# A COMPARATIVE STUDY OF PROBLEM FRAMING IN MULTIPLE SETTINGS

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**Abstract.** Problem framing is an essential element of the design process because it is an important design activity in solving design problems. It is the first part of a cyclical design process which involves "framing", "moving", and "reflecting". Framing activities can be considered as a typical cognitive design process involving several levels. As an essential design activity, framing can be considered an indicator to trace whether digital media changes the way designers engage in their work. The results indicate that problem framing activities are significantly different in an online remote setting as compared to the two other settings. It appears that a chat line-based remote setting does not only facilitate a greater proportion of framing activities, particularly high level framing, but also shows more richly interlinked design activities.

## 1. Introduction

Studies on categorization, feature, and relation of different kinds of design activities have been carried out since 1960. Eventually, different design paradigms were developed, in which design activities with different names were found to be related with each other under particular relationships identified in each paradigm. The investigators of this study chose problem framing as a particular case to explore because this design behavior occurs in each design paradigm and is an essential part of the design process. Problem framing was chosen as the indicator to trace whether digital media changes the way designers engage in their work as compared to paper media.



*J.S. Gero (ed.), Design Computing and Cognition '06*, 245–263.

## 2. Problem Framing

Design problems have been categorized as well-defined, ill-defined or wicked, reflecting the extent to which their solutions are immediately apparent. Design processes have been explored extensively and described according to features of these different categories of design problems. In particular, Schon's cyclical design process, which he describes as a "reflective conversation with the material of the situation", has been extensively used in research into design education and design activities. Schon has referred to the act of problem definition as "problem framing", the term we will use in this paper. He postulated that the activity of framing was central to a successful process of design and hence is a key activity in design.

### 2.1. MEANING OF PROBLEM FRAMING

When a designer faces a design problem, problem framing is the initial step taken. "It requires first the discovery of a problem area or topic, and later the structuring of the problem into a workable springboard for solution generation"(Jay and Perkins 1997). Reitman (1964) claimed that problem transformation plays a key role in solving ill-defined problems. Within this transformation, each subproblem (or which he called as a problem vector) as an information structure might be considered as a plan involving a state, process, or objects. Simon (1984) emphasized the importance of the planning method in dealing with ill-defined problems. "Planning was done by abstracting from the detail of a problem space, and carrying out preliminary problem solving in the abstracted space". This "abstracting" aims to decompose an ill-defined design problem into a smaller problem. Problem framing is a key element adopted to transform an ill-defined or wicked problem into a well-defined one. On the other hand, designers, are not limited to "given" problems, but they instead find and formulate problems within the broad context of the design brief (Cross 2001). Through the formulation and reformulation of design problems, planning can be constructed to imagine; a scenario can be documented involving setting goals and following rules (Coyne 2005).

### 2.2. COGNITIVE PROCESS

Problem framing is a developmental process involving systematic transformation. It is not just an external design activity represented in a variety of design media, but is also a process influenced by human memory and the outside environments. According to Schon's description of problem framing, we can observe several categories of those actions. In his words, "As [inquirers] frame the problem of the situation, they determine the features to which they will attend, the order they will attempt to impose on the situation, the directions in which they will try to change it. In this process, they identify both the ends to be sought and the means to be employed"(Schon 1983:50-54). Here, three different categories of problem framing can be identified, namely, conjecture, setting rules, and planning. Framing activities, therefore, play different roles in the design process. From Minsky's study, problem framing could be classified into different types or levels. This classification is a common phenomenon in some cognitive and social studies. This section will analyze some studies on the categorization of problem framing. As mentioned earlier, problem framing can be considered as a process of searching and transformation. A similar classification of human thinking has appeared in other studies, showing a strong cognitive background.

## 3. Assumption About Design Tools

Paper-based design tools have been dominant in studio teaching since the formalization of design learning in Ecole des Beaux Arts. For many designers, the medium is inextricably bound into the activity of designing, with designers largely using paper to frame design problems (Robbins and Cullinan 1994). Indeed, the advent of the use of paper in designing has been noted as the moment at which design became an intellectual activity (Wigley 2001). As compared to digital design tools, paper seems to afford more predictability, and therefore, greater communication (Sellen and Harper 2001). Others suggest that digital design tools inhibit communication between the mind and the hand because of the precision demanded by the system, hence interrupting the conversation of design and disrupting framing activities (Lawson 1994; Corona Martinez and Quantrill 2003). Corona-Martinez and Quantrill observed that a computer is not a drawing instrument like a pencil, but it engages the designer in a different relationship with the act of drawing, changing the act with "an intermediate system of drawing according to our indications provided by the pressure on the button of mouse, which in turn responds to the feedback from our sight of what appears on a screen … something new has invaded the apparently intangible craftsmanship of drawing" (Corona Martinez and Quantrill 2003). Interviewing several architects, Lawson (1994) found that most of them preferred using paper-based design tools to help them in design thinking, and then using digital tools for documentation and presentation rather than as part of the design process. Burton, for example, considered that when interacting with a computer, he feels difficult to modify a drawing directly. "This close interaction between himself and his drawing leaves Richard Burton personally unenthusiastic about the idea of computer-aided design, of which he makes no use himself. He considers that the directness with which he can alter a drawing is missing when mediated by a computer, and thus the feeling is lost". Similarly, Wilford preferred paper and pencil in designing. Echoing Schon's 'conversation', he called this process of designing an iterative and comparative process, claiming that it is impossible for designers to be detached from "this very immediate process of drawing lines on paper and tracing through".

Several studies have been carried out to investigate the effects of computer collaborative tools on design communication. Kvan et al. (1997) found that designers engage in more high-level communication when using textual communication tools as compared to using video conferencing tools. Gabriel and Maher (1999) conducted three sets of experiments adopting different types of communication, namely, face-to-face communication, computer-mediated communication using video conferencing, and computer-mediated communication using a chat line. They, too, found that design communication was significantly different among the three settings, and in particular, that text better supported design collaboration. Neither these nor other studies have identified the ways in which the media supported problem exploration and definition, noting only that problem spaces were more widely searched in textual-based communication.

## 4. Research Method

In this study we compare the pattern of problem framing activities in paper-based to digital-based settings. Protocol analysis is selected as research method to explore this design activity. Statistical analysis and linkograph study are employed to analysis data

### 4.1. PROTOCOL ANALYSIS IN DESIGNS STUDIES

Protocol analysis may not be explicit enough in studying design inquiry, but it is a more solid and thorough method as compared to other examinational techniques. It has been adopted in different design disciplines like mechanical engineering, software design, electrical design, industrial design, architecture, and interior design. As a popularly used method, it brings out into the open the mysterious cognitive abilities of designers (Cross 2001), and is well suited for the comparison of what we are interested in (Goldschmidt 1995). This method includes soft and hard techniques. The soft technique refers to the observation of design activities, and the hard technique refers to coding and analysis mechanisms (Oxman 1995). Gero and Mc Neill (1998) conducted protocol analysis to explore designers' intention and described this method in great detail. One distinct characteristic of this method is that when subjects conduct the task, they are required to concurrently verbalize what they think. Concurrent verbalization is considered as an equivalent of the cognitive process in humans (Ericsson and Simon 1993).

In design studies, protocol analysis was first adopted by Eastman to study design cognition (Eastman 1968). Starting from Eastman's first usage of this method, protocol analysis has four types which are "think aloud", "retrospective analysis", "teamwork analysis", and "replication protocol analysis". Teamwork protocol analysis is developed from the concurrent verbalization analysis. This method was first adopted in the workshop of Delft University of Technology (Dorst 1995). Since then, this method has been adopted to test the effects of computer-supported communication tools on the design process (Goldschmidt and Weil 1998; Kvan et al. 1999; Gabriel and Maher 2000). Teamwork protocol analysis could solve to a certain extent the problems previously mentioned because the discussion of design issue is not only a regular activity in the design process (Cuff 1991; Kvan 2001), but also expresses the social and perception aspects of design (Cross and Cross 1995; Dorst 1995). Instead of requiring individual designers to think aloud, it allows two or more designers to work together. Through recording their discussion, the design protocol can be naturally elicited (Goldschmidt and Weil 1998).

### 4.2. DESIGN EXPERIMENTS

This study aims to identify the difference in problem framing in three design settings. To explore this design activity, the subjects are required to use computer tools or paper-based tools to solve a simple wicked design problem within a given time. Eighteen pairs of students are the participants of the design exercise. They are equally assigned into three settings which are online remote setting, online co-located setting, and paper-based co-located setting. In both co-located settings, the verbal and visual design protocols are videotaped. In online remote setting, the textual and visual design protocols are recorded by a computer. After transcribing the verbal design protocol, two types of coding scheme are adopted to examine the problem framing activities. The techniques adopted to measure problem framing are statistical analysis and linkographic study. Inter-coder reliability is conducted to validate this measurement.

### 4.3. CODING SCHEMA

The coding schema is based on Schon's "framing", "moving", "reflecting" design process and has been described in detail elsewhere. This model is employed to isolate framing from design process. The description of coding schema adopted is shown below. Table 1 shows the definition and correspondence examples of Schon's model.

4.4. LINKOGRAPHY STUDIES

Protocol data are loosely organized and analyzed; linkography study holistically describes protocol data in an organized way. The first of part study identifies there are different ways designer's engage in problem framing under different design environments. Through employing linkography technique, the whole structure of design activities can be unfolded, from which we wish to discover whether framing activities show any difference within the structure of linkography. In this study therefore we not only use statistical method for data analysis, but also adopt linkography technique to structure links among problem framing with other activities within different contexts. Using the protocols in which we have previously encoded designs actions using the Framing-Moving-Reflecting model, the linkograph reveals the interconnected actions and thus the depth of an idea. Framing, as one type of design moves, is more specific. We define several terms generated from this system. A component is the unit in which all design moves are inter-linked. A diameter means the number of the nodes linking two design moves in one component, thus the greater the diameter, the larger the component. We isolate the largest component from each setting, and adopt statistical technique to compare the incidences of problem framing in three designed settings. By this technique, the pattern of a design process can be visualized holistically.

TABLE 1. Coding schema and examples (after Schon).

| **Coding category** | **Definition** | **Examples** |
|---|---|---|
| Framing | Identify a new design problem;<br><br>Interpret further from design brief; | "We have to provide a sense of arrival at each site access point." |
| Moving | Proposed explanation of problem solving, a tentative solution. | "Maybe some here can put the playground" |
| Reflecting | Evaluate or judge the explanation in 'moving'. | "I think it is ok. Just represent the design" |

Table 2 illustrates the definition of terms adopted in this paper. These terms are used to measure this triangular web. Some of them are same with the terms used by Goldschmidt; others derive from the domain of graph theory.

TABLE 2. The definition of terms derived from linkography.

| Name | Abbr. | Description |
|---|---|---|
| Links | L | The number of linked design moves in a component; the larger the diameter of a single component, the more extensive a design thought. |
| Index | I | A process or a portion of it is the ratio between the number of links and the number of moves that form them (Goldschmidt 1990). |
| Component | C | One unit in which all design moves are inter-linked; the larger the number of components, the more fragmented the design session. |
| Diameter | Di | The number of linked design moves in the largest component in one setting; the larger the diameter of a single component, the more extensive a design idea. |
| Depth | De | The largest number of nodes linking two discrete design actions in a component and hence describes complexity of relationships between design actions. |

## 5. Results

By employing these method, two parts of results can be observed in the below, which are framing in Schon’s design conversation and linkography study.

### 5.1. FRAMING IN DESIGN CONVERSATION

Schon’s design model is largely rooted in studying the relationship between design activities with tools, and thus has been adopted in many human-tool interaction design studies. This model includes three separated design actions: framing, moving, and reflecting. The three design activities compose a cyclical design cycle. This theory was developed from a paper-based design setting in which Schon observed the discussion between a tutor and a student in a design studio. Through analyzing the 20-minute discussion, Schon claimed that the tutor used drawing and talking as the design language to help him engage in the design conversation. In this co-located setting, verbal discussion and paper-based sketch are the tools which the designer adopted to support his design communication. If the design tools are different, will this same cyclical design pattern occur?

#### *5.1.1. Within the variable*

Schon’s design model demonstrates that framing is an initial activity evoking other design actions. We compare these design activities (including framing, moving, and reflecting) in different design environments. We find that when the modes of both design tools are different from those in the paper-based setting, there is a significant difference among the three design activities (remote setting); when the mode of the drawing is different, however, no significant difference is found when comparing the three design activities. Table 3 presents the communication mode for each setting and the results of the ANOVA test. From Table 3, we can observe that in a remote setting, the F value is 7.61 larger than the critical F value. Meanwhile, the P value is 0.003 which shows a significant difference when comparing the three design activities, whereas in both co-located settings, no significant difference is found. These results indicate that a remote setting fundamentally changes the way designers engage in the design process as compared to both co-located settings.

### *5.1.2. Between the variable*

We counted the number of these design activities in terms of this “framing-moving-reflecting” model, and calculated the percentage of the three categories. Figure 1 presents the number of the three design activities across the three settings, and Figure 2 shows the percentage of the three design activities across the three settings.

TABLE 3. Results of ANOVA Test in comparing three design activities in each setting.

| The name of setting | Communication mode | Categories | F | P |
|---|---|---|---|---|
| Remote setting | Chat line and digital sketching | Framing vs. Moving vs. Reflecting | 7.61 | 0.003 |
| Digital co-located setting | Verbal communication and digital sketching | Framing vs. Moving vs. Reflecting | 0.74 | 0.49 |
| Paper-based co-located setting | Verbal communication and paper-based sketching | Framing vs. Moving vs. Reflecting | 0.27 | 0.77 |

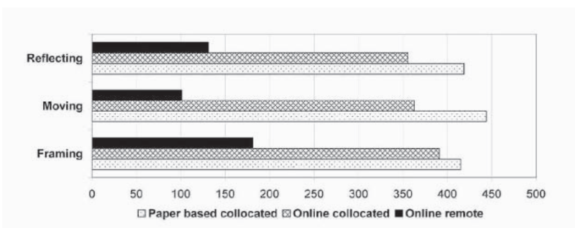



*Figure 1.* The number of the design activities across the three settings.

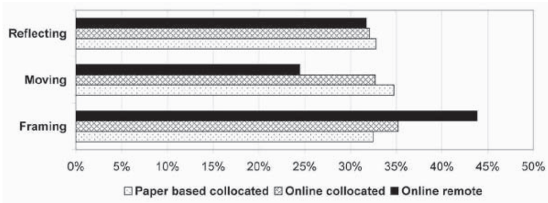



*Figure 2. The percentage of the design activities across the three settings.*

As indicated by the bar charts above, there is a substantial difference in the total communication in each setting. It can be seen that the number of framing activities is 415 in the paper based co-located setting, 391 in the online co-located setting, and 181 in the online remote setting. The number of communication in the other two categories is similar and proportionate. Thus, the results suggest that face-to-face working supports greater communication than digital-supported textual communication. In co-located environments, the subjects can draw while talking, but in a remote environment, the two actions are separated. When we calculate the percentage of framing in these settings, we find that the percentage of framing is higher in an online remote setting than in paper and online co-located settings (43.8% online remote, 32.5% paper-based co-located versus 35.2% online co-located setting). The chat line setting therefore appears to support a greater proportion of framing than the two other activities (moving and reflecting).

5.2. LINKOGRAPHIC STUDIES

Linkography study gives us a holistic way on studying framing by using a design graphic system. Three parts of study are incorporated. First studies full graphs of linkograph; secondly by quantifying linkographic representation, largest components from each setting are isolated for comparison. Lastly a case study is adopted to explore the effects of framing on latter activities.

*5.2.1. Quantitative results*

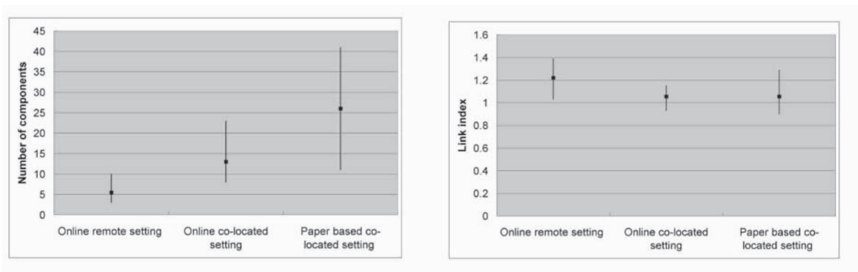
To identify developmental steps in designing, we have used the graphic technique of linkographs to track the development of design ideas. Developed by Goldschmidt (1990), the linkograph is a tool to encode design activities by identifying interlinked design moves by way of a systematic triangular web. We analyze the resulting graph using graph theory to distinguish the graphs.

To examine the implication further, we have represented the encoding using linkograph to examine the connectedness of frames, moves and reflection throughout the design sessions.

- Full graph

The following figure shows maximum, minimum, and median of number of components (Figure 3). The highest median of number component is in paper based setting; next is online co-located setting, last is online remote setting. We assume that the less number of components, the more connectivity of linkage among design activities. This figure therefore indicates that online remote setting has higher degree of connectivity of links.

The term of link index (LI) is adopted from Goldschmidt's study (1990). According to her, "Low L.I.'s were found in the cases of inexperienced designers and those experiencing difficulties in dealing with a particular design problem"(Goldschmidt 1990). Figure 4 presents the link index of full graph of each setting. The highest value of link index is in remote setting, next is paper based co-located setting, last is online co-located setting. The higher value of link index, the more design productivity; this figure indicates online remote setting (with chat-line based textual communication) could achieve richer links of design activities. The results of full graph suggest remote setting better support design productivity and show richer links than other two co-locates settings.




(a) (b)

*Figure 3.* (a) The number of components across the three settings; (b) the link index across the three settings.

*Largest component:*

Using Goldschmidt's (1990) index, the largest component (the component with largest number of diameter in each setting) in each protocol in setting was measured and the mean of these numbers calculated. From this measure, we see that the largest mean index number is obtained for the online co-located setting. The measure of the index, however, does not inform us of the breadth of the complexity in the design activity. To identify this, we have employed the three standard graph descriptors introduced in the section above, component, diameter and depth.

Table 4 compares the mean value of total number of components and diameters across the three settings; and their ratio. For each metric we have shown the mean of each across the six protocols recorded in each setting. The first column shows the mean value of the number of component in each setting. The mean of the number of components in remote setting is much less (5.8) compared to paper (26.8) and digital based co-located settings (13.5). The next row presents the mean value of the number of links. By comparing the mean value of number of links among the three settings paper co-located setting contains largest number (238); remote setting has 81; and digital co-located setting has 188.We assume that if fewer components occur while richer links found, then leading to design complexity. In other words, the ratio of link and component (ML/MC) is an indication of the design productivity. The ratio in online co-located setting is the highest (14.90), next is online remote setting (13.96) and the last is paper co-located setting (8.88).

TABLE 4. Component and diameter among the three settings.

| | Number of Component | | Number of Link | | Ratio (ML/MC) |
|---|---|---|---|---|---|
| | Mean (MC) | SD | Mean (ML) | SD | |
| Online remote setting | 5.8 | 2.79 | 81 | 21.40 | 13.96 |
| Paper co-located setting | 26.8 | 10.76 | 238 | 49.86 | 8.88 |
| Online co-located setting | 13.5 | 5.5 | 188.8 | 74.01 | 14.90 |

Table 5 describes the index metric of the largest components among the three settings and three largest components in each setting. In each design session we choose the largest component, thus totally six components in each setting. The first three columns compare the mean value of total link; mean value of the numbers of moves; and index. Results indicate the mean value of total link and the mean value of numbers of moves in paper-based co-located setting is the highest (85.7; 121); next is the remote setting (59.7; 61); and in digital based co-located setting the mean value of total link and moves are 87 and 93.3. When comparing the value of index it shows digital co-located setting holds the largest number (1.12); remote setting is the next, which is 1.07; and paper-based co-located setting is 0.71.

By isolating the largest component in the three settings for investigating we find that digital co-located setting contains the largest number of diameter (164); the greatest depth is 5. The remote setting holds the largest number of greatest depth (9) though the diameter of it is less than that of digital face-to-face environment that is 83. The largest component in paper-based setting has 132 diameter and 7 of the greatest depth.

As described above, a component is a unit of inter-connected design moves, which represents the process of the development of design ideas. We observe that remote setting has far fewer components, that is, far fewer discrete design threads are developed which then are abandoned and not continued; designers appear to engage in more limited exploration of a problem. In addition, the remote setting exhibits the greatest depth among components. From this, we observe that purposeful design activity is more often engaged in the remote setting. This suggests that initial ideas developed and recorded in the remote setting, where a chat line is employed, are more persistent while in the paper-based setting the idea is developed sequentially. Although online co-located setting has the largest number of diameter and the highest value of ratio, the depth is only five even less than paper-based co-located setting. This implies that the design ideas raised in online co-located setting are not re-visited or re-modified as often as those raised in other two settings.

TABLE 5. Index metric of the largest components among three settings.

| | **Total link** | | **The number of moves** | | **Index** | | **The largest one in each setting** | |
|---|---|---|---|---|---|---|---|---|
| | **Mean** | **SD** | **Mean** | **SD** | **Mean** | **SD** | **The Diameter (Depth)** | **Greatest Depth** |
| Online Remote setting | 59.7 | 16.81 | 61 | 17.25 | 1.07 | 0.32 | 83 (9) | 9 (83) |
| Paper-based co-located setting | 85.7 | 36.45 | 121 | 25.20 | 0.72 | 0.32 | 132 (4) | 7 (83) |
| Online based co-located setting | 87 | 49.78 | 93.3 | 54.73 | 1.12 | 0.05 | 164 (4) | 5 (147) |

### *5.2.2. Descriptive case study*

Previous studies focus on the dimension of largest components and greatest depth and ignore the relationship of largest components and greatest depth with full graphics. Here we introduce two analysis techniques. The first analysis technique is to calculate two sets of ratio values. The first is to calculate the ratio value between number of design activities of largest component and the total number of design activities in each setting. The second is to calculate the ratio value between the greatest depth of linkograph and the total number of design activities in each setting. The second technique is case study of greatest depth in the three design environments. Through this case study we wish to understand how an idea was developed and improved.

The protocols recorded for each session were coded using the schema above to identify frame, move and reflection actions. Framing actions were then further encoded using the second schema to identify high and low level framing. Linkographs were drawn for each session.

Goldschmidt (1990) devised a measure of link index to measure the comparative complexity of critical moves and to identify the critical path in a linkograph. As she noted, a low index value suggests inexperience and a poor grasp of the design problem. The index does not tell us of the complexity of the links in a graph, so we have identified two additional metrics. One is the ratio value that tells us of the structure of the graph, and the second, depth, measures the continuity of design ideas across a graph.

*Ratio value:*

These protocols have been previously reported in Kvan and Gao (2005) where analysis was conducted on the largest component only in each setting. For these, the depth and diameter were calculated; in that analysis, we found that the largest components in the remote settings exhibited the largest depth but not the largest diameters. That analysis, however, did not examine the largest component in its larger context of the whole protocol. The analysis technique we adopt in this study emphasizes the relation between largest component and the whole design process. To examine this, we have used two ratio values:

$$\text{Ratio value 1} = \frac{\text{the number of design activities of largest component}}{\text{the total number of design activities in the protocol}}$$

This ratio value, R1, measures the coherence of the largest component within the overall design process. If the ratio is low, the largest component represents but a small part of the overall process and hence suggests that the overall process was fragmented into many discrete and disconnected design actions. A large R1 indicates a persistency in design ideas as they are re-examined and interpreted, in which instance the largest component represents a major part of the design process thus suggesting internal coherence and continuity.

$$\text{Ratio value 2} = \frac{\text{the greatest depth in a component for the protocol}}{\text{the total number of design activities in the protocol}}$$

Ratio value R2 measures the reach and extent of revisiting of early ideas as the design progresses. Depth is a measure of the largest number of nodes linking two discrete design actions in a component and hence describes complexity of relationships between design actions. If a protocol exhibits a high R2, ideas are closely linked from beginning to end of the design session. A low R2 indicates rapid chaining of concepts but little cross-checking to earlier intentions. Using the terminology from Vygotskii's complexes, a high R2 suggests complexes of a higher order.

Results from calculating the two R values are presented for the three settings in Figure 5; in each setting the minimum, maximum and median are indicated. We can see that the value for R1 and R2 are substantially higher in the remote setting.

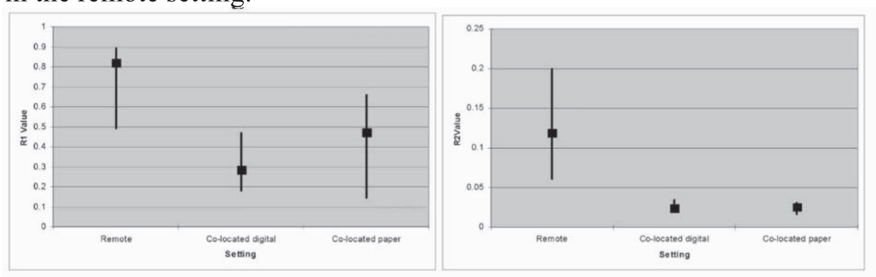



*Figure 5.* Results for R1 and R2.

Case study

As we have reported elsewhere, the proportions of framing found in these protocols varied significantly in the three settings (Figure 6), with the remote setting exhibiting a higher ratio of framing than the co-located settings and that the protocols from the remote setting exhibited more of both high and low level frames that the co-located settings.

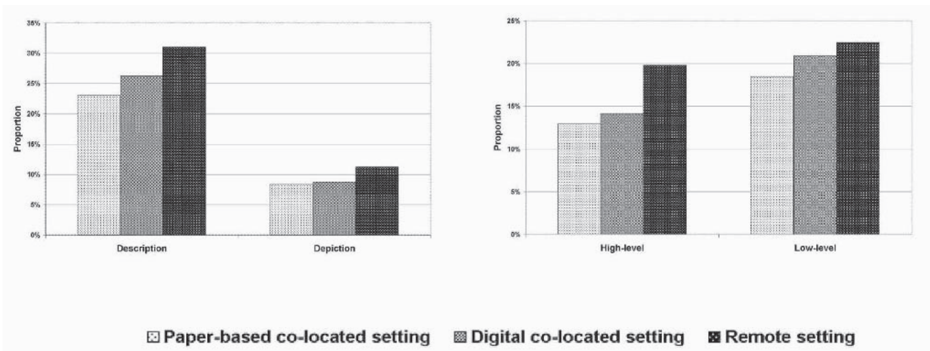



*Figure 6.* The comparison of the proportion of different frames of the largest components across the three settings (left: description vs. depiction; right: high and low-level of frames).

These initial findings are clarified by examination of three examples, one from each design environment, in which we can examine how a creative idea is introduced, improved and carried to later activities. Figures 6, 7 and 8 we show the linkograph for the largest component with the highest R1 value for each of the settings.

*Remote setting:*
In this design environment, textual communication and digital drawing are main channels for design communication. The first protocol, Figure 7, shows designers' creative design ideas interlinking richly and over a considerable span of the design session. Design ideas are constructed into complexes by association and continuation of thoughts. We observed in this protocol that this pair of students continuously produces several high-level frames to correspond the first problem, like underground, open structure, evoked by the first high-level framing. Framing activities represent 39% of the actions in the component. The R2 value is 0.06, the lowest R2 of all remote protocols, indicating other protocols should yet richer complexes.

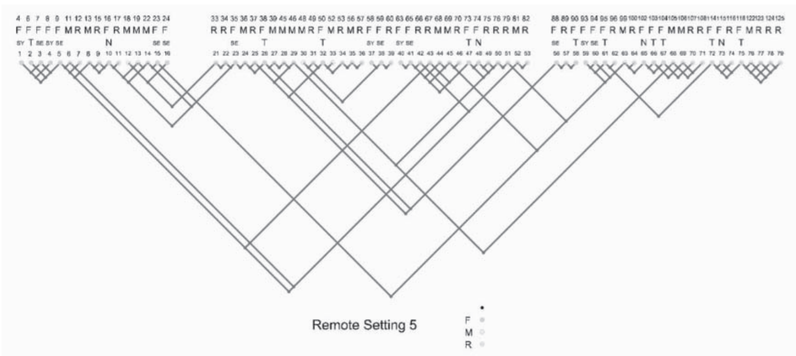



*Figure 7.* Highest R1 in the remote setting.

*Digital co-located setting:*
In this design environment, verbal communication and digital drawings are the primary channels adopted by designers for design communication. From the protocol, Figure 8, we observe a small amount of chaining even though this is the highest R1 recorded; framing occurs 29% of the time. The R2 value is 0.0234 which is close to the median value for this setting.

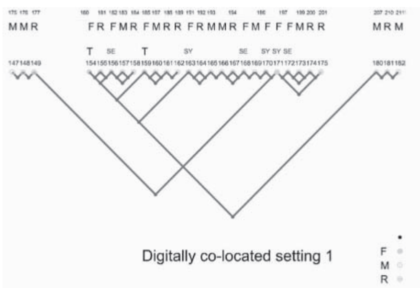



*Figure 8.* Highest R1 in the digital co-located setting.

*Paper-based co-located setting:*
In this design environment, verbal communication and paper based drawing are main channels adopted by designers. The design engagement in this component has a short span (action 2 to action 48) but the, Figure 9. Frames represent 28% of the actions; the R2 for this component is 0.0247, close to the median value for the setting.

Through comparing the content of each highest R1 of the three design environments, we find that in remote setting early designs idea lead to larger complexes with more frames than in both co-located settings. In this comparison writing communication again shows its advantage in problem framing process.

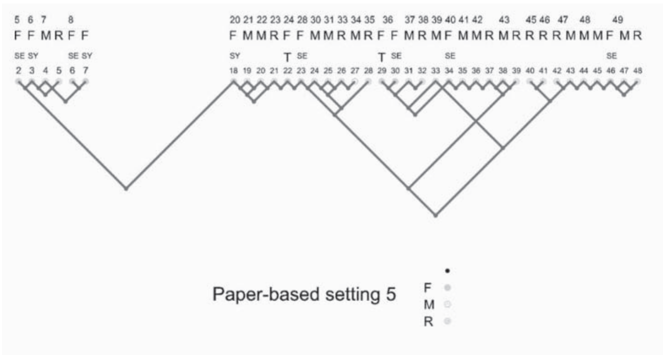



*Figure 9.* Highest R1 in the paper-based setting.

## 6. Discussion

Problem framing is closely related with Schon's design paradigm; therefore, it is necessary for us to investigate the relationship between design tools and the design process. Zeisel (1984) and Schon (1985) identified a design cycle designers engage in. The design process is like a spiral consisting of three consecutive design activities: framing, moving, and reflecting. According to the results, this design metaphor or design paradigm is well suited to co-located settings, while in a remote setting, it is changed by textual communication. This change confirms the theory of affordance (Sellen and Harper 2001) in which the properties of design tools determine the possibility of actions. Schon's design paradigm was developed from the observation of the conversation between a tutor and a student. In such situation, the two persons mainly adopted verbal communication and paper-based sketching as the design tools for the design process. In a verbal communication environment, the designers produce the problem to solve, and then propose a possible solution for it, After which, they test or evaluate this solution which might evoke other problems. However, in a remote setting, this is not the case. We find that sometimes, designers propose several problems in advance, and in other times, they propose a serial of solutions. In a chat line-based remote setting, the design communications are stored in a computer which helps designers unload their design exchanges in an explicit way. This characteristic of a remote setting delays designers from referring to their previous design exchanges, thus prolonging this design to be spiral. Schon's design paradigm is a normal thinking process which professionals usually adopt in their career (Schon 1983). Sketch-supported verbal communication has its characteristics in supporting this thinking process (Schon 1983; Fish 1996). However, sketch-supported textual-based communication changes this thinking process to some extent, raising the issue on whether or not this design tool has its own potential in supporting particular design activities.

This study has introduced the use of linkographs to measure protocols in an effort to characterize the richness and complexity of design activity. We have applied three new measures, components, diameter, and depth, as the metrics of richness, and have adopted the idea of Goldschmidt's index. We have demonstrated that these measures correlate with the findings derived in earlier papers using statistical measures. The conclusion is that the discussions on design activity in chat lines can be measured to be richer in design complexity than those taking place face to face. Goldschmidt (1990) noted that "design productivity is related to the generation of a high proportion of design moves which are rich with links". In her paper, Goldschmidt developed an index as a measure of the percentage of linked moves. She proposed that a higher linkage value is an indicator of greater interconnectedness in design moves. In this figure, we observe that the pattern of design activities in the remote setting are richly interlinked as suggested by the considerable interconnections in the design activities; the framing activity in this setting appears to have an impact on subsequent moves. In a co-located setting, however, many design moves are isolated and disconnected. Thus, the remote setting seems to facilitate richer design productivity than co-located settings.

## 7. Conclusion

Preliminary study demonstrates that using digital design tools do not interrupt design process, suggesting that the preconception of digital tools interrupting the design conversation is unfounded, at least in so far as the conversation is measured as a framing process. The results also suggest that the design tools have some influence on the activity of problem framing. It would appear from this study that digital tools belong in the category of tools that contribute to the process of design and should not be relegated to a role of supporting 'hardlining' and presentation after design thinking is completed. The positive effect observed here in the non-co-located setting continues to surprise the researchers as it is counter-intuitive and is not supported by the lore of designing, deserving further consideration. Overall, these experimental findings show that digital design tools appear *not* to be detrimental to problem framing activities and may also enhance the efficiency of design exploration, contrary to commentary from practitioners. If digital tools are constraining inventiveness and disrupting the design conversation, it may not be in the density of framing activities but other aspects of the design process that are being disrupted. Digital design tools therefore show some potential to enable exploration beyond traditional design processes, perhaps to fulfill the wish to free designers from the traditional paradigm of designers formalized in the era of Renaissance.

This study identifies that there is indeed significant difference of framing activities when using different design tools; especially in remote setting framing activities are proportionately higher. Linkograph study shows richer links in remote setting in terms of link index in full graph and ratio value. Future study could be employed to examine the reason why these incidences occur.

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