SKETCHING AS MENTAL IMAGERY PROCESSING

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Abstract: Analysis of results of design protocols of novice and expert designers, although based on a limited number of designers, has shown that there are differences in the balance of cognitive actions between them. In this paper, we investigate the possible reasons for this imbalance in cognitive activity between the novice and expert designers in the rate of information processing driven by their relative experience in drawing production and sketch recognition. We use the theory of mental imagery to explain these differences.

1. Introduction

Results of analysis of design protocols of novice and expert designers, although based on a limited number of designers, have shown that there are differences in the balance of cognitive actions between the novice and the expert designers (Kavakli et al., 1999). Our hypothesis is that the reason for the imbalance in cognitive activity between the novice and the expert designers in the conceptual design process is the rate of information processing driven by their relative experience in drawing production and sketch recognition. To explore this hypothesis, first, we investigate imagery and perception. Then, we discuss sketching as mental imagery processing by interpreting the differences in the cognitive activities of the novice and the expert designers.

1.1. IMAGERY AND PERCEPTION

Imagery and perception share many of the same types of neural mechanisms (Farah, 1988, Finke, 1980, 1989) and all characterizations of imagery rest on its resemblance to perception (Kosslyn, 1995). As pointed out by Finke et al. (1992), experimental studies reveal that mental images can exhibit a variety of perceptual-like properties. We use vision primarily to identify objects, parts, and characteristics. Similarly, one purpose of imagery is to identify properties of imaged objects, which allows us to retrieve information from memory. Imagery is used when we reason about the appearance of an object when it is transformed, especially when we want to know about spatial relations. Given the apparent parallels between the uses of imagery and those of like-modality perception, it is not surprising that imagery apparently shares some of the same processing mechanisms used in recognition (Finke and Shepard, 1986, Kosslyn, 1995). Indeed, the process of looking at objects in images shares many properties of actual perception.

1.2. MENTAL IMAGERY VERSUS PHYSICAL

Perceptual interpretive processes are applied to mental images in much the same way that they are applied to actual physical objects. In this sense, imagined objects can be "interpreted" much like physical objects (Finke, 1990). The interpretive processes may not be as efficiently applied in imagery as they are in perception, however, given the tendency for images to fade over time (Pinker, 1984). The general notion that imagined objects and forms can often function in equivalent ways to real objects and forms has been supported by many previous studies (Farah, 1985, Finke, 1980, 1986a, Finke and Kurtzman, 1981, Podgorny and Shepard, 1978, Shepard, 1984, Shepard and Cooper, 1982). Neblett, Finke, and Ginsburg compared mental and physical synthesis (Finke et al., 1992). Comparisons among the conditions revealed no significant differences in the number of patterns generated in mental and physical synthesis. Their findings suggested that mental synthesis is at least as effective as physical synthesis. In other words, there seems to be no particular advantage to physically combining the parts, compared to simply imagining the combinations, when attempting to discover recognizable or creative patterns.

Anderson and Helstrup (1993a,b) also compared mental and physical synthesis. They also found equivalent performances for mental and physical synthesis, with one exception. When told to generate as many patterns as they could on each trial, subjects were able to generate more patterns in the physical synthesis condition. These patterns, however, were no more recognizable or creative than those generated during mental synthesis (Finke et al., 1992). One advantage of using mental synthesis is that it can be carried out with minimal effort, although we would expect that physical synthesis would become easier, relative to mental synthesis, as the number of parts increases, because there are capacity limitations on how many parts and features an image can contain at the same time (Kosslyn, 1975, 1980). These findings are in general agreement with those referred to earlier showing that imagery and perception can often be considered functionally equivalent processes (Finke, 1980, Shepard, 1984). Based on the evidence of these previous studies, using the resemblance of mental imagery and perception, we can adopt the theory of mental imagery to explain the differences in cognitive activities of the novice and the expert designers.

2. Cognitive Actions in Imagery Processing

We have examined similarities and differences between novice and expert designers. For this purpose, we used a coding scheme that enables us to systematically code cognitive actions of designers from video/audio protocols. This coding scheme (Suwa et al., 1998a) is a modified version of the coding scheme developed by Suwa and Tversky (1997). The coding scheme has produced relatively similar results, even when used by different analyzers. The method involves two independent coders who then arbitrate differences and this has been found elsewhere to produce robust results (Gero and McNeill, 1998). Using this coding scheme, we analyzed the cognitive processes of novice and expert designers. In the protocols, the novice is a second year student of architecture and the expert is a practising architect with more than 25 years experience. The purpose of the analysis was not to directly obtain results with full generality but to assess whether this type of approach could produce useful results. The results of our protocol analysis studies and coding of designers' cognitive actions led us to evaluate sketching using concepts from mental imagery processing.

2.1. CODES OF COGNITIVE ACTIONS

Protocol analysis methods are divided into two categories: the process-oriented approach and the content-oriented approach (Dorst and Dijkhuis, 1995). The retrospective protocol analysis method used in this study is based on the content-oriented approach. Suwa and Tversky (1996) classified the contents of what designers see, attend to, and think of into four information categories: depicted elements and their perceptual features, spatial relations, functional thoughts, and knowledge. The first two give us visual information, while the latter two give us non-visual information. In retrospective protocol analysis, design protocols are collected as a retrospective report after the design session. These protocols are divided into segments, indexed and coded according to the information categories. Different modes of designer's cognitive actions are coded for each segment. There are four modes of cognitive actions in this version of the coding scheme (Suwa et al., 1998a): physical, perceptual, functional, and conceptual.

a) Physical Actions

Physical actions refer to three main groups of actions: drawing new elements, tracing over and copying previously drawn elements on another sheet (D-actions), paying attention to previously drawn elements (L-actions), and movements on design depictions (M-actions). There is no subcategory in L-actions which is an abbreviation for looking at depictions. D-actions and M-actions each have 6 different categories as shown in the Table 1.

TABLE 1. Subcodes of D-actions and M-actions in the category of physical actions

D-actions: drawing actions	**M-actions: moves**
Dc: create a new depiction	Moa: motion over an area
Drf: revise an old depiction	Mod: motion over a depiction
Dts: trace over the sketch	Mrf: move attending to relations or features
Dtd: trace over the sketch on a different sheet	Ma: move a sketch against the sheet beneath
Dsy: depict a symbol	Mut: motion to use tools
Dwo: write words	Mge: hand gestures

b) Perceptual Actions

Perceptual actions (P-actions) refer to the mention of visual features of elements (such as shape, size, or texture), spatial relations among elements (such as proximity, remoteness, alignment, intersection, connectivity, etc.), organization and comparison among elements (such as grouping, similarity, contrast/difference), and implicit spaces that exist in between depicted elements. Perceptual actions have 8 different categories, Table 2.

TABLE 2. Codes of P-actions

P-actions: perceptual actions related to implicit spaces	**P-actions: perceptual actions related to features**	**P-actions: perceptual actions related to relations**
Psg: discover a space as a ground	Pfn: attend to the feature of a new depiction	Prn: create or attend to a new relation
Posg: discover an old space as a ground	Pof: attend to an old feature of a depiction	Prp: discover a spatial or organizational relation
	Pfp: discover a new feature of a new depiction	Por: mention or revisit a relation

c) Functional Actions

Functional actions (F-actions) refer to associations of particular visuo-spatial features in sketches with meanings, functions or abstract concepts. Functional actions have 6 different categories as shown in Table 3.

d) Conceptual Actions

Conceptual actions refer to preferential or aesthetic evaluations, the set-up of goals (G-actions), and the retrieval of knowledge or past similar cases (Suwa et al., 1998b). In this group, we only examined goals for this study. Goals have 7 different categories as shown in Table 4.

TABLE 3. Codes of F-actions

F-actions:Functional actions related to new functions	**F-actions:Functional actions related to revisited functions**	**F-actions:Functional actions related to implementation**
Fn: associate a new depiction, feature or relation with a new function	Fo: continual or revisited thought of a function	Fi: implementation of a previous concept in a new setting
Frei: reinterpretation of a function	Fop: revisited thought independent of depictions	

Fnp: conceiving of a new meaning independent of depictions		

TABLE 4. Codes of G-actions

G-actions: Goals	**Subcategories of G1 type goals:**
G1: goals to introduce new functions	G1.1: based on the initial requirements
G2: goals to resolve problematic conflicts	G1.2: directed by the use of explicit knowledge or past cases (strategies)
G3: goals to apply introduced functions or arrangements in the current context	G1.3: extended from a previous goal
G4: repeated goals from a previous segment	G1.4: not supported by knowledge, given requirements or a previous goal

2.2. RATE OF COGNITIVE ACTIONS

We investigated cognitive actions of novice and expert designers and found that the design protocol of the expert includes 2,916 actions and 348 segments, while the novice's protocol includes 1,027 actions and 122 segments. Considering that the same amount of time was given to both participants, the expert's design protocol is 2.84 times as rich as the novice's in terms of actions. There were 2.85 times as many segments in the expert designer's session as in the novice's. Based on these results, we can claim that the expert is more active than the novice during the conceptual design process.

Is the expert also more productive than the novice? How can we measure productivity? According to Finke et al. (1992), one can measure the productivity of ideas, in terms of the number of ideas generated within a particular time period or the time it takes to generate a single idea. Such measures need to be used with care, however, since they tend to confound the process of discovery with that of expressing or communicating the ideas. For example, a person might be skilled at generating ideas but poor at reporting or describing them. This is the main handicap of protocol analysis studies in design. Therefore, we also estimated the rates of sketches produced by the novice and the expert designers. During the design process, the expert produced 13 pages of sketches including 7 different design alternatives, while the novice produced 4 pages including 2 design alternatives. In other words, the expert produced three and a half times as many pages and alternatives as the novice. Samples of these can be seen in Figures 1 and 2.

The major distinction in their sketches is the greater intensity in the expression of design ideas as seen in the expert's design alternatives. Based on the pages and quantities of alternatives produced, we can also claim that the expert is more productive than the novice. In this paper, we examine the expert's productivity based on his high cognitive activity. Why is the expert more active and productive than the novice in the conceptual design process? To give an answer to this question, we will analyze similarities and differences in their imagery processing.

3. Cognitive Activity of Expert and Novice Designers

We investigated the rate of cognitive activities of expert and novice designers for the pages they produced. The rate of cognitive activity of the novice over the pages produced in the design session decreases with a slope of -0.11, while the expert's cognitive activity increases with a slope of 0.11 as shown in Figure 3. How can we explain this dramatic difference in cognitive activities of the expert and the novice designers?

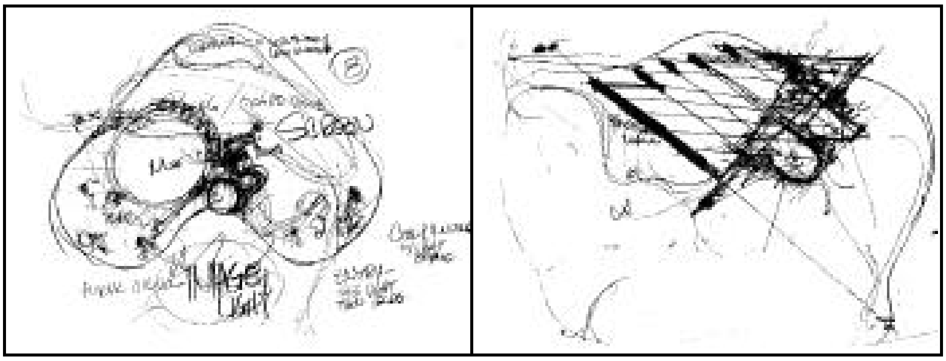

Figure 1. Samples from the sketches of the expert

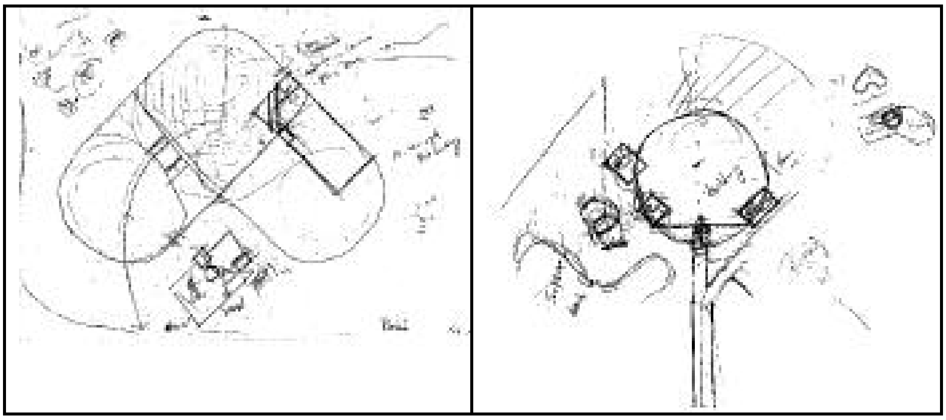

Figure 2. Samples from the sketches of the novice

Could the difference in cognitive activities cause the difference in performance? Figure 4 shows that cognitive actions including physical, perceptual and functional actions, as well as goals, increase and decrease approximately in parallel with each other in both protocols. Thus, our analysis results from the design protocols of the novice and the expert designers have shown that although there is no clear evidence for the causality among cognitive actions, there is evidence for the coexistence of the cognitive actions. We found evidence from Finke (1992) and Kosslyn (1994) to support our hypothesis based on the coexistence of different types of cognitive actions in creative processes. In creative cognition, there are usually many kinds of cognitive processes operating in conjunction and with varying rates (Finke et al., 1992). Many of the brain areas that are activated, when we recognize and identify objects are also activated during visual mental imagery (Kosslyn, 1994). Imagery involves different systems (visual, spatial, verbal, temporal, propositional/semantic), which are usually handled in different parts of the brain (Petre and Blackwell, 1997). For instance, in generating a creative image, one might begin by mentally synthesizing the parts of an object, followed by various mental transformations and rearrangements of the parts, followed, perhaps, by additional syntheses and transformations. Eventually, all of these processes affect the rate of the cognitive activity based on image generation (drawing production), inspection (attention), transformation (reinterpretation), and information retrieval from a case base in long-term memory.

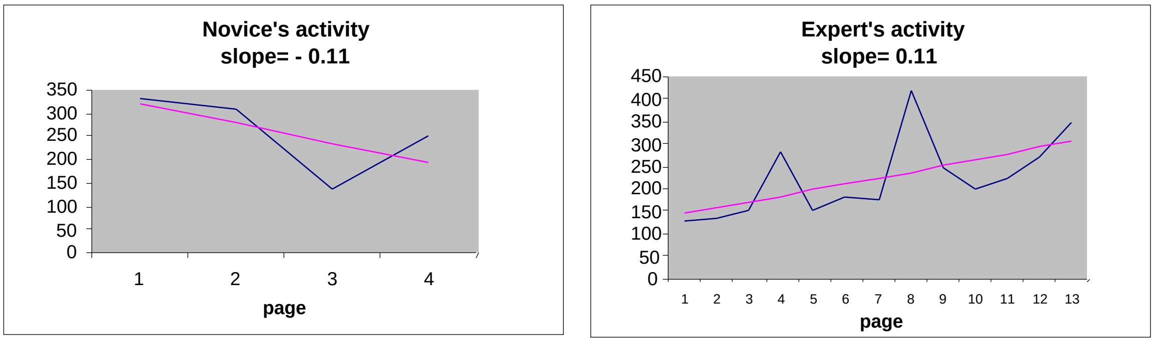

Figure 3. Linear regression graphs of novice's and expert's cognitive activities

Is the reason for the difference in cognitive activity between the novice and the expert designers in the conceptual design process in the rate of information processing driven by the experience in drawing production and sketch recognition? If this is the case, what causes the difference in the rate of information processing between the novice and the expert designers? Does information processing drop or slow down at some point in the novice's design protocol? We will look for some answers to these questions in information processing theories related to imagery.

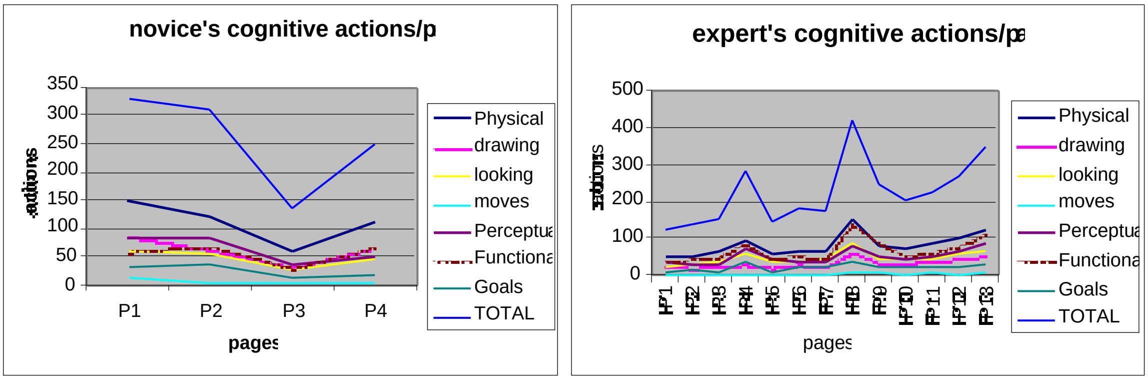

Figure 4. Novice's and expert's cognitive activities

4. Individual Differences in Types of Imagery Processing

The following tables, Table 5, 6, 7, 8, and 9, indicate the rates of certain types of cognitive actions that we interpret by means of the theory of mental imagery. The shaded cells in the tables refer to results that indicate potentially significant differences in particular types of actions.

TABLE 5. Action Categories.

ACTIONS	Expert (%)	Novice (%)
Physical	38	45
Drawing	15	23
Looking	21	19
Moves	2	3
Functional	30	21
Perceptual	23	24
Conceptual	10	10
Goals	10	10

TABLE 6. Drawing Actions.

DRAWING ACTIONS	**Expert (%)**	**Novice (%)**
Depicting	54	62
Drawings (Dc)	40	42
Symbols (Dsy)	14	20
Modifying	31	23
Revising (Drf)	13	5
Overtracing (Dts)	11	15
Copying (Dtd)	7	3
Writing (Dwo)	15	15

TABLE 7. Functional Actions.

FUNCTIONAL ACTIONS	**Expert (%)**	**Novice (%)**
Revisited functions	42	33
Continual or revisited thought of a function (Fo)	41	32
Continual or revisited thought independent of depictions (Fop)	1	1
New functions	42	45
Associate a new depiction, feature or relation with a function (Fn)	30	32
Reinterpretation of a function (Frei)	11	11
Conceiving of a new meaning independent of depictions (Fnp)	1	2
Implementations	16	23
Implementation of a previous concept in a new setting (Fi)	16	23

TABLE 8. Perceptual Actions.

PERCEPTUAL ACTIONS	**Expert (%)**	**Novice (%)**
Implicit spaces	14	34
Discovery of a new space as a ground (Psg)	5	12
Discovery of an old space as a ground (Posg)	9	22
Features	22	25
Attention to the feature of a new depiction (Pfn)	9	11
Discovery of a feature of a new depiction (Pfp)	6	6
Attention to an old feature of a depiction (Pof)	7	8
Relations	65	41
Discovery of a spatial or organizational relation (Prp)	17	10
Creation of or attention to a relation (Prn)	28	21
Mention of a relation (Por)	20	10

TABLE 9. Goals.

GOALS	**Expert (%)**	**Novice (%)**
Goals to introduce new functions (G1)	62	75
based on the initial requirements (G1.1)	11	25
directed by the use of explicit knowledge or past cases (G1.2)	16	19
extended from a previous goal (G1.3)	17	7
not supported by knowledge, requirements or goals (G1.4)	18	24
Goals to resolve problematic conflicts (G2)	8	13
Goals to apply introduced functions in the current context (G3)	20	4
Goals repeated from a previous segment (G4)	11	8

The statistical results (chi squared test, $\chi^2 > c$, at 0.5% significance level) indicate that there are differences between the expert's and the novice's cognitive actions. The strongest differences statistically are in perceptual actions and goals. Drawing actions in the physical actions' category also indicate stronger differences than other types of actions. The data tested statistically are internal and cannot be generalized. We need to carry out more experiments to corroborate these results, so as to achieve adequate statistical validity of our conclusions in general. However, given the large number of actions in each protocol, we can make reasonably well-founded claims based on this evidence.

On one hand, we have coexistence of certain types of cognitive activities in both designers' protocols. On the other hand, we have Kosslyn's theory of mental imagery, which is based on actual perception. The resemblance between imagery and perception led us to adopt the theory of mental imagery to explain the differences in the rates of the cognitive actions between the novice and the expert designers. Kosslyn (1995) has specified four basic types of imagery processing. The different types of processes are those used in generating, inspecting, and transforming images, as well as those that are necessary for information retrieval from long-term memory.

4.1. IMAGE GENERATION

There are only two ways a visual mental image can be formed. One can retain a perceptual image or one can activate information stored in long-term memory. Kosslyn (1995) asserts that "Several mechanisms working together could generate images, and these mechanisms may have other roles as well. By analogy, a car can slow down if one simply takes one's foot off the gas, which does not activate a separate *slowing-down* system". Considering that the same amount of time was given to both participants in our experiment, the expert's design protocol is 2.84 times as rich as the novice's in terms of actions. There were 2.85 times as many segments in the expert designer's session as in the novice's, as well as three times as many alternatives and pages produced. In other words, image generation in the novice's design protocol was as slow as his cognitive activity.

Although the novice's cognitive activity started with a peak, as shown in Figure 3, it drops down continuously until the production of page 3. Whereas the expert's cognitive activity continuously rose during the conceptual design process. Here, we can claim that production of sketches of alternative designs correlates with cognitive activity. In the stagnation of producing alternatives, cognitive activity dramatically drops. The consistency of the key pages in design protocols may also clarify this idea. The expert chose to develop the design produced when his cognitive activity was at its peak, even though he produced other alternatives after the peak period. This strategy leads him to a systematic increase in his cognitive activity. On the other hand, the third page produced by the novice, which indicates the lowest rate in cognitive activity, refers to the stagnation of his alternative production. After this stage, he continues the design process with the second and last alternative he produced without seeing further possible options. In this case, we can not say that this strategy leads the novice designer to systematic expansion of his cognitive activity. We found support for the systematic expansion in the experts' design protocols in the experimental findings of Adelson and Soloway (1985). Then, what is the reason for the drop in cognitive activity? Adopting Kosslyn's approach, we can state that if the cognitive activities slow down at some stage, this may be due not only to one activity, but also to the other activities having different roles that run together. Assuming that image generation slows down in parallel with the cognitive activity, when the novice's image generation slowed down at some stage in the conceptual design process, we should look for some reason in parallel cognitive actions, rather than only in one group of cognitive actions.

According to Kosslyn (1995), imagery ability is not all-or-none; a given person is not generally good or bad at imagery. If imagery ability is a single trait, then those who did well on one task should have done well on the others. This did not occur in the experiments conducted by Kosslyn et al. (1984). Rather, there was a wide range of correlations in the performance of the tasks. Indeed, for some pairs of the tasks, doing well on one implied doing poorly on the other.

These results make sense if different aspects of imagery are accomplished by using separate subsystems, which are invoked in different combinations in different tasks. A person, who is poor at one process, such as shifting the image during rotation (because one or more necessary subsystems are ineffective), will be poor at all tasks that require it - but not necessarily poor at tasks that do not require it. The precise nature of the task is an important variable in assessing imagery ability.

This may explain the reason for the difference in unexpected discoveries between the novice and the expert designers. As shown in Table 8, one type of unexpected discovery is more frequent in the novice: discovery of a space as a ground. However, another type of unexpected discovery, discovery of a relation is more frequent in the expert. Both discovery of a new space as a ground and discovery of an old space as a ground in the implicit spaces' category of perceptual actions are approximately two and a half times as much in the novice's design protocol as the expert's. This indicates that the novice's attention focuses more on discovery of implicit spaces than the expert, although the expert's cognitive activity is 2.84 times as much as the novice's in the overall design process. This may be parallel to the goals. The rate of the goals that bring about spontaneous ideas (G1.4) is also higher in the novice's design protocol (18 vs 24%). We can begin to explain this by using the theory of mental imagery: different types of unexpected discoveries may require different tasks and processes to occur in parallel.

We have also searched for the effect of time on imagery. There have been a large number of experimental studies on the time it takes to assemble a mental image and to recognize the resulting pattern or form. Images can be retained only with effort and apparently often cannot be retained long enough to reorganize them. If images are simple enough, subjects can in fact reorganize and discover new patterns in them (Finke, Pinker, and Farah, 1989). People can retain relatively little information at once (Weber and Harnish, 1974). The critical measure is the number of chunks, the number of perceptual units that are present (Kosslyn, 1995). We may explain the expert's lower performance in certain types of discoveries based on this evidence. As shown in Figure 1, the expert's sketches may not be simple enough to discover new patterns. However, the novice's performance on the discovery of implicit spaces is two and a half times as much as the experts (14 vs 34%), as shown in Table 8.

4.2. IMAGE INSPECTION

As stated earlier, the process of looking at objects in images shares many properties of actual perception. Attention is important at this stage. Images can be formed by activating visual memories of global patterns, by activating visual memories of individual parts and then arranging them, or by selectively allocating attention (Kosslyn, 1995). Although the slope of an associative hierarchy may reflect the characteristics of a particular item, it can also relate to how one's attention is allocated (Martindale, 1981). Narrowly focused attention steepens the gradient of the hierarchy, highlighting the strongest associations to the exclusion of weaker ones. Defocused attention, in contrast, makes remote associations more accessible (Martindale, 1981). In addition, defocused attention may result from lowered arousal, which has long been thought to stimulate creative insight (Thurstone, 1952). Evidence on the need for an associative interpretation for creative thinking also comes from Mednick's studies (1962). The creative thinking process is defined as the "forming of associative elements into new combinations, which either meet specified requirements or are in some way useful."

We found strong evidence on the differences in associations in our protocol analysis studies between the novice and the expert designers. Although the rate of perceptual actions are proportional to the total cognitive actions for both expert and novice designers (23 vs 24%), as shown in Table 5, there is a considerable difference in the associations (65 vs 41%) between them, as shown in Table 8. In perceptual actions, paying attention to the features is almost at the same level for both designers (22 vs 25%). Although, the rate of paying attention to the features is slightly higher in the novice, the rate of paying attention to the relations (their creation, discovery, and repeated mention) in the expert's design protocol is more than one and half times as much as the novice's. Especially, repeated mention of old relations holds the highest proportional difference in the perceptual actions' category.

An example of remote association is divergent thinking which refers to the general process of thinking of unusual associations rather than common ones (Mednick, 1962). It may therefore be important to deliberately defocus one's attention when attempting to discover creative solutions to a problem. Our experiment showed that there is a considerable difference (65 vs 41%) in paying attention to the relations between the expert and the novice designers, as shown in Table 8, while the novice's attention mainly focuses on implicit spaces (14 vs 34%). The novice's defocused attention to the relations may not only explain the reason for the drop in the novice's cognitive activity, but also may explain the reason for his almost two and a half times as high performance as the expert's in the discovery of new and old spaces as a ground (5 vs 12% and 9 vs 22%).

Finke et al. (1992) assert that concentrating attention on the common uses of an object, as when one is under pressure to perform, might lead to increased functional fixedness besides reduced amount of divergent thinking. According to the experimental findings of Adelson and Soloway (1985, 1988), experts are better able to form overviews, but thereafter they take longer to develop their understanding and representations, and they more fully consider interactions among functions or components of a system. Our experimental results also indicate that, as shown in Table 7, there is a considerable difference in revisited functions between the expert and the novice (42 vs 33%).

4.3. IMAGE TRANSFORMATION

We store in long-term memory the information necessary to form images, but some process or processes must use that information to create the image per se. To see, we must be able to inspect the object in the image, classifying it in a new way. In many situations we want to transform the object in an image in some way. We can categorize the factors affecting image transformation as follows.

4.3.1. Representational Richness

There is evidence in the literature (Jeffries et al., 1981, Adelson and Soloway, 1985) that experts' models accommodate multiple levels and are rich enough to support mental simulations. Our protocol analysis results also showed that although the rate of drawing actions in the novice's design protocol is one and a half times as much as the expert's (15 vs 23%), as shown in Table 5, this does not positively affect the rate of other cognitive actions in his design process. In other words, the effort spent on physical actions (especially on drawing as its subcategory) by the novice does not correspond to the same rate of perceptual activity. This means that drawing actions of the novice, for some reason, do not directly support the occurrence of the same rate of perceptual actions. Apparently, the novice's sketches are not rich enough to support mental simulations as much as the expert's. However, in the beginning of the conceptual design process, the novice's perceptual activity is twice as much as the expert's. Petre and Blackwell (1997) have found: "Experts tend to spend more time than novices in planning and evaluating, as well as building and exploring structures ‘in their heads’ before making commitments to external representations." This may be a reason for the difference in the rate of drawing actions between the novice and the expert designers. The expert's sketches may be more structured and, therefore, offer more for perceptual and cognitive inferences.

4.3.2. Pattern Goodness

On the other hand, pattern goodness may also have an impact for a possible correspondence to the perceptual actions. Subjects could not reinterpret an ambiguous figure in an image, seeing the alternative interpretation. Perceptual mechanisms organize the input into units and spatial relations among them, and reorganizing these units requires time (Chambers and Reisberg, 1985). The rate of information processing is slower when a designer scans a bad or insufficient image. There is considerable evidence that the perceived goodness of the parts of a pattern affects how easily the parts can be detected (Palmer, 1977) and how effectively they can serve as retrieval cues for the pattern (Bower and Glass, 1976). Designers make revisions not only to correct or to improve a sketch, but also to re-examine the features of a sketch. We also found evidence of differences in revising features between the expert and the novice designers. Besides the higher rate in revising features in the expert designer's protocol (13 vs 5%), as shown in Table 6, we also found higher rates in attention to and mention of a relation as well as discovery of a relation in the expert's design protocol, as shown in Table 8. We can also claim that pattern goodness may positively affect the rate of that type of perceptual actions. In the expert's design protocol, revising features may also positively affect the rate of revisited functions, as shown in Table 7. The novice designer in our experiment revisited the thought of a function less than the expert (42 vs 33%), as shown in Table 7. His performance on perceptual actions related to the relations (such as discovery of spatial or organizational relations, creation of or attention to a relation and mention of a relation), was also much less than the expert's (65 vs 41%), as shown in Table 8. Therefore, perception of the alternative interpretation and organization of spatial relations might take a longer time for the novice. Thus, the novice could only produce 2 alternatives versus 7 of the expert, and 4 pages versus 13 of the expert. This raises a question: are the visual features in the novice's own sketches ambiguous for even himself?

4.3.3. Representational Mismatch

There may be another reason for poorer performance in cognitive activity and productivity. As defined by Finke (1990), subjects show poorer performance when the imagined and perceived stimuli are mismatched or misaligned (Brooks, 1968, Finke, 1986b, Segal and Fusella, 1970). This demonstrated that "perceptual processes can interfere with imagery". In this condition, the parts could be inspected and manipulated, but not actually combined; observing the separated parts could have interfered with the imagined synthesis. This could also explain the poorer performance of the novice designer in our experiment. If a designer's sketching ability does not help him to match the model in his mental imagery to the one on paper, there is a possibility of that his perceptual processes could interfere with his imagery and cause a delay in information processing as well as production of alternative drawings.

4.3.4. Image Size

In addition to the other assertions related to pattern goodness, image size is also an important factor in imagery. More time is required to see parts of objects when they are imaged at smaller sizes (Kosslyn, 1980). Both mental distance and amount of material scanned affect the reaction time. As shown in Figure 2, the novice produced bubble diagrams and alternative layouts on the same page in smaller sizes. Whereas, the expert designer preferred to use a different page for each alternative. Taking it as a design strategy, we could also assume that this might affect the speed of imagery processing.

4.3.5. Mental Rotation

Another reason for the latency in imagery processing can be mental rotation ability. It is possible that one forms moving images by priming the visual system as if expecting to see the results of physically manipulating an object. If so, then the incremental nature of transformation may occur (Kosslyn, 1995). People can "mentally rotate" imaged objects, and the time to do so increases linearly with increasing amounts of rotation (Shepard and Cooper, 1982). Cooper and Shepard (1973) presented evidence that response latency in spatial-relations problems reflects four discrete stages of processing: encoding the stimuli, rotation of the mental representation, comparison of the stimulus, and response. The greater the mental distance to be traveled, the longer it takes to solve the problem. The expert in our protocol analysis studies produced three and a half times as many alternatives as the novice, by continuously transforming one image to the other. The difference in the cognitive activity between the novice and the expert designers may also be due to the latency in information processing based on mental imagery ability in mental rotations. However, in this study we did not assess mental rotation ability, therefore, we have no evidence to support this.

5. Conclusion

In this paper, we utilised the concept that imagery and perception can be considered functionally equivalent processes and imagery shares some of the same processing mechanisms used in perception and recognition, and that imagined objects can be interpreted like physical objects. As put by Slack (1984), research on visual mental imagery has explored what images are, how they are produced, how and when they are used, and what it means to "look at" and "transform" them. Therefore, a model of visual mental imagery might specify the underlying knowledge structures and processes that operate on them. Using the resemblance of imagery and perception, we adopted the theory of mental imagery to explain the differences in cognitive activities between the expert and the novice designers.

5.1. PERCEPTION OF REMEMBERED INFORMATION

We investigated the differences between the expert and the novice designers and found that the expert is more active and productive in the conceptual design process in terms of the rates of cognitive actions and the alternatives produced. The difference in cognitive activities may cause the difference in performance. The imbalance in cognitive activities between the novice and the expert designers may be due to the rate of information processing driven by experience. The theory of mental imagery highlights this hypothesis.

Visual mental imagery is seeing in the absence of the appropriate immediate sensory input; imagery is a perception of remembered information, not new input (Kosslyn, 1995). Our analysis results showed that the rate of remembered information in the expert's design protocol is almost twice as high as the one in the novice's. The expert's ability to use remembered information (visual mental imagery using Kosslyn's terminology) is one of the major differences between the expert and the novice designers.

We searched for the remembered information that we indexed as "old" in both designers' protocols: in physical actions, the rates of revising (13 vs 5%) and copying "old" features (7 vs 3%) in the expert's design protocol are more than twice as much as the novice's, as shown in Table 6. In perceptual actions, the rate of mention of an "old" relation by the expert is twiceas much as the novice's (20 vs 10%), as shown in Table 8. In functional actions, the rate of revisited thought of an "old" function (42-33%) is almost one and half times as much as the novice's, as shown in Table 7. As shown in Table 9, the rate of goals to apply "previously" introduced functions (G3) in the expert's design protocol is five times as much as the novice's (20 vs 4%). Again, as shown in Table 9, the percentage of the goals extended from a "previous" goal (G1.3) in the expert's design protocol is two and a half times as much as the novice's (17 vs 7%). This means that the expert much more frequently sets up chained goals based on "previous" goals, and links goals to each other in comparison to the novice. Based on the differences in the use of remembered information, we could assert that the expert designer uses his imagery more efficiently than the novice in the conceptual design process. Then, what are the crucial effects on mental imagery processing?

5.2. EFFECTS ON MENTAL IMAGERY PROCESSING

The experience and use of mental imagery cannot be conceived of as an independent, unitary facet of human cognition. Rather, it is associated with an array of related psychological phenomena (Slack, 1984). If the cognitive activities slow down at some point, this may be because of not only one activity, but also the other activities have different roles that proceed together. There is a wide range of correlations in the performance of the tasks. If the novice's image generation is slow in the conceptual design process, this may be due to the cognitive activity slowing down. In this case, we should look for its reason in the parallel processing of cognitive actions, rather than only in a certain group of cognitive actions. The effects summarized as follows altogether may be the reason for the drop in the novice's cognitive activity and for the latency in visual/mental imagery processing.

- Different aspects of imagery are accomplished by using separate subsystems, which are invoked in different combinations in different tasks. A designer may be poor at a certain type of imagery process, because one or more necessary subsystems are ineffective, but not necessarily poor at tasks that do not require it. Different types of unexpected discoveries may require different tasks and processes.
- Defocused attention might make remote associations more accessible and stimulate creative insight. Concentrating attention on the common uses of an object might lead to increased functional fixedness besides reducing divergent thinking.
- Ambiguity in sketches may be an advantage for distant associations and, therefore, may support the discovery of implicit spaces, while the structure in sketches recalls the thought of function and supports the occurrence of discovery of associations.
- Pattern goodness and revising features may positively affect the rate of perceptual actions, however, the rate of other drawing actions may not positively affect the rate of cognitive actions unless perceptual actions correspond to some knowledge structures represented by the sketches. Structured sketches may offer more perceptual and cognitive inferences.
- Higher performance in cognitive activity may be dependent on the richness of representational structures and pattern goodness, while poorer performance may be due to a representational mismatch between imagined and perceived stimuli. Mental rotation ability and image size in the sketches may also cause latency in imagery processing.

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