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Sketches from a Design Process: Creative Cognition Inferred From Intermediate Products

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Abstract

Novice designers produced a sequence of sketches while inventing a logo for a novel brand of soft drink. The sketches were scored for the presence of specific objects, their local features and global composition. Self-assessment scores for each sketch and art critics' scores for the end products were collected. It was investigated whether the design evolves in an essentially random fashion or according to an overall heuristic. The results indicated a macrostructure in the evolution of the design, characterized by two stages. For the majority of participants, the first stage is marked by the introduction and modification of novel objects and their local and global aspects; the second stage is characterized by changes in their global composition. The minority that showed the better designs has a different strategy, in which most global changes were made in the beginning. Although participants did not consciously apply these strategies, their self-assessment scores reflect the stages of the process.

Keywords: Creative cognition; Design process; Ill-defined problem solving; Creativity

1. Introduction

People are creative in their everyday lives, whether planning a trip or just doodling a sketch while answering the phone. Less mundane forms of creative behavior are at the root of innovation in every aspect of the economy as well as the arts and sciences. Yet, in the problem-solving literature (Anderson, 1987; Barsalou, 1992; Gardner, 1983, 1985; Kotovsky, Hayes, & Simon, 1985; Newell, Shaw, & Simon, 1958; Newell & Simon, 1972; Posner, 1989; Simon, 1978; Sternberg, 1982) the study of creativity has played only a minor role (Goel & Pirolli, 1989; Greeno, 1978; Guilford, 1950; Reitman, 1965; Sternberg & Lubart, 1996).

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One of the obstacles to research is that creativity is surrounded by an air of mysticism. Creative processes are often regarded as unique, spontaneous, and inaccessible to study in laboratory conditions. As has become increasingly clear over the last 2 decades, at least the more humble forms of creativity can be made accessible to scientific observation in laboratory studies.

Our study aims to track the behavior of novices as they come to grasp with a creative design problem. A design is judged to be creative to the extent that it is both novel and appropriate, useful, correct, or a valuable solution to a problem (Lubart, 2000). Correlations between the amount and quality of preparation and the quality of the end product in a design task (Getzels & Csikszentmihalyi, 1976; Hayes, 1989a, 1989b) indicate that novices are less likely than experts to find such solutions. Nevertheless, a study of novice designers may provide us with insights that cannot easily be obtained in studies using expert designers.

Design problems have no prespecified answers and can be solved in many ways (Boden, 1992; Flower, Schriver, Carey, Haas, & Hayes, 1989; Guilford, 1950, 1956, 1967; Hayes & Flowers, 1986; Koestler, 1964; Maher, 1990; Reitman, 1965; Vernon, 1970; Wertheimer, 1945/1968). For expert designers the task may be relatively well structured in contrast to novices (Gero & McNeill, 1998; Voss & Post, 1988) and be executed in the laboratory with a cognitive fluency not manifested by our present participants. This may also imply that experts are producing routine solutions that fail to compare to their creative work in informal contexts (Schank & Goldstein, 1997), or in relatively unrestricted conditions (Finke, 1990). For this reason, it may be of interest to study the behavior of a group of novice designers, who lack such fallback strategies, but who are used to working in an experimental setting. For this reason, we performed our current study with psychology students.

Where no preconceived plan exists, creative design can exhibit seemingly erratic ways. Consequently, if we wish to understand the creative process, we cannot satisfy ourselves with an evaluation of its end product. Whereas end products often do not convey their history of creation, this may be revealed in a study of the *intermediate products,* which were made during the design process. Research that aims at analyzing the process in which a solution to a design problem is formulated therefore may be served best by the study of intermediate products.

Graphical and industrial designers (Verstijnen, Goldschmidt, van Leeuwen, Hamel, & Hennessey, 1998; Verstijnen, van Leeuwen, Hamel, & Hennessey, 2000), architects (Suwa & Tversky, 1997), and artists (van Leeuwen, Verstijnen, & Hekkert, 1999) often make sketches as intermediate products before producing their final design. Several studies have addressed the role of sketching in creative design processes (Anderson & Helstrup, 1993a, 1993b; Roskos-Ewoldson, 1993; Suwa & Tversky, 1997; van Leeuwen et al., 1999; Verstijnen et al., 1998, 2000). In principle, the design process may depend on these preliminary sketches in several ways. First, the sketches are used to decide which direction to pursue toward the solution. Second, the intermediate products enable the designer to represent and compare alternatives, and they help one to see the consequences of a decision. Finally, the sketches enable the designer to evaluate the intermediate state of the design in relation to the design criteria and his or her own interpretations of the design task. This means that sketches mark the junctions of a design process, and hence, an analysis of sketches is most likely to provide us with insight as to how the design evolved.

The study of intermediate products, such as sketches, could be considered a nonverbal counterpart to the analysis of think-aloud protocols. Think-aloud protocols have been applied in the field of design research (Akin, 1986; Anzai & Simon, 1979; Flower et al., 1989; Goldschmidt, 1992a, 1992b; Hamel, 1990, 1994; Qin & Simon, 1990; Simon, 1973) but face the limitation that they only provide insight into the declarative and verbal aspects of design processes. These techniques are not suitable for procedural and nonverbal aspects of the task. Creative design often involves nonverbal mental structures, for instance, a mental image that can be externalized through sketching.

1.1. Erratic behavior or guided inference?

Although the product of creative design is expected to meet a variety of constraints and requirements, it is commonly agreed that creative discoveries cannot be coerced out of a restricted domain; they typically require a broad search of the possibilities, or a relatively unrestricted generation of possibilities followed by a test of their feasibility. These assumptions led, for instance, to the Geneplore model (generate and explore) proposed by Finke, Ward, and Smith (1992). The Geneplore model is closely related to genetic algorithms for the evolution of creative solutions (Boden, 1990) and their survival and dispersal in a cultural context (Gabora, 2002). These models assume that creative ideas are, in principle, generated as random mutations from preexisting types and subsequently evaluated for fitness. An iterative process of generation, testing, and selection ultimately leads to an optimally fit design. In this perspective, sketches could be seen as the product of such subsequent generations. By using sketches as intermediate products of a design process, we may study the generation of novel items or features and their introduction in the design.

Whereas the selection is made according to some predefined fitness function, the generation itself is essentially random (Simonton, 1988). In this understanding, the design process is a sequence of random generations. When the design takes erratic ways, this may simply be understood as one generation temporarily prevailing over the other, only to be overtaken by another one in later stages of the design. This would mean that the creative process lacks a macrostructure and that its erratic character only betrays its essential randomness.

1.2. Divergent and convergent activity

The processes that occur in these models may be called “creative” in the same sense as natural evolution. This does not explain why some specific solutions are more creative than others, other than that they happen to survive in a process of random generation and selection. Alternatively, we may assume that rather than blind evolution, generation in creative problem solving is guided by some heuristic principles. These heuristics may not be apparent, given the above-mentioned erratic character of the creative process. Yet, a careful study of the intermediate products, such as sketches, and the order in which they appear, may reveal the macrostructure of the process. Such a macrostructure could, in principle, make use of random generation, but would give different preferences at different stages to certain types of productions. We will try to determine whether such a macrostructure exists.

The problem of a macrostructure in the design process can be approached using the terminology of *divergent* and *convergent production.* These terms have a long history in creativity research. They formed part of the Structure of Intellect model, proposed by Guilford (1956). With respect to the creative process, divergent activity was assumed to be the major determining factor (Getzels, 1987; Getzels & Csikszentmihalyi, 1976; Runco, 1992; Torrance, 1987). Divergence implies the generation of new items. Studies from the area of creative writing (Hayes, 1989a), and architecture (Akin, 1986) have suggested that, among others, new meanings are continuously added to existing structure. In sketching, we may therefore look at the production of *new* items or features as an index of divergent production.

Getzels (1975), Getzels and Czikszentmihalyi (1976), Smilanski (1984), Smilanski and Halberstadt (1986), and Wertheimer (1945/1968) argued that a design problem could not be solved by divergent activity alone. Both convergent and divergent thinking processes have to be integrated to arrive at a quality formulation. Intermediate products are evaluated, among others, in relation to the task criteria. Convergence in a design process implies that from one intermediate product to the next, some features will remain unaltered, or previously explored elements will be reintroduced and brought together in the final product. This means that when *old* items are repeated from previous sketches, or reintroduced from earlier ones, this should count as convergent activity.

Alternatively, given the importance of divergent production in design, novel introductions may continue throughout all the stages of the design. Still, we may expect that toward the end of the design convergent production becomes increasingly important, as designers pull their previously generated ideas together once the final production has to be made. Thus, even though new items will continue to be introduced until the end, we may observe an increase in reintroductions as designers proceed toward their final product.

1.3. Local and global processing

Based on earlier work with artists (van Leeuwen et al., 1999), we may propose an additional, more specific hypothesis regarding the way in which divergent and convergent thinking are selectively focused on certain productions. We had planned to study the extent to which design is focused on objects and their features or on their relation with other objects. We call the former *local* and the latter relational, or *global.* In perceptual categorization learning, it has been shown that objects are preferably classified initially by means of their local features. This preference gradually shifts toward relational, global features (Goldstone & Medin, 1994). In learning a serial pattern, it is initially remembered by its local structure and later by its relational global structure (van Leeuwen, Buffart, & van der Vegt, 1988).

Experiments suggest that prolonged practice will have the same kind of effect on figural imagery. Bethell-Fox and Shepard (1988) argued that effects of practice in transforming mental images could be explained on the assumption that images first are transformed in a piecemeal fashion, element by element, but later as a global gestalt. Van Leeuwen et al. (1999) suggested that in the initial stages of design, sketchers are more concerned with local features and more with global ones in later stages. This hypothesis can be tested in this study by coding the local or global characteristics of new, repeated, and reintroduced items. Local-structure processing should be more frequent during the initial phases of the design process, and global-structure processing should be more frequent toward the end.

1.4. Reflexive awareness of design heuristics

If, indeed, creative processes are guided by a heuristic macrostructure, an interesting question is to what degree designers are aware of the heuristics used. This awareness could take two forms: Designers may use the heuristics in an explicit, reflexively conscious manner. In this case, we may expect that they are able to retrospectively communicate that to us. To find out if this is the case, we conducted an exit interview with our participants. Alternatively, although they may not be deploying this strategy in a reflexively conscious way, their conscious evaluation may still depend on this stage of their design. We asked our participants during the design process to reflect on their current sketch in terms of task criteria. Most criteria in a design task are underspecified (Akin, 1986; Goldschmidt, 1990, 1992a; Kotovsky & Simon, 1990; Simon, 1973; Sternberg & Lubart, 1996) and demand personal interpretation (Finke, 1990; Hamel, 1990; Maher, 1990). Some criteria can be altered by the designer without altering the character of the design problem (Akin, 1986; Goel & Pirolli, 1992; Hamel, 1990). In contrast with puzzle-like problems (Missionaries and Cannibals, and Tower of Hanoi), where progress can be inferred from the actual state of the problem (Simon, 1978), a special, additional, self-assessment score, *self-evaluation of progress* was used. Self-evaluation of progress is an indication of the match between the just-finished sketch and participants' ideas about what the end product should be. This measure was inspired by the notion of "feeling of knowing" (Koriat, 1993), the ability to predict one's own future memory performance.

1.5. Individual differences

A panel of art experts rated the final designs of our participants. These ratings enabled us to study the differences between high-rated and low-rated novice design. As it may be assumed that the high-rated designers resemble experts more than the low-rated ones, this comparison may allow us to extrapolate from their behavior to that of experts. Our intention is to investigate to what extent these groups show different profiles in their design behavior. If creative design is a random process, we are likely to observe quantitative differences, for instance, a larger number of productions in the higher scoring group. If the design process is guided by a heuristic, we may find qualitative difference as well, both in the type of heuristic used and in the degree to which these groups are able to reflect on their progress.

2. Method

2.1. Participants

Thirty-one 1st-year students (12 male and 19 female) of the Department of Psychology of the University of Amsterdam received an experimental credit for their participation. They were naive with respect to the professional figural design, including its graphical and aesthetic features.

2.2. Materials

Participants were seated at a large table facing the wall, to create a somewhat secluded work space. The experimenter remained present throughout the procedure but was seated at a separate table, outside of the participant's view. Prior to, and during the task, the participant's table contained: eight written guidelines (see Guidelines in the online annex: http://www.cognitivesciencesociety.org/supplements), a set of numbered sheets of sketching forms and a black marker pen, a small sheet of paper marked "label" (10 × 10 cm in size), and a large one marked "wrapping paper" (30 × 30 cm in size). The experimenter's table contained an experimentation form, a list with requisites, a questionnaire for an exit interview, and a tape recorder.

Each sketching form was divided into two sections: the left side was two thirds of the paper and was outlined by a black frame of 20 cm^2, within which the sketch had to be made. The remaining space on the right contained a list of seven 1 to 100 scales for self-assessment related to task criteria that are given in the instruction: (a) cafe atmosphere, (b) nonalcoholism, (c) intellectualism, (d) large–small, (e) black–white, (f) line shading, and (g) self-evaluation of progress. The first three scales score the required *semantic* features of the sketch; the next three scales concern the *technical* implementation of the sketch and parallel some of the design features of a logo mentioned in the instruction. Participants assessed to what extent they believed their sketch displayed the forms or features that can be associated with the related criteria. The seventh scale concerns the self-evaluation of progress that the relevant sketch brings about (cf. Koriat, 1993). This scale was presented to the participants asking, "To what extent do you think you are making progress in getting closer to the final design" (see Guideline 8 in the online annex). The last and final design was sketched on special sheets, called label and wrapping paper. No scoring form was attached to these sheets.

2.3. Design and procedure

Participants were given written guidelines to the design of a logo. The logo was to advertise a new soft drink with the name "Great Neutral." Guidelines specified the image of the drink as a nonalcoholic alternative to lager beer in pub or cafe settings and mentioned the targeted consumer group as that of young intellectuals. Participants had to work the first letters of the brand name (*G* and *N*) into their design. Participants were shown examples (Igarashi, 1987; Jasaburo, 1977) of the graphical and aesthetic task criteria of the logo. These examples showed that letters could be brought together with other figural components to build a logo and that a logo should be meaningfully related to the image conveyed by the brand. Furthermore, the examples showed that a logo should display a balance between black and white surfaces and that it should preferably be formed using line as well as shading (see Guidelines 3–6 in the online annex). The logo should be usable on both labels and wrapping paper; therefore, it should maintain its clarity on a small and on a large scale (see Guideline 2 in the online annex).

Participants were instructed to make several sketches as preliminary studies for the final design (see Guideline 7 in the online annex). These sketches were collected for subsequent analysis. Each sketch had to be made within the frame of the special sketching form. No deleting or crossing out was allowed. After completing each sketch, participants completed the self-assessment questions before moving on to the next sketch.

Participants were free to decide when to use a new sketching form and at which point a satisfactory design was reached. Participants were instructed about the amount of time allocated to complete the task (1 hr) but were not told how many sketches to draw before making the final design. The final design had to be drawn twice: once on the label sheet and once on the wrapping paper sheet.

The experimenter registered the time spent on each sketch and the cumulative time on task. After participants' completion of the final design, a tape-recorded exit interview was conducted according to a questionnaire. Questions were asked about participants' evaluation of the task in general, and comments were solicited on features of the drawings the experimenter thought unclear. Each of the sketches was reviewed to ensure that they were collected in the proper order, and the participants were invited to explain their motivations for certain decisions relating to the design. Participants were asked whether they were satisfied with the design. Their answers were selected from the categories, *yes, reasonably satisfied, neutral,* or *not quite satisfied.* The exit interview lasted maximally 30 min.

2.4. Analysis

We used the sketches as intermediate products of the design process as it unfolds. We encoded within each sketch the *objects* it contains, its *features,* such as type and graphical and morphological qualities, the objects' location in the *composition* of the sketch, and the *combination* of objects used in the sketch. Features are considered "local," and composition and combination are considered "global" productions. This allowed us to track local and global attributes through the design process and study with across-sketch measures when the attributes were introduced (*new*), repeated from the previous sketch (*repetition*), or reintroduced from an earlier sketch (*old*). We compared these measures for the first and second half of each series of sketches. Together with the exit interview, self-assessment scores, and the art critics' scores for the final design, these data were used to investigate the time course of the design.

3. Results

3.1. General measures

Typical examples of end products are presented in Fig. 1, illustrating that these designs met the requirements given by the instructions. Before producing their end products, participants made a total of 479 sketches, which means their series contained 16 sketches on average (see Descriptive Statistics and Sketches From a Design Process in the online annex: http:/www.cognitivesciencesociety.org/supplements). They needed about 43 min on average to complete the task. A nonconstraining environment is generally considered optimal for creative design (Finke, 1990). The nonconstraining character of this task is reflected in a large variation in time on task, ranging from 13 to 84 min ($SD = 15.33$). There was also a large variety in the number

Fig. 1. Four end products of series. Participants designed a logo for a new soft drink with the name “great neutral”. They were instructed to use the letters ‘G’ and ‘N’, and to attend to semantical and technical criteria.

of sketches produced: between 5 and 49 ($N = 479$, $SD = 9.50$). Despite the guidelines, 17 participants (55%) sketched more than one design on one sketching form ($N = 54$, $M = 2.72$, $SD =$ 2. 02, max = 9, min = 1). This behavior resulted in a total of 144 (29%) *subsketches.* These subsketches could be encoded for alterations but not for time on task. Also, self-assessment scores could not be collected for these subsketches, as each sketch form contained only one scoring section.

There was a great deal of consistency among participants in objects chosen: A total of only 27 different objects occurred across all participants. There was a positive correlation between time on task and the number of objects per sketch, $\rho = .23$, $N = 320$, $p < .05$, subsketches excluded. All correlations in this study are rank correlations, Spearman’s ρ, two-tailed, because of the nonparametric character of the data.

3.2. Within-sketch measures

3.2.1. Object categories

Twenty-seven object categories were distinguished (see Object categories in the online annex) and subdivided into *fixed* objects (1–4), *free* objects (5–23), and *idiosyncratic* objects (24–27). Fixed objects were the ones mentioned in the instruction: the letters *G* and *N* required to occur in the sketches by instruction and the words *great* and *neutral.* For instance, in the top left design of Fig. 1, only the letters *G* and *N* are used. Free objects were introduced by participants’ own choice and have an obvious semantic association with the task criteria: For instance, a glass, a bottle with a bow tie, or a book. Idiosyncratic objects have no obvious relation to the task. For example, a mountain would be encoded as an idiosyncratic object.

3.2.2. Local feature categories

Local structure was scored, first, as the type of object. Maximally four types were distinguished (see Object categories in the online annex). For instance, object category “1” (referring to the letter *G* in a sketch), can be encoded as a capital print (Type 1), a small print (Type 2), a capital script (Type 3), or a small script (Type 4). Object category "19" (referring to a book), can be encoded as a book (Type 1), or a newspaper (Type 2). Furthermore, local structure was scored in terms of a set of feature codes. Feature codes indicate for each object the type of line, texture, position, size, and detail used (see Appendix B in the online annex).

3.2.3. Global-structure categories

The measures used for scoring global structure are combination and composition. *Combination* scores the type of object combination that occurs in a sketch. Only one combination is possible in principle per sketch. When all sketches in a series show the same objects, for example, *G, N,* glass, bottle, and book, then the score is 1 (see Fig. 1, end product, top left). With each sketch showing a different combination of objects, for example, *G, N,* glass, and bottle, or *G, N,* and glass, the score increases with 1 point. On average participants used 8 to 9 combinations in their series with a minimum of 2 and a maximum of 19 (see Descriptive statistics in the online annex). Given an average of 9 objects per series and 4 objects per sketch, this is a small proportion of the 126 possible object combinations. From this we may infer that participants consider only a restricted set of combinations. *Composition* is illustrated in Fig. 2. The location of an object in the sketch was encoded with a lattice method. A rectangular frame is fitted around the sketch. This frame is subdivided in 3 × 3 cells numbered clockwise from 1 to 9. Each object is encoded according to the number of the cell in which it is positioned. For deciding its position, the object itself is framed within a rectangle. The location of the object is determined according to the crossing diagonals of this rectangle. For instance, glass,

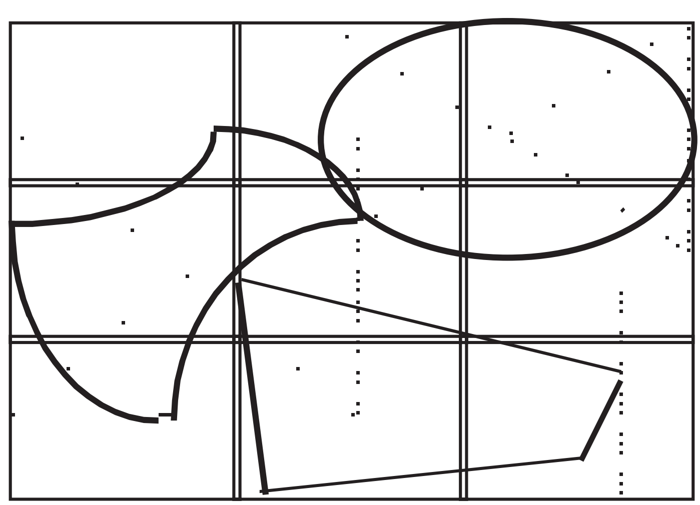

Fig. 2. Encoding of composition. Illustration of the lattice method for the identification of object placement within the composition. Each sketch is divided into nine cells, numbered 1–9, starting at 12 o'clock. Because the center of the rectangle embracing the oval falls in cell Number 2, the oval receives the location score "2" criteria where the score movement (decreases, equal, and increase) of the Self-Evaluation of Progress occur together with more (>3) or less (<3) than three criteria.

G, butterfly tie, and *N* (in end product top left in Fig. 1) receive the composition scores 7, 8, 1, and 9. Participants made on average two alterations in composition per sketch, with a maximum of 10 and a minimum of 0. Related to the 4 objects that occur on average in a sketch, we may conclude that on average, 2 objects appeared in a new place in the composition of a design sketch.

3.3. Across-sketch measures

We distinguish (a) a *new* item, (b) a *repetition* of an item of the previous sketch, and (c) the reintroduction of an *old* item from an earlier sketch. According to this method, when, for instance, the object *G* is drawn in capital script in the first sketch and in capital print in the next, the letter *G* is encoded in the second sketch as *repetition,* and the implementation feature capital print is encoded as *new.* When in a sketch, for instance, one object is repeated from the previous sketch and another is reintroduced from an earlier sketch, and both have not occurred together in a sketch before, the first is encoded as *repetition,* the second as *old,* and their combination as a *new* combination.

The first sketch of necessity contained only *new* items, whereas the last sketch, the wrapping paper, contained 94% repetitions. In the penultimate sketch we observed 92% feature repetitions. The predominance of *repetition* scores in the final stage of the design is understood as a clear sign of converging operation in that stage.

We observed that *new* features and compositions were less frequent than *repeated* ones and more frequent than *old* features and compositions (see New, repeated, and old features, compositions, and combinations in the online annex). *Repeated* combinations were less frequent than *new* ones and more frequent than *old* combinations. In sum, although features and compositions are predominantly *repeated* throughout the design process, *new* object combinations are continually introduced.

3.3.1. First versus second half of the series

We expected that the earlier stage of a design process would be characterized by more local-structure processing, relative to the later stage in which there would be more global-structure processing. We therefore predicted a significant number of within-object (feature) alterations in the first half and between-object (composition and combination) alterations in the last half of the series. The difference between the distributions of feature alterations in the first and the second half of each series was calculated in chi-squares (smallest observed chi-square, $\chi^2(2, N = 105) = 16.41$ $p < .01$. The number of series with a significant chi-square ($n = 23$) was larger than the number of series with a nonsignificant one ($n = 8$): $Z = 2.51$, $p < .01$. These results indicate that two thirds of our series, which varied greatly in length, showed a first part that was different from the second part as to the types of alterations occurring. The observation that the first part of these series was characterized by new features, and the second part by repetitions and reintroductions, corroborates the hypothesis that local alterations feature in the first part of the design process.

As the number of alterations for combination and composition were too small for chi-square tests per series, we calculated frequencies over all series. We observed more *new* compositions and combinations in the first half and more *old* ones in the second half (for exact results see Alterations in features, compositions, and combinations, in online annex). Repeated compositions were also observed more frequently in the second half; however, repeated combinations occurred in equal numbers in the first and second halves.

In sum, as the early phase of the design process showed more new introductions for local features as well as for global composition and combination, we cannot conclude from these results that the design process evolves from local to global. It seems to be more a matter of evolving from divergence to convergence—more introductions in the first phase and more reintroductions and repetitions in the second phase. It is noticeable, however, that repetitions of previous global combinations occurred with equal frequency through earlier and later phases.

3.3.2. Local alterations and global composition

Next we analyzed relations between local- and global-structure processing. We assumed that the amount of processing is indicated by the number of *new* items (divergent production) as well as by the reintroduction of *old* ones (convergent production), as both involve more cognitive activity than repeating an item unchanged from a previous sketch. Local processing was defined as the occurrence of new and old features. The sum values of new and old features were calculated per sketch. The sketches within a series containing, respectively, the maximum or minimum values were identified. Next, we defined four profiles and scored participants according to the type of profile shown by their series. A series could show a maximum (max) or minimum (min) of local features in its first (1) or second (2) part. We thus obtained four profiles: 1max1min, 1max2min, 1min2max, and 2max2min. Sketches that contained a maximum or minimum in the middle sketch or for which the maximum or minimum could not be uniquely determined fell in the category "other." The same was done for the global compositions. Local features and global compositions showed a different frequency distribution over these profiles, $\chi^2(2, N = 31) = 13.66$, $p < .01$ (see Table 1). Local-structure processing predominantly shows the 1max2min profile; 21 (68%) participants made a maximum local processing index in the first half, and a minimal value in the second half. Global composition has either the 1max2min or 1min2max profile, for 11 (36%) and 13 (42%) of the participants, respectively.

The results showed that when local and global processing is not defined as the separate processing of new, old, and repeated items, but as an activity of processing both new and old items,

Table 1
Profiles of local and global processing within series

	Profiles[a]		
Processing	1max2min	1min2max	Other[b]
Local features[c]	21	1	9
Global composition[d]	11	13	7

Note. The values presented are the numbers of series in which the relevant profile was observed ($N = 31$). Global processing is by no means absent in the first part of the process. The first half of the design process is characterized by local as well as global processing but in the second half global processing prevails.

[a]Maximum (max) or minimum (min) in first (1) or second (2) half of the series. [b]Maximum or a minimum in the middle sketch of uneven series. [c]Local is the alteration in features other than repetition and composition. [d]Global is the alteration new and old in composition.

then local processing predominantly occurs in the first half and global processing of composition in the first as well as in the second part of a series. Global processing is by no means absent in the first part of the process. We may conclude that the first half of a design process is characterized by local as well as global processing but that in the second half, global processing of composition prevails. These findings are in line with the assumptions of Wertheimer (1945/1968) who stated that in productive thinking there may be two guidelines at work simultaneously, one working to get at the parts, the other to make the central idea clearer. Despite the fact that they overlap in time, however, the latter prevails in the second stage (Goldstone & Medin, 1994; van Leeuwen et al., 1988, 1999).

3.3.3. Local alterations and global object combination

The relation between feature alterations and object combinations could not be analyzed along similar lines as for composition because each sketch contains only one combination. For the 21 series with the 1max2min profile, we checked whether the sketches that showed a maximum of local feature alterations in the first phase, and a minimum in the second, corresponded to a new, repeated, or old combination. We found that 19 sketches (91%) with a maximum in the first phase showed a new combination and that 15 sketches (71%) with a minimum in the second phase corresponded to a repeated combination. For the 9 sketches in the "other" profile, these frequencies were 8 and 4, respectively. It seems, therefore, that for combination, other than for composition, local and global processing appears to be interdependent throughout the stages.

These results motivated a more detailed look at the combinations. We scored number of objects (*more, less,* or *identical*) and novelty of object (new, repetition, old, or mixtures of these) of all new, repeated, and old combinations. This resulted in three 3 × 7 matrices shown in Table 2. Thirty-seven (59%) of the cells are empty because of logical impossibilities. For instance, a combination, whether new or old, cannot be formed exclusively with objects repeated from the previous sketch when at the same time the number of objects is to be increased. New, repeated, and old combinations were formed, respectively, in 234 (50%), 160 (34%), and 72 (16%) of all 466 sketches. These numbers differed significantly, binomial $p < .00$. The earlier observation of interdependence, therefore, cannot be maintained on a more detailed analysis: There are only 6 new combinations formed exclusively with new objects, and only 4 old combinations with only old objects. New combinations most frequently are formed with a subset of objects from the previous sketch ($n = 52$). New combinations formed with additional objects show a mixture of new and repeated ($n = 51$), old and repeated ($n = 36$), or new, old, and repeated objects ($n = 34$). Also old combinations are mostly formed using a subset of objects from the previous sketch ($n = 36$) or using additional old ones ($n = 28$). In sum, combinations preferably use objects from a previous sketch, sometimes with new or old ones added. The interrelation between local features and global compositions in first and second phases, observed in the previous section, is thus revealed to reflect the "from local to global" order of the whole design at a smaller scale, between subsequent sketches. A novel combination of objects evolves from the set of objects of the preceding sketch.

Table 2
Character of new, repeated, and old combinations according to object type and number

	Type							
Object number	N	R	O	N + R	N + O	R + O	N + R + O	Total
Combination new								
1 more	0	—	—	51	5	36	34	126
2 less	5	52	2	13	2	9	2	85
3 identical	1	—	2	9	2	8	1	23
Total	6	52	4	73	9	53	37	234
Combination repeated								
1	—	—	—	—	—	—	—	0
2	—	—	—	—	—	—	—	0
3	—	160	—	—	—	—	—	160
Total		160						160
Combination old								
1	—	—	3	—	—	28	—	31
2	—	36	1	—	—	0	—	37
3	—	—	0	—	—	4	—	4
Total		36	4			32		72

Note. N = new; R = repetition; O = old. Values represent the number of sketches ($N = 466$) in which the relevant combination was observed. Less than half of the combinations in the matrix are feasible ($n = 26$, 41%). Totals of new, repeated, and old combinations differed significantly; binomial $p < .00$.

3.4. Exit interview

An exit interview was taken, confirming that, first, participants had indeed understood that no prespecified solution was requested and that the problem could be solved in a variety of ways. All participants reported having worked in an undisturbed and concentrated manner. Most (94%) quite enjoyed the task. They liked in particular to use their fantasy and invent things. Eighteen participants (60%) reported that they were positively or reasonably satisfied with the final results, 8 participants (27%) reported they were not quite satisfied, and 4 participants (13%) reported a neutral evaluation of their work. Half of the participants who expressed satisfaction (53%) gave their final drawing a moderate score on self-evaluation of progress; most of the others (37%) gave it a high score. Nine participants gave a "moderately satisfied" score to their final design. However, later in the exit interview they reported being positively or reasonably satisfied.

There was no evidence in the exit interview of any deliberate, overall strategies being applied. One participant captured the ill-defined nature of the task as follows: "Right now I am quite satisfied with the results but I think that in a week from now I would come up with something differently. I would like to continue at home." Second, participants reported more than one occasion in the process on which a "breakthrough" had occurred. These remarks suggest that, to the contrary, progress does not occur in a consciously planned manner, that is, without a road map at hand.

3.5. Self-assessment

Self-assessment scores of sketches ($N = 291$) were collected on the semantic and technical criteria given to participants in the instruction, as well as on the self-evaluation of progress. The subsketches were not counted in these analyses and neither were the first and last sketches. Scores were coded in relation to the preceding sketch with an *increasing, decreasing,* or *unchanged* score. First, we expected fluctuations in the scores of the criteria and self-evaluation of progress, because we assume that the design process does not evolve in an evenly incremental way. Second, we expected a relation between self-evaluation of progress and the criteria, because we assume that sketches' degree of fit with the criteria influences the self-evaluation of progress.

For criteria and self-evaluation of progress, *increasing* scores were more frequent than *decreasing* ones, and *decreasing* scores were significantly more frequent than *unchanged* ones. The larger number for increasing scores is expected; participants generally start their evaluation at 0. The frequent occurrence of decreasing scores, however, showed that participants experience episodes in which a sketch does not answer their requirements. This illustrates that the design process does not evolve in an evenly incremental way. Furthermore, the rank between self-evaluation of progress and cumulative time on task was significant for 15 series (48%). This means that for a large number of the participants, there was no evidence of a linear relation between the time spent on the task and how close they thought they were to the goal.

In 14 series (45%) we observed a significant rank correlation between criteria and self-evaluation of progress. From this we may infer that within sketches, the self-assessment scores of the criteria and the self-evaluation of progress did not always show the same movement.

3.6. High versus low art critics' scores and their correlates

Four professionals assessed the final designs of each participant. These professionals were an independent artist (painter), applied artist (illustrator), art salesperson (artist representative), and a manager (artist counselor). The art critics scored the end products on a scale of 1 to 7. Their scores showed rank correlations ranging from .00 (painter and illustrator) to .06 (manager and painter). Four of the six correlations were significant at the .05 level and two were nonsignificant—two of those involving the manager.

Participants were divided into three groups according to their average art critics' score, resulting in a *high*- and a *low*-scoring group for each 10 participants, and a middle group with 11 participants. Participants who received a *high* score used more objects per series ($M = 10.60$, $SD = 3.86$) than participants who received a *low* score ($M = 6.63$, $SD = 3.70$), $t(18) = 2.35$, $p < .05$. Participants with a *high* score also used more objects per sketch ($M = 4.36$, $SD = 0.89$) than participants with a *low* score ($M = 2.80$, $SD = 1.76$), $t(18) = 2.64$, $p < .01$. Participants with a *high* art critics' score showed no difference in number of objects used between first and second half of series, whereas participants with a *low* score used fewer objects in the first, $n = 235$, than in the second half of the series, $n = 308$, $Z = 3.09$, $p < .00$.

3.6.1. Local- and global-structure processing

Whereas almost all participants showed the 1max2min profile (see Table 1), the one with the 1min2max profile received a lower art critics' score, $M = 1.50$, than the others, $M = 3.73$ ($n = 21$). The category "other" did not show differences from the average.

Global-structure processing profiles differed significantly between high- and low-scoring participants. Participants who used the 1max2min profile for global structure showed a higher art critics' score ($M = 4.11$, $SD = 1.16$) than those who used the 1min2max profile ($M = 3.13$, $SD = 1.36$), $t = 2.13$, $p < .05$. End products that received a higher art critics' score evolved from series in which the maximum of global-structure processing took place in the first half and the minimum in the second. For instance, Participant 1 (see Fig. 1, top right), who produced 22 sketches with an average change per sketch of 9.95, and an art critics' score of 6.25, showed a global maximum in Sketch 8 (the first half) by sketching six objects (*N,* tray, frame, bubbles, fruit, and "other") at a new location and two (*great* and glass) at an old one. By contrast, this participant showed a global minimum in Sketch 13 (the second half) where not one object was sketched at a new or old location. The inverse, maximum in the second and minimum in the first, was characteristic of series with lower art critics' scores. For instance, Participant 12, who produced 5 sketches with an average change per sketch of 20.00, and an art critics' score of 1.75, sketched in Sketch 2 (the first half) one object (bubbles) at a new location and none at an old one. By contrast, in Sketch 4 (the second half) this participant sketched five objects (*G*, *great,* background, bubbles, and spectacles) at a new location and two (*N* and *neutral*) at an old one. These data indicate that the global structure of a design that received a higher art critics' score emerged in the first part of the series. This observation is of importance for the question, whether the most frequently observed profile (from local to global) is preferred because it is an optimal design strategy, or for different reasons. This result shows that the strategy is far from optimal, as the reversed strategy seems to bring a better result. Going from local to global, therefore, appears to be a default strategy of the cognitive system (Goldstone & Medin, 1994; van Leeuwen et al., 1988). This, in turn, suggests that the strength of the more successful designers resides, among others, in their ability to avoid this default strategy.

3.6.2. Match and coherence

We developed the measures *match* and *coherence* to further distinguish between high- and low-scoring design processes. Match describes differences between intermediate and end products and is useful for observing convergent operations. Objects in sketches were scored for features that are identical to the end product, resulting in a sum value per sketch. Participants whose final design received a high art critics' score had series that showed a higher mean match value ($M = 64.11$, $SD = 16.65$) than those whose design received a low score ($M = 56.71$, $SD = 17.60$), $t(338) = 1.86$, $p < .05$. This may indicate that high-scoring participants already worked earlier with object features that would show in the final design. It may also indicate that at an earlier time they already had a clearer picture in their mind of what their end product should look like. During their design process, they consistently tried to produce their imagined product. Attempting to realize one's imagined end product may be considered a form of convergent production. The result, therefore, emphasizes the importance of convergent production in the design process.

Coherence indicates continuity of the process. This measure is based on the frequency of occurrence of a given pair of objects in a sketch, expressed as a percentage of all the sketches of a series. The coherence value of a sketch equals the average frequency of the occurring pairs of objects. Coherence is highest in sketches that are formed exclusively of those objects that occur frequently in the entire series. From the first to the second half of all series, we observed increased, decreased, and unchanged coherence with equal frequency, χ^2 $(2, N = 418) = 0.69$, $p >$

.50, first, last, and middle sketches excluded. We developed four significantly different coherence profiles, χ^2 (3, N = 31) = 11.19, $p < .05$. These profiles express whether the coherence value of the first (F) and the last (L) sketch of a series falls under (U) or above (A) the individual mean coherence value. The FULA profile showed a higher art critics' score (n = 7) (M = 4.36, SD = 1.68) than the most frequently used FALU profile (n = 15) (M = 3.00, SD = 0.89), t(20) = 2.51, $p < .05$. The profiles FALA (n = 7) (M = 3.68, SD = 1.02) and FULU (n = 2) (M = 4.13, SD = 3.01) showed no differences in mean art critics' scores. High-scoring participants used objects in their first sketch that are less frequent in their series overall, but in their last sketch they used objects that had occurred more often than average. The reverse, however, was most frequently observed, first sketch with objects of a high coherence together with a last sketch formed of objects that showed a low coherence. This result suggests that successful designers avoid the default cognitive strategy, not just by focusing on global combinations from the beginning, but also by using certain set combinations and staying with them persistently throughout the design.

Match and coherence showed no significant correlation over all series. However, the correlation between these two measures was significant in the series that received a high art critics' score (ρ = .18, N = 112, $p < .05$, one-tailed) and not significant in series that received a low score. This indicates that high-scoring participants made sketches in which a relation was observed between the end product and the continuity of the process.

3.6.3. Self-evaluation of progress

Self-evaluation of progress averaged scores were higher for the high-scoring group (M = 42, SD = 24) than for the low-scoring group (M = 38, SD = 19), t(18) = 1.93.

Number of objects per sketch and the self-evaluation of progress showed a positive correlation over all series (ρ = .27, N = 320, $p < .01$), in the low-scoring series (ρ = .32, N = 103, $p < .01$), but not in the high-scoring series. This suggests that the lower scoring group evaluated progress in relation to the quantity of work done, rather than in relation to the quality. However, there was no difference between high- and low-scoring groups in the frequency of significant rank correlations between self-evaluation of progress and cumulative time on task. In both groups there were 6 series out of 10 that showed a significant rank correlation between self-evaluation of progress and cumulative time on task. The amount of work done across the task as a whole, therefore, was used by both high- and low-scoring groups to the same extent as an instrument of evaluation.

Match and self-evaluation of progress showed a positive correlation for the whole group (ρ = .39, N = 320, $p < .00$). In the high-scoring series this correlation was stronger (ρ = .43, N = 112, $p < .00$), than in the low-scoring series (ρ = .30, N = 103, $p < .01$), Fischer-Z = 2.19, p = .05. These results indicate that higher scoring participants have a better understanding of how close their design has come to its final stage.

Coherence and self-evaluation of progress showed a positive correlation in the high-scoring series (ρ = .19, N = 112, $p < .05$), but not in the low-scoring series (ρ = .008, N = 103, $p > .50$). These results indicate that high-scoring participants seemed able to select and work consistently on those items that in their understanding improve the quality of the design. We may conclude that high-scoring participants and low-scoring participants differ in a specific way: High-scoring participants do not use the commonly used local-to-global profile. They give greater emphasis to global structure in the initial stage of their design and from the beginning put objects in new relations, which are repeatedly used throughout the design, only to be replaced by a better global idea toward the end. They show a greater predominance of coherent production than low-scoring participants; the high-scoring participants have a different coherence profile, in which they introduce from the beginning the objects that will be found in their final design, and they are able to give more reliable estimates of their progress.

4. Discussion

Our study sought to evaluate the development of a creative design from the given task set by analyzing a sequence of intermediate sketches made while participants advance toward their final design. We analyzed these sketches for structural features, the alterations in these features from one sketch to the next, and the way in which novelty is introduced into the design. Qualitative and quantitative descriptions of the design process were based on the encodings of many series of sketches. These encodings were used to construct measurements about object use and combination, level of novelty, and continuity. With this method, nonverbal and procedural aspects of creative cognition could be revealed. We investigated whether the apparently erratic ways in which the design evolves imply that the evolution is essentially random, or whether there is an underlying macrostructure in the design process.

Participants in our study had no prior design experience. Prior knowledge and experience contribute to the solving of design problems (Maher, 1997). Our study bypassed this problem by providing each participant with a clear task set, based on the guidelines, which included extensive information about the task and a set of examples. Consequently, and in line with the conformity hypothesis (Smith, Ward, & Schumacher, 1993), aspects of the designs showed direct or indirect links to the examples. Generation in imaginative tasks should cross conceptual boundaries, but in doing so it faces limitations because there has to be a balance between comprehensibility and novelty (Cacciari, Levorato, & Cicogna, 1997; Smith et al., 1993; Ward & Sifonis, 1997; Ward, Smith, & Vaid, 1997). Generation, therefore, has even been shown to pick up concepts underlying the features of the examples shown (Marsh, Bink, & Hicks, 1999). The large amount of consistency among the objects selected by our participants suggests that an effective task set has been provided that worked as a vehicle for their creativity, rather than as an obstacle to it.

The analysis produced information about the cognitive processes involved in generation of intermediate products and the reflexive monitoring of creative behavior during the task. We observed that the design process evolved according to specific patterns of item generation. We defined the generation of ideas as divergent and the retake and repetition of items as convergent cognitive activity. Earlier studies (Akin, 1986; Goldschmidt, 1992a; Hayes, 1989a) found that new items not only emerge in the initial state, but also enter into the design process at every stage, including the last episodes of the design process. Items are continuously added to the existing structure. This result was also obtained in this study. Our results thus corroborated the importance of divergent cognitive activity, as Torrance (1987) assumed, in creative design.

For most participants the maximum of novel introductions is situated in the first half of the series. This was independent of the number of sketches made. Divergent activity, therefore, was most frequently observed in the first part of the series, and convergent activity in the second part. This result is in accordance with the hypothesis of Getzels and Csikszentmihalyi (1976), and Smilanski and Halberstadt (1986) that both divergent and convergent thinking abilities are required in the creative process as a whole. We add to this the observation that our participants showed different rates in different stages of the design process. The overall shift from divergent to convergent activity provides a first characterization of the macrostructure of creativity in design processes.

Sketching activities could be focused on more local or global aspects of the design. For local as well as global attributes, *new* introductions occurred mostly in the first part, and repetitions or reintroductions occurred mostly in the second part of the design process. A shift from divergent to convergent operations, therefore, applies both to the processing of local and global structure. According to studies in visual imaging (Bethell-Fox & Shepard, 1988) and sketching (van Leeuwen et al., 1999), we expected an image, a nonverbal structure, once introduced, to be transformed first with respect to its details and only later with respect to its whole structure. Confirmation for this hypothesis was found in the observation that newly introduced objects occurred in novel combinations in a subsequent sketch. The prevalent strategy, therefore, appears to be, first to introduce an object, and next to optimize its relations with the other items. This behavior was observed throughout the design process.

Despite the fact that both local and global processing occur from the beginning, *local processing,* defined as introduction of novel features, or their reintroduction from earlier sketches, appears to be more predominant in the first part of the series. *Global processing* defined as introduction of novel compositions, or their reintroduction from earlier sketches, was observed with equal frequency throughout both parts of the series.

Given that there is such structure, what sense could be made of the erratic appearance of the design process? Object use, attention for task criteria, frequencies of alteration, and self-assessment scores, all contain not only episodes of stability and of progress, but also episodes of discontinuity. One predominant aspect is the frequent interruptions of the ongoing development of an item. Obviously, not all ideas from a preceding sketch are explored and consolidated in the next. We may regard the design process as composed of cycles of focus shifts and continuing thoughts (Suwa & Tversky, 1997). On the other hand, we showed how objects, compositions, and combinations are frequently reintroduced after they had disappeared and after a certain number of intermediate sketches have been made. The interruptions may indicate concentrating on one aspect of the design. Accordingly, those periods in which participants worked with a smaller number of objects than average showed a decline in their progress evaluation and in their scores on the self-assessment criteria. This suggests that these interruptions have the function of removing an obstacle in one aspect of the task criteria. The decrease in the self-assessment criteria expresses frustration or difficulty experienced in dealing with interruptions.

On closer inspection, the design process is often less erratic than it seems. Combinations evolved in large part from the contents of preceding sketches. *New* combinations were rarely formed using only *new* or only *old* objects. Instead, *new* combinations were mostly generated using a mixture of *old* and *new* objects. This specifies the heuristics that guide generating novelty in the design and illustrates how it evolves as one sketch follows the other. Furthermore, despite the relative lack of external constraints for the design task, the restricted number of objects and object combinations that participants employed seems to indicate that production in this task was internally constrained. Taken together, we may infer from these observations that the generation of an item evolves in large part from the preceding sketches.

Chance may play a role in the creative process, but a chance occurrence is meaningful only to the prepared mind (Boden, 1990; Perkins, 1988; Weisberg, 1993). Certain facts or situations only strike us as relevant when we are elaborating on a problem. The advantage of chance is used in the random generation of ideas, in software programs (Dehn & Schank, 1982) and in models of human generation processes. Parnes (1970) pointed out that according to Osborn (1953) evaluation should be deferred to give full play to imagination and idea generation. Chance may also bring about configurations of elements of thought. According to Simonton (1988) the principle of selection is not a deferred evaluation, but the stability of a configuration. Only stable configurations, those with a clear pattern of interrelated parts, rise above the unconscious levels of processing and are thus retained and evaluated in relation to a certain problem situation. The Geneplore Model (generate and explore) proposed by Finke et al. (1992) also assumed that postponing the exploration and evaluation of generated ideas may be associated with more original solutions.

Our current observations are complementary to the models cited previously. Random generations may occur, but what we show is that the design process as a whole is more than just a sequence of random generations. Designers do not move blindly from one generation to the next. Rather, it seems that these generations follow a certain order, in which different productions (local or global) predominate at different times, and where the designer moves from generation in divergent production to generation in convergent production in which the earlier productions are wrapped up and integrated in the final design.

Based on the evidence for a macrostructure in the design process, we may address the question whether participants are aware of it or not. The exit interviews gave us little evidence of reflexive awareness of any strategies used. Self-evaluation of progress showed a reliable relation to the degree to which a sketch contained features of the final design. Evaluations were consistent in the sense that changes in self-evaluation of progress scores were related to changes in the criteria. When more than three of these criteria showed an identical increase or decrease, the self-evaluation of progress moved in the same direction as well. When the scores of the criteria diverged, the self-evaluation of progress was kept the same as for the previous sketch. We may conclude that participants were sensitively oriented to the stage of their design.

Sketches containing a small number of objects are associated with a decrease in the self-evaluation of progress. It could well be that episodes in which a small number of objects is used are indications of participants zooming in on details for troubleshooting purposes. While doing so they may experience creative frustration, or lack of progress. Correspondingly, we found that some of our participants recorded a decrease in the self-evaluation of progress, when introducing new objects, features, or compositions. Some of the participants recorded an increase in their self-evaluation of progress when items of the preceding sketch, or items that had been used earlier in the series, were integrated in the design.

Participants who received a higher art critics' score for their final design could be characterized more specifically, that is, higher scoring participants worked from the beginning with object features that would be employed in the final design. They showed a greater predominance of coherent production than low-scoring participants. This means that they worked consistently with certain object combinations. Moreover, these objects and relations are introduced and modified in an early stage. They give greater emphasis on global structure in the initial stage of their design and from the beginning quickly put objects in new relations, which are persistently explored throughout the design. They were also able to give more reliable estimates of their progress. High-scoring participants seemed better in assessing their design activity in relation to continuity in the process. This is in line with Boden's (1996) observation that creative cognition depends in part on the ability to reflect on one's own creative behavior.

These results showed that the measures developed to describe the relation among intermediate products made it possible to distinguish among individuals' methods of handling a design situation. In the domain of design research it is usually possible to distinguish between experts and nonexperts. In our case, however, our methods have allowed us to observe differences among nonexpert designers.

Participants in this task were not expert designers. The creative cognition approach assumes that normal cognitive processes are open to experimental investigation (Smith, Ward, & Finke, 1995, 1999). Experiments using normal participants doing relatively low-level tasks are informative about creative processes—even Einstein's creative processes (Amabile, 1990). The study of any designer, no matter how inexperienced, must tell us something about designing (Lloyd, Lawson, & Scott, 1995). For an expert designer the task may be relatively well-structured compared to a novice (Gero & McNeill, 1998; Voss & Post, 1988). As a result, more experienced designers may have gone through the task more quickly, thereby producing fewer sketches and using a larger repertoire of design strategies, such as evaluation, and clarifying a solution (Gero & McNeill, 1998). That is, they have acquired a cognitive fluency not manifested by our present participants.

An interesting question, therefore, is whether the cognitive design processes of experts are similar or different in nature compared to those shown by the nonexpert participants. Based on our results, a differentiated answer to this question is possible. The designs that were scored high in our study were produced by participants who used a strategy different from the majority. Whereas most participants were initially concerned with individual features, high-scoring participants initially concentrated on the configuration, which was persistently explored during the design process until the final stage. We may speculate that such a configuration offers an "anchor" for their ideas. It stands to be seen whether this result, obtained by studying a group of novices, turns out to be the preferred strategy for experts.

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