were used more to express agreement.

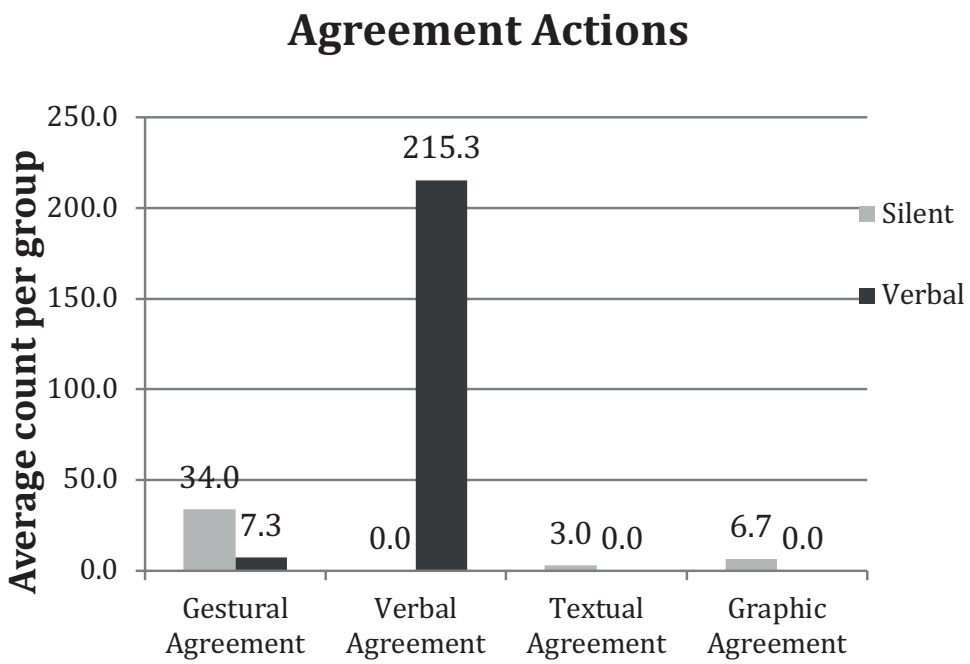


Figure 24. Average agreement actions per group for each communication modality

7.5.2 Agreement actions over time

The large decrease in the total agreement actions in the silent condition prompted us to explore if silent groups expressed agreement more sparingly and efficiently. This refers to situations when communicating agreement was critical. The initial thought of this study was that groups had to express agreement during concept selection, which suggested that the few agreement actions that they took might be toward the end of the session. Therefore, how agreement actions manifested themselves over the course of each session was analysed by assigning each agreement action to a 10-minute interval and plotting the results over time (see Figures 25 and 26).

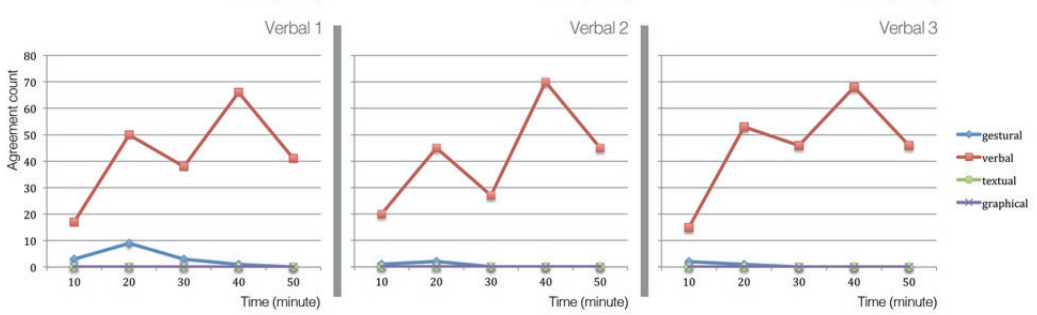


Figure 25. Agreement counts over session time for each verbal sketching group

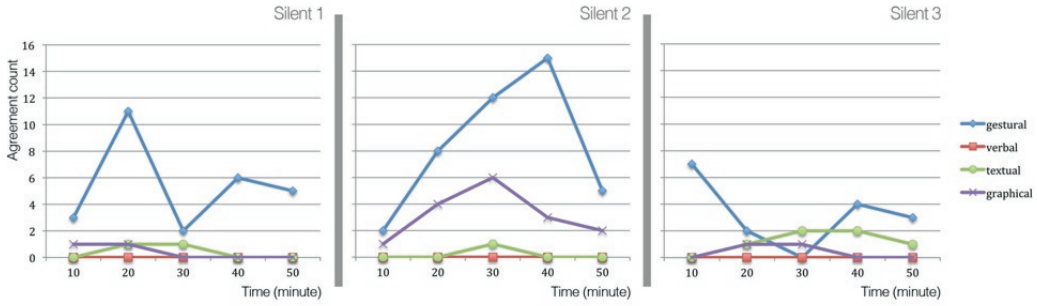


Figure 26. Agreement counts over session time for each silent sketching group

In the verbal groups, verbal agreement actions illustrated an increasing trend over time with declines in the middle and near the end of the session. This trend is surprisingly similar for all three verbal groups. This increasing trend is congruent with the study's premise that more agreement actions are taken toward the end of a session.

It is expected that the trend is more apparent in the silent groups. However, as observed in Figure 26, that was not the case for two of the three silent groups. This finding suggests that the silent groups might have achieved agreement to a much lesser extent than the verbal groups. Consequently, this might have constructed less shared understanding. This result prompted an analysis of the evolution of the sketches' content to assess the extent of synthesis and integration that took place in the group discussion.

7.5.3 Qualitative observation on how design teams reached shared understanding during idea generation in collaboration

An analysis of how sketch contents evolved over time has revealed two different approaches (Figures 28 and 29) for how design teams reached a shared understanding during concept development. These patterns are expressed in terms of four previously identified basic cognitive operations - generation, exploration, comparison, and selection (Stempfle & Badke-Schaub, 2003).

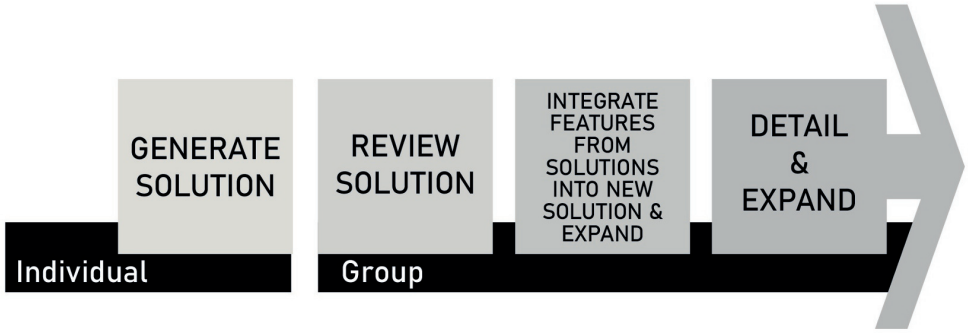


Figure 27. Pattern 1: silent sketching groups in reaching shared understanding

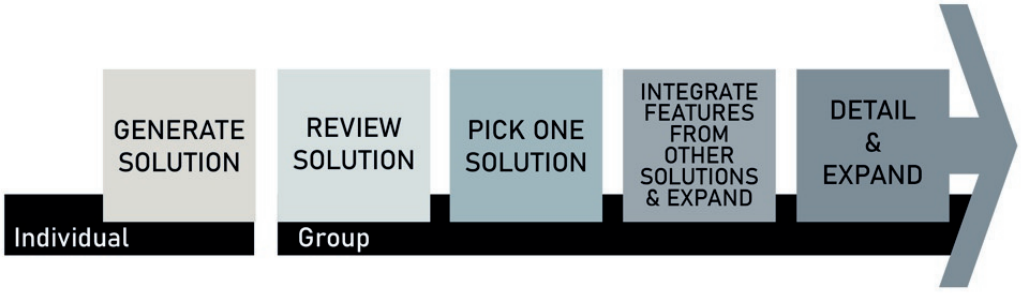


Figure 28. Pattern 2: verbal sketching groups in reaching shared understanding

Pattern 1 is viewed as a representative of the strategy employed by the silent groups, whereas Pattern 2 was viewed as a representative of the strategy employed by the verbal groups. The key distinction between the two approaches is that in Pattern 2, one of the concepts that was developed during the individual ideation phase was chosen and used as a

template for the final solution without significant modifications to the core idea, whereas in Pattern 1, several individual solutions were integrated to finalise an idea that is significantly different from the individual ideas to form the basis for the final solution. This distinction might explain the higher incidence of the agreement actions in the verbal group. At the beginning of the collaborative phase, verbal groups seem to simply default to a concept created by an individual. That does not help them reach a shared understanding as it requires them to renegotiate the concept to integrate features from the other concepts created by the other team members as well to construct a shared understanding.

7.6 Conclusions

The findings supported the study's premise whereby blocking verbal communication encourages designers to rely on other communication channels—gestural, textual and graphical to express agreement on product information under consideration. However, there was a large decrease in the number of total agreement actions. An analysis attributes the decrease to the groups' attempt to integrate each other's thinking with less negotiation when verbal communication was not possible.

Therefore, it seems that verbal communication plays a critical role in negotiating shared understanding and reaching agreement at a complex and integrative manner. This does not mean that the other communication modalities do not play a role. For instance, without drawing, there would be no shared representation to negotiate or reach agreement on, and gesturing seems to communicate additional information during the discussions. However, our preliminary findings suggest that agreement seems to be made explicit primarily through verbal communication during the conceptual design phase.

8

Discussion And Conclusion

Chapter 8

Discussion And Conclusion

This chapter discusses the implications for education and practice, limitations, and recommendations for future research. Thus, this chapter ends with a general conclusion.

Our initial findings suggested that:

1. The silent sketching participants needed more time to understand and produce new ideas in the individual phase of designing.

2. In collaborative work, the participants of the silent sketching group started changing the sketches among them and try to understand each other's ideas. But, in the control group, participants started with the discussion.

3. Instead of verbal talking, the participants' written words on papers became an emergency medium of interaction among the group members in the silent sketching group. Fewer sketches were found during collaborative work.

4. The "aha" moment occurred when the participants started to understand each other's idea(s).

5. During the presentation, the participant that drew the final idea was the one that presented. The implication of this is, they know better about the drawing.

These findings deepened the research scope of this study in examining sketching activities in the design teams and how sketching can create bonding towards sharing mental models of designers. Further analyses will deliver more detailed results of sketching as a medium of communication in different contexts.

8.1 Conclusions

Theoretical framework for reaching shared understanding during sketching in design teams

Sketching is a continuous activity throughout the design task. Detailing, explaining, and transferring activities are built on drawing elements to negotiate and develop the idea(s). This ensures that the ideas are transferrable to the team. Transferring activities can be considered effective when a common understanding of a given idea is established.

Figure 29 illustrates the process that relates the four activity categories – drawing (DTg), detailing (DTg), explaining (EXg), and transferring (TRg). Moreover, figure 29 depicts a cycle (the green arrows) that builds on and revolves around drawing activity (the orange arrows). As the team executed that cycle in an iterative fashion, the level of ambiguity in the drawing elements decreased and the ideas became more concrete. In producing the final concept, four activities were performed in both experimental conditions – silent and non-silent groups. The findings also suggested that the difference denotes to what was happening around the drawing activity.

Figure 29. Framework for reaching shared understanding during sketching in design teams

Comparing the impact of sketching and verbal communication on shared understanding

Sketching is a reliable technique for designers to visualise and transfer their ideas. However, verbal communication is required to ensure the ideas are transferrable and clearer to other designers in a team. Therefore, language is mandatory to transfer details. The results display that although the drawing activity itself creates the foundation of discourse, clarifying, specifying, and transfer activities promote more concrete ideas that are understandable and transferrable within the team. This aligns with the prior outcomes where sketches are identified to contribute to a more cohesive group process (Van Der Lugt, 2005). The findings also show that when verbal communication is blocked, the distinction between drawing and explaining, detailing, and transfer activities becomes clearer.

Thus, team members do not only cultivate collective mental models about the task at hand, but also the process and the team since they must lead their group process appropriately. In order to do this,

a strong comprehension of each other's viewpoints and current works. These findings are in accordance with preceding findings which indicated that common sketching and use of sketches in a team as a common ground could assist in the creation of shared mental models (Neumann et. al., 2009].

A framework was developed based on the outcomes. The framework illustrates the elements that assist in achieving a shared understanding during sketching in design teams that is referred to as the design-communication block (see Figure 30 and Table 8).

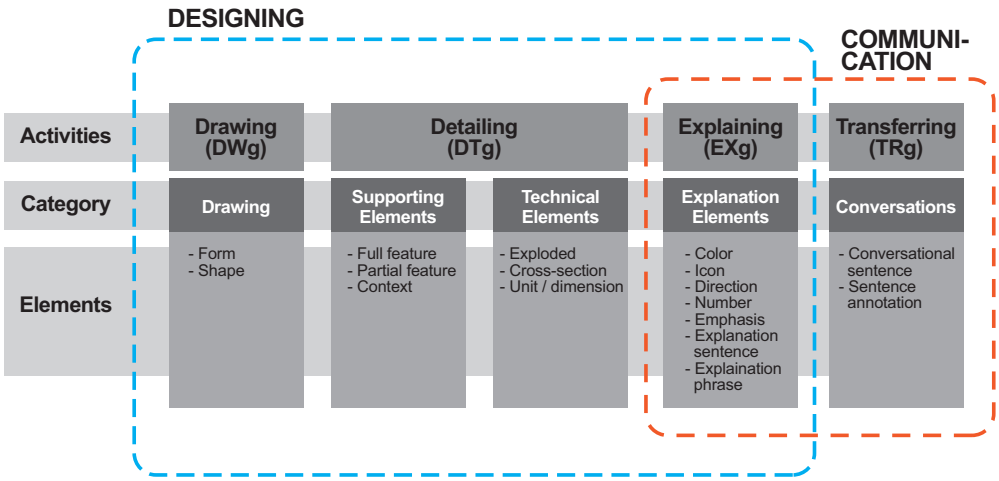


Figure 30. The Design-Communication block framework

Table 8. Categorisation of activities

Activities	Element of Categorisations	Elements
Drawing (DWg) Drawing / sketching on paper.	**Drawing elements:** Elements of a drawing that communicate functionality at the level of a product and have distinct physical forms. (e.g. stove, pot, sink)	**Sketch :** Sketch elements with low level of detail and high level of ambiguity. **Form :** Sketch elements with high level of detail and low level of ambiguity.
Detailing (DTg) Extending/ refining a drawing element through the use of supplemental drawing or technical elements.	**Supporting elements:** Drawing elements that re-visualise and existing drawing element in additional detail.	**Full feature :** An additional and more detailed drawing of an entire existing drawing element. **Partial feature :** An additional and more detailed drawing of a part of an existing drawing element. **Context :** An additional drawing of an entire existing drawing element in a specific context - often to visualize a usage scenario.
	Technical elements: Technical elements that convey a technically detailed understanding of existing drawing elements.	**Exploded :** Exploded view of an assembly that further specifies its geometry. **Cross-section :** Cross sectional view of a part that further specifies its geometry. **Unit / dimension :** Value and/or units of technical parameters such as length (mm) or 10mm.
Explaining (EXg) Annotating existing drawing elements with graphical, numerical or textual information to clarify their meaning.	**Explanation elements:** Elements that clarify the meaning of existing drawing elements in the form of annotations.	**Color :** Use of color to indicate meaning (e.g. Red is hot). **Icon :** A graphical symbol commonly understood within the group that is used to identify or communicate meaning. Can be very general such as the addition symbol "+", or can be internal to the group such as creating an icon to represent *blind people*. **Direction :** Lines that indicate direction (e.g. Arrow) from one point/area to another point/area on the drawing. **Number :** An arithmetical value, expressed by a word, symbol, or figure that is used to calculate, order in a series, or to identify. **Emphasis :** Special importance or prominence given to a drawing element such as underlining. **Explanation Sentence :** A note written in a form of a sentence to further explain a drawing element. **Explanation Phrase :** A brief textual annotation used to explain a drawing element.
Transferring (TRg) Carrying out a conversation to establish common understanding within the group around the drawing elements.	**Conversation elements:** Elements enable written communication on the meaning of existing drawing elements.	**Conversational Sentence :** A note written in the form of a sentence to further explain a drawing element. **Sentence Annotation :** A brief textual annotation used to explain a conversational sentence.

Analysing the implications and influences of sketching to individual and team contexts

This study suggests that verbal communication is essential in the sharing of individual mental models during sketching. It complements graphical and textual communication channels. However, design teams are able to work without verbal communication and generate solution ideas for design problems. They seem to compensate for the absence of the verbal

communication channel by using graphical and textual channels more, and relying on a different communication structure. A natural and arguably more desirable interaction utilises all three channels simultaneously.

Another suggestion is 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 to manage group interactions. Therefore figure 31 shows the relationship of visual and verbal representations.

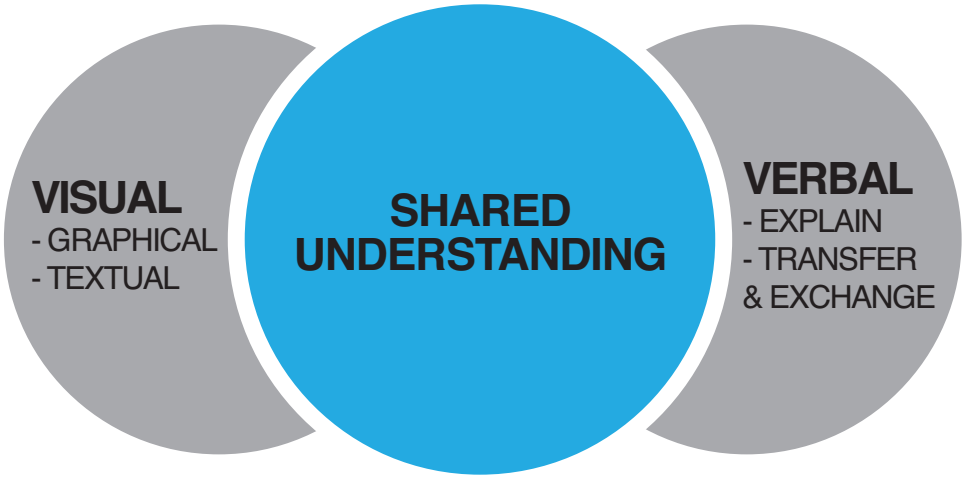


Figure 31. The relationship of visual and verbal representations

As conclusion, this research findings revealed that, other than verbal, sketching is also a mode of communication among designers. Designers use sketches to visualise their thinking process at individual level as well as during collaboration with other team members. Conversely, when both visual and verbal representations emerge together at the same time, the sharing of mental models of a design team become well communicated, and concreting the knowledge transfer meaning that lead to a shared understanding among the team members. Here, it is shown that visual and verbal representations are symbiosis with each other.

As indicated in figure 31, verbal consists of information related to explanation, transfer and exchange of a designing task while visual consists of graphical and textual image. Furthermore, both representations always carry the information related to the discussion of process and contents of a specific design task to achieved a shared understanding.

8.2 Limitations and recommendations

The main aim of this study is to examine the role of sketching as a communication tool to attain a shared understanding during concept generation in a design team. The studies that were conducted reported that it provides many advantages. However, it has some limitations that are linked to its exploratory nature.

Measuring performance

This study mainly focuses on the role of sketching as a communication tool for design teams. This study wants to look into how sketching can help the design team to reach a shared understanding among the team members and finalised one complete solution that is agreed upon among them at the conceptual design phase. The studies conducted were a good start for measuring the uniqueness and strength of sketching as a communication tool for design teams. However, how sketching affects individual and group performances was not examined in this study. Still, sketching itself creates an important interplay between designers' ability to sketch and the ability to visualise (Yang, Maria & Jorge, 2007). Thus, future studies are recommended to assess how sketching can affect the performance of the designers in individual and group setups.

Controlled research setting

Our experiments are setup in a quasi-experiment condition. In all experiments, the control group is known as the verbal sketching

group while the experimental group is known as the silent sketching group. The silent sketching groups were conditioned as a group of 3 designers that were not allowed to talk during the designing process. There is no restriction for the verbal sketching groups. This is due to our main goal of this study which was to find out how sketching can be communicated among the design teams in order to attain a shared understanding at the conceptual phase. With that, this condition can be the best way to determine the uniqueness and strength sketching as a tool for designers.

Expert designers

All studies were conducted with postgraduate students (Masters and PhD) as the subjects in the experiments. Although it was ensured that experienced postgraduate students participated in the design tasks, the result might not be generalisable to all designers. Expert designers might act differently as they are likely to be more confident about their ideas. For example, they might need fewer discussions. Also, they might come up with qualitatively better ideas at the conceptual stage of designing and they might be better in distinguishing good ideas from bad ones through experience, and their process might evolve differently. However, it is believed that the general process that expert designers go through is likely to be the same as described in our studies, but that expert designers go through the process in a different manner. They might be faster, go into more depth, or differentiate more. Although the results might not be generalised to expert designers, the mechanisms that were identified in the individual and the team processes should be alike.

Recommendation for future research

The previously identified limitations identified several areas for further research which are recommended for future research.

Performance measures

The need for measuring performance through sketching is an interesting topic to be developed and revealed. As mentioned in the literature, sketching is a very unique mode of communication tool for designers that consist of valuable input to be shared while working individually and in the team context.

Novice vs expert designers

The framework and method presented in this study could help to identify the differences between novice and expert designers in general, and how they develop sketching as a communication tool to obtain sharedness in design teams at the conceptual stage. Although research has proven that expert designers work differently compared to novices (Ahmed, Wallace, & Blessing, 2003; Cross, 2004; Lawson & Dorst, 2009), little is known how this influences teamwork. Further research could help to investigate better how expert knowledge is used within a team. For example, novice designers might need more team cohesion than expert designers as they are less secure about their contributions.

This research provided an approach for studying the role of sketching as a communication tool at the conceptual design stage in design teams. Based on the theoretical framework in Chapter 2, the development of sketching as a tool in design teams at the conceptual design stage was commenced. Based on five empirical studies and the transformation of the tool, several lessons were identified as follows:

1. Sketching is a vital aspect of the conceptual design stage at individual and team setups. This is not only because sketching is the preferred form of representation of designers, but also sketches function as a communication tool to reach a shared understanding among designers.

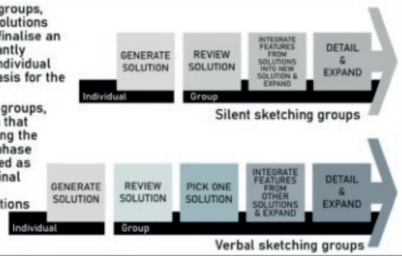
2. Design research can gain a lot by adapting research methods from other fields like social sciences as these methods help to formulate conceptualisations about what happens during the design process. Such approaches contribute to maturity in design research by shifting from descriptive studies to theory testing.

3. Sharedness about the design process is important for successful designing. Even when no specific design method is applied in a project, designers should ensure that all team members share their views on the process.

Table 9 summarizes the research questions and the findings from this PhD studies.

Finally, it is hoped that this study is an initial step for a better understanding of individuals and teams engagement in designing. Although some results can only be generalised to novice designers or different design phases, this approach offers well-formulated and operationalised concepts that can be used to conceptualise designing. This study strongly believes that such concepts will enrich the literature by enabling researchers to share their views better.

Table 9. Summary of research findings

MAIN RESEARCH QUESTIONS	SUB-RESEARCH QUESTIONS	RESULTS	CHAPTER
How does sketching influence the design process when working in design teams?	How will the sketching process be changed if verbalisation during sketching activity is limited?	Restriction of verbal description promoted the substitution of utilising explanation sentences, conversation sentences, and explanation phrases to clarify ideas and confer their definitions. Moreover, the explanation sentences, conversation sentences, and explanation phrases constructed by the silent groups are more comprehensive than the ones formed by the non-silent group.	4
	How are ideas transferred within a design team when verbal communication is blocked?	The detailing process during sketching primarily signifies to elements of explanation, and conversation to transfer, and share ideas within the team when speaking is not permitted. The inclusion of these elements in the drawings creates more concrete, transferrable, understandable ideas within the team.	5
	Are the agreements reached while constructing shared understanding expressed through multimodal communication? If so, what is the interplay among the different communication channels that are involved? Is there a dominant one?	Blocking verbal communication encourages designers to rely on other communication channels—gestural, textual and graphical to express agreement on product information under consideration. However, there was a large decrease in the number of total agreement actions. An analysis attributes the decrease to the groups' attempt to integrate each other's thinking with less negotiation when verbal communication was not possible.	7
How does sketching influence the way of collaboration in design teams?	What role does verbal communication play for sketching activity?	To ensure that the ideas are more transferrable and clearer to the other designers in a team, verbal communication is necessary. Language is a necessity to transfer details. However the detailness of the subject matter of the discussion are more clear when sketching is taking place.	4
	How does information and knowledge transfer change during sketching if verbal communication is blocked?	The usage of form and function element in the sketches are more detail. However, the detailness of explaining the function via sketches had became the choices for the information and knowledge transfer when verbal communication is blocked.	5
	How different communication channels that were used during sketching activity in design teams for sharing mental models?	Verbal communication clearly 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 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 concurrently.	6
	What strategies are used by design teams to build a shared understanding while sketching?	In Silent sketching groups, several individual solutions were integrated to finalise an idea that is significantly different from the individual ideas to form the basis for the final solution. In verbal sketching groups, one of the concepts that was developed during the individual ideation phase was chosen and used as a template for the final solution without significant modifications to the core idea. 	7

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Appendix A | **Design Brief**

Brief V01

On behalf of the "Sketchers" team I want to thank you for participate in this experiment as part of our SPD Research Project. This project focus on the role of sketch in the creative process.

This experiment will consist in two parts. In this first part of the experiment and after read this brief, we ask you to work 10 minutes individually and then 20 min collaborately so you can share your ideas with your group to come up with one final concept idea. After this part we will have a 10 minutes break... Let's start!

Design competition.

The *Comfort inside Design* company is organizing a brand new design competition: "blindness and cooking." After many years in designing cooking equipment, a new challenge is available for development.

How do we can help blind people to enjoy the simply daily joy of cooking?

The theme of the competition is to design products which help blind people to utilize cooking experience. The design concepts are selected according to form, and emotional aspects of the product; the designs are considered for their degree of innovation, aesthetic qualities, functionality and usefulness in addition to human interaction.

Welcome Again!
This is the second part of this experiment. You will have 20 minutes to work with your group and 5 more minutes at the end of the session to present the final conceptual idea.

***Chinook Cookware* is interested in our effort and want for us to investigate the concept of how blind people can perform in camping sites. In particular Chinook Cookware invite us, to include into their product line, products related to cooking experience for blind people in camping sites. Due the late announcement it will be another deadline for the participants in order to elaborate and finalize their concepts.**

These are some cooking tools that already exist on the market to use it in camping context.

Thank you for participating in this study, which investigates the conceptual design process. The study consists of two phases.

The 1st Phase entails individual work. After reading this introduction, you will have 15 minutes to respond to a design brief by sketching potential solutions.

In the 2nd Phase, you will work with two other designers for 35 minutes. You can share the concepts you created by yourself with your teammates to seed the team discussion. Your team's goal will be to produce one final concept.

After you finalize a solution as a team, there will be a 5 minute break during which we will photograph your final concept for documentation purposes.

You will then have 5 minutes to decide how you want to present your final concept to us, and another 3 minutes to present it.

Finally, you will be asked to respond to a short paper-based survey.

The study will take a total of 90 minutes.

In order for us to better analyze the activity for research purposes, the room contains videotaping equipment.
We are not interested in judging the performance of individuals, so this is not a test. However, if you would rather not be videotaped, let us know.

Design Brief

Design a product that will enhance the cooking experience of blind people. Pay particular interest to novelty, and aim to develop solutions that differ significantly from existing cooking products.

Please use same the pen throughout the exercise.

Apart from that, feel free to use any of the materials provided to express and develop your concepts.

Welcome again!

You are now in the Collaborative Phase.
You have 35 minutes to work as a team.

In order to seed the team discussion, you can share the sketches you created individually with your teammates.

Your team's goal is to produce one final concept by the end of this phase.

After you finalize a solution as a team, there will be a 5 minute break during which we will photograph your final concept for documentation purposes.

You will then have 5 minutes to decide how you want to present your final concept to us, and another 3 minutes to present it.

Before you continue, please note the following new information regarding the design task.

Design Brief Update

**New user information have become available,
which points at a specific usage scenario as a significant opportunity.**

**During the rest of the exercise, design for blind people
who cook during a camping trip.**

Design Brief

Design a product that will enhance the cooking experience of blind people.

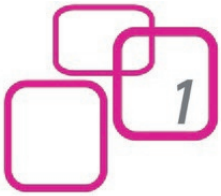
Try to develop solutions that are novel and different from existing cooking products.

Please use the same pen throughout the exercise.

When sketching your final concept, please use the plain thicker A2 paper.

Apart from that, feel free to use any of the materials provided to express and develop your concepts.

Appendix B | **Instructions**



Instruction

Thank you for participating in this study, which investigates the conceptual design process. The study consists of two phases.

The 1st Phase entails individual work. After reading this introduction, you will have 15 minutes to respond to a design brief by sketching potential solutions.

In the 2nd Phase, you will work with two other designers for 40 minutes. You can share the concepts you created by yourself with your teammates to seed the team discussion. Your team's goal will be to produce one final concept.

After you finalize a solution as a team, there will be a 5 minute break during which we will photograph your final concept for documentation purposes.

You will then have 5 minutes to decide how you want to present your final concept to us, and another 3 minutes to present it.

Finally, you will be asked to respond to a short paper-based survey.

The study will take a total of 90 minutes.

In order for us to better analyze the activity for research purposes, the room contains videotaping equipment.
We are not interested in judging the performance of individuals, so this is not a test. However, if you would rather not be videotaped, let us know.

Instruction

Welcome again!

You are now in the Collaborative Phase.
You have 40 minutes to work as a team.

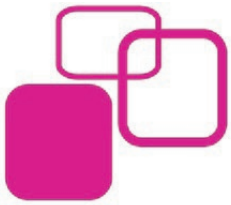
In order to seed the team discussion, you can share the sketches you created with your teammates.

Your team's goal is to produce one final concept by the end of this phase.

After you finalize a solution as a team, there will be a 5 minute break during which we will photograph your final concept for documentation purposes.

You will then have 5 minutes to decide
how you want to present your final concept to us, and another 3 minutes to present it.

Before proceeding, please note that there is new information regarding the design task.



Instructions

Thank you for participating in this design exercise, which investigates the design process. The exercise has two parts.

In the 1st Part, you will have 20 minutes to individually respond to a design brief by sketching as many solutions as possible.

In the 2nd Part, you will work with two other designers for 50 minutes. Feel free to share the concepts you created in the 1st Part to seed the group discussion.

At the end of the 2nd Part, you need to deliver a final sketch of the one concept that you think is the best solution you came up with as group.

After the exercise, you will be asked to respond to a short questionnaire.

For the purposes of the study, we ask that ***you do not speak with each other*** throughout the exercise. However, you are free to draw or write anything on paper. If you write, please do so in English.

The study will take a total of 90 minutes.

In order for us to better analyze the activity for research purposes, the room contains videotaping equipment. We are not interested in judging the performance of individuals, so this is not a test.

This activity is for research purposes only.

Silent groups

Instructions

Thank you for participating in this design exercise, which investigates the design process. The exercise has two parts.

In the 1st Part, you will have 20 minutes to individually respond to a design brief by sketching as many solutions as possible.

In the 2nd Part, you will work with two other designers for 50 minutes. Feel free to share the concepts you created in the 1st Part to seed the group discussion.

At the end of the 2nd Part, you need to deliver a final sketch of the one concept that you think is the best solution you came up with as group.

After the exercise, you will be asked to respond to a short questionnaire.

The study will take a total of 90 minutes.

In order for us to better analyze the activity for research purposes, the room contains videotaping equipment. We are not interested in judging the performance of individuals, so this is not a test.

This activity is for research purposes only.

Verbal groups

Appendix C | **Survey**

Name :.....
Gender :.....
Age :.....
Academic Qualification :.....

Please rate your agreement or disagreement with the following statements using the indicated 5-point scale.

Circle the appropriate response on each line.

(5) Strongly agree
(4)
(3)
(2)
(1) Strongly disagree

In general:

1.	I am skilled at communicating my ideas by sketching.....	1	2	3	4	5
2.	I am skilled at communicating my ideas by writing.....	1	2	3	4	5
3.	I am skilled at communicating my ideas by talking.....	1	2	3	4	5
4.	It is important to be truthful.....	1	2	3	4	5
5.	Creative thinking is one of my strengths.....	1	2	3	4	5
6.	Things people say can be shown to be true or false.....	1	2	3	4	5
7.	I don't like it when others think what I say is false.....	1	2	3	4	5
8.	I am confident in my leadership skills.....	1	2	3	4	5
9.	When solving a problem, making false statements is not productive.....	1	2	3	4	5
10.	When solving a problem, not focusing on discovering the truth can be advantageous.....	1	2	3	4	5
11.	I am confident in my communication skills.....	1	2	3	4	5
12.	One does not always have to tell the truth.....	1	2	3	4	5
13.	I am skilled at solving problems that have multiple solutions.....	1	2	3	4	5
14.	Saying things that do not make sense is foolish.....	1	2	3	4	5
15.	I am confident in my ability to perform in teams.....	1	2	3	4	5
16.	Any situation can be interpreted in multiple ways.....	1	2	3	4	5
17.	I am experienced in designing products for visually impaired people.....		Yes		No	

During the session :

18.	I recognized differences in knowledge among the group.....	1	2	3	4	5
19.	I recognized differences in beliefs and preferences among the group.....	1	2	3	4	5
20.	When explaining my views, I made an effort to clarify the terminology I used....	1	2	3	4	5
21.	By the end of the meeting, we shared a common understanding of the topics we discussed.....	1	2	3	4	5
22.	Participants inquired about my viewpoint on the topics we discussed.....	1	2	3	4	5
23.	When I thought I had a distinct understanding of a topic, I was able to communicate it.....	1	2	3	4	5
24.	I felt comfortable in expressing my opinion.....	1	2	3	4	5
25.	We reached consensus on the meeting outcomes.....	1	2	3	4	5
26.	We integrated the different viewpoints into the representations (or meeting outcomes).....	1	2	3	4	5
27.	I was able to influence the representations created by the group.....	1	2	3	4	5
28.	I was able to influence meeting outcomes.....	1	2	3	4	5

Appendix D | **Flyer**

Summary

This thesis explores the role of sketching as a communication tool for reaching shared understanding during concept generation in design teams. The thesis compiles 5 studies involving groups of designers from Delft University of Technology postgraduates. The first study was conducted with Master students of Industrial Design Engineering at Delft University of Technology, the Netherlands. The experiment was made up in as two conditions – termed as verbal and silent sketching groups. The experimental treatment groups were not allowed to talk during the design process, while the control groups did not receive any restrictions. The experiments were recorded, the data were transcribed, categorised and analysed. At this phase, the research aims to contribute to a better understanding of how sketching affects creativity and quality of the final outcome, and in how far sketching enhances the value of idea development in design.

Chapter 2 consists of an analysis of relevant literature related to sketching, cognition, mental models, shared understanding and communication. Later, this analysis is used to combine the findings of different fields as basis to build up a theoretical background related to the added value of sketching in individual and in teams settings when reaching shared understanding.

Chapter 3 explains the research methodology and the empirical approach of this study. The method focuses on examining sketching in the conceptual design phase and to identify suitable steps to enhance the positive impact of sketching. Two main research questions with sub-research questions and its studies are elaborated.

Chapter 4 analyses the relationship between sketching and communication in teams throughout the idea generation process in the early concept generation. Here the focus is on the understanding of the role of sketching that can be utilised as a communication medium. Sketching is a reliable tool for designers

to visualise and communicate individually and in teams. Furthermore verbal communication is necessary in any collaborative environment. It is very likely that the combination of sketching and verbal representations lead to better outcomes.

Chapter 5 examines the communication processes throughout sketching in design teams. Two frameworks are proposed in this chapter. Although verbal representations is needed during the design process, sketching cannot be neglected. Sketches are rich with detailing that consist of elements of explanation and conversation to transfer.

Chapter 6 reports the results of the exploratory study on the use of diverse communication channels during sketching. The main focus is on the question on how individual designers allocate and transfer their mental models among other designers in the group. Their usage of textual, verbal, graphical communication are analysed during concept generation. The findings propose that verbal communication contributes during the sharing process and supplements textual and graphical communication channels. However, design teams can still function without verbal communication and address design problems as well as producing solution(s).

Chapter 7 further expands the analysis of verbal communication role in reaching shared understanding during idea generation in design teams. Specifically, the interest was on the investigation of specific communication actions that designers take in different communication modalities that lead to shared understanding. In this final analysis, I look at what and how the characteristic of silent and verbal sketching groups during the design process. The pattern of how to reach shared understanding is established and other communication channels are highlighted.

Chapter 8 concludes all findings from this research. Limitations of this study and recommendations for future research are elaborated.

Finally, the main contributions of this thesis are concluded as below:

1. A theoretical framework for reaching shared understanding during sketching in design teams has been developed.
2. A comparison of the impact of sketching and verbal communication on shared understanding has been done in order to understand the different input from verbal and visual representation.
3. Investigating the role of sketching process in conceptual stage.
4. An analysis of the implications and influences of sketching on individual and team's context has brought up a better understanding of the development of shared mental models in design teams.

Samenvatting

Dit proefschrift onderzoekt de rol van schetsen als communicatiemiddel voor het bereiken van gedeeld begrip tijdens het genereren van concepten in ontwerpteams. In het proefschrift zijn 5 onderzoeken samengebracht met groepen ontwerpers van postdoctorale studenten van de TU Delft. De eerste studie is uitgevoerd met masterstudenten Industrieel Ontwerpen aan de Technische Universiteit Delft, Nederland. Het experiment bestond uit twee condities: verbale en stille schetsgroepen. De experimentele behandelgroepen mochten tijdens het ontwerpproces niet praten, terwijl de controlegroepen geen beperkingen kregen. De experimenten werden geregistreerd, de gegevens werden getranscribeerd, gecategoriseerd en geanalyseerd. In deze fase beoogt het onderzoek bij te dragen tot een beter begrip van hoe schetsen de creativiteit en kwaliteit van het uiteindelijke resultaat beïnvloedt, en in hoeverre schetsen de waarde van idee-ontwikkeling in ontwerp vergroot.

Hoofdstuk 2 bestaat uit een analyse van relevante literatuur met betrekking tot schetsen, cognitie, mentale modellen, gedeeld begrip en communicatie. Later wordt deze analyse gebruikt om de bevindingen van verschillende vakgebieden te combineren als basis om een theoretische achtergrond op te bouwen met betrekking tot de meerwaarde van schetsen in individuele en in teamverband bij het bereiken van gedeeld begrip.

Hoofdstuk 3 legt de onderzoeksmethodologie en de empirische benadering van deze studie uit. De methode richt zich op het onderzoeken van schetsen in de conceptuele ontwerpfase en het identificeren van geschikte stappen om de positieve impact van schetsen te vergroten. Twee hoofdonderzoeksvragen met deelonderzoeksvragen en de onderzoeken daarvan worden uitgewerkt.

Hoofdstuk 4 analyseert de relatie tussen schetsen en communicatie in teams gedurende het hele proces voor het genereren van ideeën in de vroege conceptgeneratie. Hier ligt de focus op het begrijpen van de rol van schetsen

die kan worden gebruikt als communicatiemedium. Schetsen is een betrouwbare tool voor ontwerpers om individueel en in teams te visualiseren en te communiceren. Bovendien is verbale communicatie noodzakelijk in elke samenwerkingsomgeving. Het is zeer waarschijnlijk dat de combinatie van schetsen en verbale representaties tot betere resultaten leidt.

Hoofdstuk 5 behandelt de communicatieprocessen tijdens het schetsen in ontwerpteams. In dit hoofdstuk worden twee kaders voorgesteld. Hoewel tijdens het ontwerpproces verbale representaties nodig zijn, kan schetsen niet worden verwaarloosd. Schetsen zijn rijk aan details die bestaan uit elementen van uitleg en conversatie om over te dragen.

Hoofdstuk 6 rapporteert de resultaten van het verkennende onderzoek naar het gebruik van diverse communicatiekanalen tijdens het schetsen. De belangrijkste focus ligt op de vraag hoe individuele ontwerpers hun mentale modellen toewijzen aan en overdragen aan andere ontwerpers in de groep. Hun gebruik van tekstuele, verbale, grafische communicatie wordt geanalyseerd tijdens het genereren van concepten. De bevindingen suggereren dat verbale communicatie bijdraagt tijdens het deelproces en een aanvulling vormt op tekstuele en grafische communicatiekanalen. Ontwerpteams kunnen echter nog steeds functioneren zonder verbale communicatie en ontwerpproblemen aanpakken en oplossing (en) produceren.

Hoofdstuk 7 breidt de analyse van de verbale communicatierol verder uit bij het bereiken van gedeeld begrip tijdens het genereren van ideeën in ontwerpteams. Specifiek ging de interesse uit naar het onderzoeken van specifieke communicatieacties die ontwerpers nemen in verschillende communicatiemodaliteiten die leiden tot gedeeld begrip. In deze eindanalyse kijk ik naar wat en hoe het kenmerk is van stille en verbale schetsgroepen tijdens het ontwerpproces. Het patroon om tot gedeeld begrip te komen is vastgesteld en andere communicatiekanalen worden benadrukt.

Hoofdstuk 8 sluit alle bevindingen van dit onderzoek af. Beperkingen van deze studie en aanbevelingen voor toekomstig onderzoek worden uitgewerkt.

Ten slotte worden de belangrijkste bijdragen van dit proefschrift als volgt geconcludeerd:

1. Er is een theoretisch raamwerk ontwikkeld om tijdens het schetsen in ontwerpteams tot gedeeld begrip te komen.
2. Een vergelijking van de impact van schetsen en verbale communicatie op gedeeld begrip is gedaan om de verschillende input van verbale en visuele representatie te begrijpen.
3. Onderzoek naar de rol van het schetsproces in de conceptuele fase.
4. Een analyse van de implicaties en invloeden van schetsen op de individuele en teamcontext heeft geleid tot een beter begrip van de ontwikkeling van gedeelde mentale modellen in ontwerpteams.

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I wish to express my sincere gratitude and appreciation to my supervisor Professor Dr. Petra Badke-Schaub for her invaluable guidance, encouragement, helps, support and patience throughout this study. You are always have been the one that trust in my research. I remember you were endlessly motivating me and having confidence in me and my research that my research is very interesting, having significance value in the design field and it is an unfortunate if my research is not been concluded. Also, I am grateful to Associate Professor Dr. Ozgur Eris for his helps, indispensable advice, suggestions and also for assisting me in my research work during the study. Not to forget, I am grateful to have Prof. Dr. Katja Thoring as my second supervisor for her guidance, suggestions and also for assisting me throughout my research work especially on the last part of this study. A million thanks also to the Dean of Faculty of Industrial Design, Prof. Dr. Ena Voute for making my research journey smooth and fruitful.

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About The Author

Nik Shahman bin Nik Ahmad Ariff was born on April 30th, 1984 in Kota Bharu, Kelantan, Malaysia. His early education started at Sekolah Rendah Sultan Ismail Satu (SRKSI 1) as his primary school located in Kota Bharu. Later, he completed his secondary school from Sultan Ismail College (SIC), Kota Bharu in the year of 2001. He continued his first degree at the International Islamic University Malaysia (IIUM), in Gombak, Kuala Lumpur, Malaysia. He was the first batch graduated from Applied Arts and Design, majoring in Industrial Design from Kuliyyah of Architecture and Environmental Design (KAED). After graduating, he started his own freelance design company and at the same time, he was a lecturer at the Universiti Malaysia Kelantan (UMK), Malaysia. During that time, he was awarded a scholarship from the Ministry of Education Malaysia to pursue his studies at Masters level. He completed his Master of Science (MSc.) in Industrial Design from Design & Technology Department at Loughborough University, United Kingdom in the year of 2009. His dissertation topic covered the Electronic Product Design segment, where he designed and produced an automated electronic powered foot dryer for the ablution area in muslim's prayer room (musolla) known as "*ForFut*". Once completed his Masters degree, he was awarded another scholarship from the Ministry of Education Malaysia to pursue his PhD study at Delft University of Technology (TU Delft), the Netherlands. Nik has more than 7 years of experience in teaching especially in the Industrial Design field. He has published his works locally and internationally. Besides, Nik is one of the founders of Kopi Mesin café in Malaysia that currently operating at 3 different states in Malaysia – Kelantan, Selangor and Perak.

List Of Publications

Nik Ahmad Ariff N. S., Badke-Schaub P., & Eris. O. (2012). "Conversations Around Design Sketches: Use of Communication Channels for Sharing Mental Models during Concept Generation", Journal of Design and Technology Education, Volume 17, No. 3, 2012, pp 27 – 36.

Nik Ahmad Ariff N. S., Badke-Schaub P., & Eris. O. (2012). "Does Sketching Stand Alone as a Communication Tool during Sketching in Design Teams?", Proceedings of the Design Research Society Conference DRS 2012, Research: Uncertainty, Contradiction and Value.

Nik Ahmad Ariff N. S., Badke-Schaub P., Eris O., & Suib S. S. S. (2012). "A Framework for Reaching Common Understanding during Sketching in Design Teams", Proceedings of the 12th International Design Conference DESIGN 2012, pp. 1525-1534.

Nik Ahmad Ariff N. S., Eris. O, & Badke-Schaub P., (2013). "How Designers Express Agreement: The role of multimodal communication in communicating agreement and reaching shared understanding during conceptual design", Proceeding of IASDR 2013, International Association Society of Design Research, August 26 – 30, 2013, Tokyo, Japan.

Nik Ahmad Ariff, N.S., & Badke-Schaub, P., (2011). "Industrial Design Sketching for Concept Generation: Sketching – A Parallel Thinking Process", Proceeding of IASDR 2011, Doctoral Colloquium, International Association Society of Design Research, October 31 – November 4, 2011, Delft, The Netherlands.

Propositions accompanying the thesis:

Exploring the role of sketching on shared understanding in design

Nik Shahman b. Nik Ahmad Ariff

1. Visual communication reduces ambiguity.

2. Sketching forms cannot be comprehensively communicated verbally.

3. Design performance in teams comes in a package of drawing (sketching) and verbalising of form and function. (Thesis)

4. People good at visual perception are not necessarily good at verbal explanation.

5. Sketching is a specific form of information transfer. (Thesis)

6. Sketching visualises information transfer in content and process.

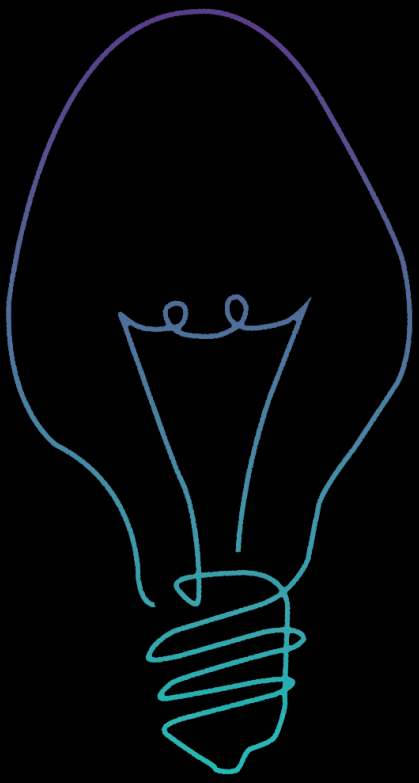
7. Levels of abstraction in sketching are dependent on the level of details in drawing. (Thesis)

8. In sketches, shared mental models can be achieved by detailing the drawing in term of functionality. (Thesis)

9. Common background knowledge enables appropriate level of understanding.

10. Design teams need a mutual understanding of the information and direction towards completing a design task.

These propositions are regarded as apposable and defendable, and have been approved as such by the promotors Prof. dr. P.G Badke-Schaub and Prof. dr. K. Thoring.



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