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# Towards supporting evocation processes in creative design: A cognitive approach

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**Abstract**

In order to contribute to a better understanding of creativity in non-routine design activities, we conducted an experimental study that focused on a cognitive mechanism involved in creative design, that of the re-use of aspects derived from previous sources of inspiration. Our objective was to determine to what extent designers consider potential sources as useful for solving a specific design problem. Since the relevance of sources of inspiration may be appreciated differently according to the level of expertise in design, the experiment was performed with two groups of participants: experienced designers and inexperienced designers. The results show differences in the number and nature of the aspects selected by each group of designers as well as in the judgments of usefulness they expressed about the different types of suggested sources of inspiration. On this basis, we discuss how these findings may influence the design of a computational system supporting creative design tasks and we consider how to facilitate the progression from novices to experienced designers.


*Keywords:* Creativity; Design; Problem solving; Expertise; Analogy; Evocation process; Support systems

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## 1. Creativity and design problem solving

Creativity can be characterized as a complex activity, consisting of a special form of problem solving (Newell et al., 1962; Guilford, 1964; Mumford et al., 1994; Matlin, 2001). A main characteristic of creative tasks, such as design tasks, is that the initial state is ill defined (Reitman, 1964; Eastman, 1969; Simon, 1973): designers have, initially, only an incomplete and imprecise mental representation of the design to be performed. The designers' mental representation evolves as the problem solving progresses. Therefore, each designer constructs his or her own representation of the design problem and deals with a problem that has become specific to him or her (Falzon et al., 1990; Simon, 1995). In practice, different designers, supposedly solving the same design problem, reach different solutions (Bisseret et al., 1988). This is especially due to the fact that they adopt various points of view and develop opportunistic reasoning (Hayes-Roth and Hayes-Roth, 1979; Guindon, 1990; Visser, 1990; Bonnardel et al., 2003). In this framework, we can attempt to better understand how creativity occurs in design activities.

Far from the earliest definitions of creativity, which suggested that to create is "to bring into being, to form out of nothing…" (Websters dictionary, 1880), a deep analysis of creative situations attest that new ideas are in fact inspired by old situations pertaining or not to the same semantic domain as the current creative context (see, for instance, Friedel and Israel, 1986; Bonnardel, 2000). Thus, creativity has been characterized by "the sudden interlocking of two previously unrelated skills, or matrices of thought" (Koestler, 1975, p. 121). More precisely, creativity is the result of a relationship between working memory and long-term memory, based on a process of "selective emphasis" (Koestler, 1975).

Creativity has also been described as consisting of the activation and recombination in a new way of previous knowledge elements in order to generate new properties based on the previous ones (Ward et al., 1997; Wilkenfeld and Ward, 2001). According to Ward's structured imagination framework, people who are engaged in generative cognitive activities have to extend the boundaries of a semantic domain by mentally crafting novel instances of the concept. However, experimental results show that people have a strong tendency to rely on exemplars (Jansson and Smith, 1991), even when they have been instructed to be as creative as possible. In fact, the more the participants move away from the first evoked sources, the more they are creative and original (Ward et al., 2002). It appears, therefore, that the most successful uses of analogies may depend on the capacity to move beyond initially retrieved information to better or more refined exemplars, interpretations and source analogues.

Analogy-making may thus be considered as a central process leading to the emergence of new ideas (see, for instance, Boden, 1990; Kolodner, 1993). Two kinds of analogies can be distinguished: intra-domain and inter-domain analogies. Intra-domain analogies refer to the same semantic domain as the object to be designed. The evoked sources of inspiration share many semantic features with the target object. Thus, the evoked objects as well as the target one pertain to the same category. For instance, if the target object is a cyber-café seat, links can be

established with an office seat, a camping seat, etc., which all belong to the "seat" category. By contrast, inter-domain analogies result from true conceptual leaps, escaping from the category of the object to be designed. These analogies are based on features or properties of the target object, which are not a priori prevailing, because they are not prototypical of the category; for instance, the softness or the warmth of a seat. Such properties may be used as cues for activating in long-term memory sources of inspiration that are a priori very far from the target object: a nest, a wave…. These inter-domain analogies seem on a linguistic basis to be the most creative ones, allowing an extension of the search space first considered.

The experimental study we are going to present aims at characterizing the impact of expertise in design on properties that are evoked in the context of design problem solving. In particular, we will highlight how experts and novices differ in their analyses of potential sources of inspiration that are suggested to them. Towards this end, participants were provided with intra- and inter-domain sources. Previous results tend to show that expertise in a domain leads to a freeze in the search space, since experts are used to deal with the same usual problems (see, for instance, Besnard and Bastien-Toniazzo, 1999). In contrast, in creative areas such as design, we argue that such an effect should not be observed, since designers have always to search for creative ideas. Thus, we hypothesize that more diverse aspects will be considered with the acquisition of expertise in design. Expert designers would be more inclined to adopt various points of view about suggested sources of inspiration and consider various types of sources. The results of this experimental study will allow us to suggest ways of supporting the evocation process in creative design.

## 2. Experimental study

### 2.1. Objective

The objective of our research is to characterize how designers judge the relevance and usefulness of various sources of inspiration, which belong or not to the same semantic domain or category as the object to be designed. Our general hypothesis is that, depending on the designers' level of expertise, the usefulness of intra- and inter-domain sources will be judged differently.

As a matter of fact, it is very difficult to access "live" the sources of inspiration that the designers spontaneously refer to, in order to determine the points of views they adopt to deal with these sources; it is also difficult to estimate how they evaluate the utility of these sources with regard to the object to be designed. Moreover, it is well known that the elaboration process unfolds over a long time (days, weeks or months) and does not occur in a continuous way. Therefore, we defined an experimental setting in order to fit as best as possible the (real) context of creative design.

First, we gathered sources of inspiration spontaneously evoked by professional designers during a real problem solving activity aiming at designing a new kind of cyber-café seat (Bonnardel and Marmèche, 2001, 2004). Three kinds of sources of

inspiration were distinguished: intra-domain sources, close inter-domain sources and far inter-domain sources. Towards this end, we used the following criteria:

- A source is judged as *intra-domain* if, without any ambiguity, it pertains to the "seat" category, which is the category the object to be designed (target object) belongs to (e.g., a dental office chair, a rocking chair, etc.).
- A source is judged *close inter-domain* if it keeps some properties of the seat category but not the most prototypical ones (e.g., we can sit on a sledge or on a rocking horse, but there is no back as is the case for the most typical seat: a chair). Moreover, close inter-domain sources integrate specific typical properties that intra-domain sources do not have (e.g., a sledge intrinsically contains a dynamic property).
- A source is judged *far inter-domain* if it obviously does not belong to the category of the target object (e.g., a wave or a nest).

For the experiment, we selected a number of sources, which were unanimously considered by three independent judges as either intra-domain, close inter-domain or far inter-domain sources. Participants in this study were either novice or experienced designers. They were provided with the same schedule of conditions as the one presented to professional designers in the previous study.

First, for each of the suggested sources, participants had to express what aspects of the sources might be considered as relevant for dealing with the design problem at hand.

Second, participants had to assess the utility of each source with regard to the object to be designed.

In order to adapt instructions and formulations to both novices and experienced participants, a professor of Industrial Design defined this experimental setting.

### 2.2. Participants

Twenty-seven students participated in this study. They were differentiated according to their level of expertise in industrial design:

- "Experienced" students had attended a professional training in industrial design for 2 years after the "baccalaureate" (9 participants).
- "Novice" designers were students in psychology who had no particular experience in design (18 participants).

### 2.3. Procedure and experimental tasks

Firstly, the participants were provided with the description of a design problem, which consisted in designing a new seat for a "cyber-café".

The description of the problem was as follows:

> The object to be designed is intended to be used in a Parisian "cyber-café". It should be a particular seat with a contemporary design in order to be attractive for young customers. Such seats should allow the user to have a good sitting

position, holding the back upright. Towards this end, the users should put their knees on a support intended to this function. In addition, these seats should allow the users to relax, by offering them the possibility to rock.

This description is deliberately vague in order to allow participants to create whatever they wish—provided that it is in accordance with the constraints expressed in the problem description. Such a design problem was new for all the participants whatever their level of expertise in design.

Then, the following instruction was read by the experimenter and given as a written text to participants:

> Professional designers already had to solve this design problem. In order to deal with it, they were inspired by various pre-existing objects. You are going to be provided with a list of objects they were inspired by. For each of these objects, we ask you to explain in what it can be useful for solving the design problem that has been described. Your answer can be as long as you wish, and you can come back on what you wrote as frequently as you want.

The participants were provided with a set of 18 source objects, presented as a list of names of objects. This list was based on objects previously evoked by professional designers while solving the problem at hand (Bonnardel and Marmèche, 2004).

The potential sources of inspiration consisted of

- 6 "intra-domain" sources, i.e. objects which belong to the same semantic domain and category as the object to design: an automatic photo booth chair, a dental office chair, a rocking chair, an office chair, a deckchair, and a camping chair.
- 6 "close inter-domain" sources, i.e. objects which belong to another semantic domain than the object to design, but which all share a seating component: a sledge, a hammock, a rocking horse, a canoe, a bicycle, and a swing.
- 6 "far inter-domain" sources, i.e. objects which also belong to another domain but do not include a seating aspect: a wave, a "Prie-Dieu", a nest, a weightlessness position, a climbing position, and a shock absorber.

Each participant was successively involved in two experimental phases.

In the first experimental phase, participants had to judge, for each source, which aspects could be re-used for designing the cyber-café seat. Each participant was provided with a notebook comprising 18 pages (presented in a random order), on which one potential source of inspiration was mentioned.

On each page the following instruction was written, instantiated with the specific name of the object: "*Which aspects of [*e.g.*, an office chair] could be useful for designing the cyber-café seat?*".

Participants had 20 min to perform this task.

In the second experimental phase, the whole set of source objects was presented as a list. Participants had "*to assess the usefulness of each source object of inspiration with regard to a utility scale in five points*" (from 1: not useful at all, to 5: very useful). Participants had 5 min to perform this second task.

### 2.4. Results

#### 2.4.1. Number of evoked aspects

In the first experimental phase (see Table 1), when subjects had to comment on the different sources, the results show that, for each source object, experienced designers evoked significantly more aspects than novice designers, whatever the kind of the suggested sources of inspiration: in mean, respectively, 2.29 vs. 1.38 aspects ($F(1,50) = 11.78; p < .002$).

In addition, novice designers evoked significantly more aspects for intra-domain sources than for close and far inter-domain sources ($F(1,25) = 7.7; p < .01$). By contrast, no significant effect of the nature of suggested sources was observed for experienced designers.

#### 2.4.2. Nature of evoked aspects

In analogy-making aiming at transferring aspects from the source to the target, it is essential to identify which aspects designers focus on and whether it depends on the designers' level of expertise. Towards this end, we referred to the typology of object properties proposed by Cordier and Tijus (2001) in order to characterize the aspects that were considered by participants as useful for solving the design problem at hand (first phase of the experiment). Especially, Cordier and Tijus (2001) defined:

- "Functional properties", which are linked to the use of the object and to changes that can be performed on it.
- "Structural properties", which refer to the description of parts of the object.

In addition, we also took into account the fact that, while designing a new object, designers do not try only to satisfy functional and structural constraints but also take into account their own feelings about the object, whether it is affective or aesthetical.

Therefore, five categories of aspects were defined in order to categorize aspects pointed out by participants:

- *Functional aspects*, referring to the use of the object; for instance, a participant pointed out that "*the seat of an automatic photo booth allows the user to adjust the height of the seat*".

Table 1
Mean number of evoked aspects with regard to the nature of suggested sources and the designers' level of expertise

| Nature of sources<br>Designers' level of expertise | Intra-domain | Close inter-domain | Far inter-domain |
|---|---|---|---|
| Novice | 1.6 | 1.2 | 1.35 |
| Experienced | 2.57 | 2.2 | 2.11 |

- *Structural* aspects, including a description of parts of the object; for instance, about a *bicycle*, a participant proposes "*to keep the pedals in order to create a foot rest*".
- *Affective* aspects, reflecting sensations or feelings produced by the object; for instance, about a *nest,* a participant considered it as "*warm*" and another one as "*bringing a feeling of protection*".
- *Aesthetic* aspects; for instance, about an *office chair*, a participant evoked its "*modern look*".
- *Other* aspects, which are too imprecise to be allocated to a specific category; for instance, aspects such as "*ergonomic*" or "*rational*".

Three judges independently categorized the various aspects mentioned by the participants. A high degree of agreement was obtained (.95). In case of hesitation, a short discussion allowed us to reach a complete agreement.

As pointed out previously, experienced designers took into account more aspects than novices, whatever the nature of the aspects. However, the proportions (in percentages) of the different kinds of aspects are close to each other for the two groups (see Tables 2 and 3).

Participants mainly focused on three kinds of aspects: functional, structural and affective aspects. Whatever the designers' level of expertise, functional aspects are the most frequently mentioned: 42% for novices and 39% for experienced designers (all kinds of sources together). Structural and affective aspects are less frequently evoked: 21% and 31% for novices, and 28% and 22% for experienced designers, respectively. Aesthetic and other aspects are in contrast very rarely mentioned, whatever the designers' level of expertise.

However, the nature of suggested sources seems to exert an influence on the aspects participants focused on, as shown by the proportions of functional, structural and affective aspects. When intra-domain sources were suggested, both novice and experienced designers favored functional aspects. In contrast, when inter-domain sources were suggested (both close and far), novices were more focused on functional aspects than on structural ones, whereas experienced designers shared their focus of attention between functional and structural aspects. Moreover, whatever the designers' level of expertise was, when participants were provided with far inter-domain sources, they mainly expressed affective aspects.

Table 2
Percentages of the different kinds of aspects evoked by novice designers, according to the nature of suggested sources

| Nature of sources<br>Evoked aspects | Intra-domain | Close inter-domain | Far inter-domain | Total |
|---|---|---|---|---|
| Functional | 48 | 48 | 33 | 42 |
| Structural | 25 | 24 | 15 | 21 |
| Affective | 22 | 23 | 45 | 31 |
| Aesthetic | 3 | 3 | 7 | 4 |
| Other | 2 | 2 | 0 | 2 |

Table 3
Percentages of the different kinds of aspects evoked by experienced designers, according to the nature of suggested sources

| Nature of sources<br>Evoked aspects | Intra-domain | Close inter-domain | Far inter-domain | Total |
|---|---|---|---|---|
| Functional | 49 | 36 | 30 | 39 |
| Structural | 21 | 36 | 30 | 28 |
| Affective | 18 | 18 | 32 | 22 |
| Aesthetic | 6 | 3 | 2 | 4 |
| Other | 6 | 70 | 6 | 7 |

In addition, we observed that 30% of the aspects mentioned by novice designers were already specified in the design problem description, whereas it is only the case for 16% of the aspects mentioned by experienced designers. Experienced designers appear to be more able than novices to identify new useful aspects of suggested sources and, thus, to go beyond the constraints specified in the problem description.

Interestingly, it was observed that experienced participants, but not novice participants, frequently integrated various aspects of a source object at the same time, in the same sentence. For instance, about the *rocking-chair*, an expert evoked both a structural aspect and a functional one: "*to keep the roundness of the stand, so that the seat can rock*". Such formulations show that experienced designers try to link different aspects and not only to juxtapose them, as it is the case for novices. It suggests that, when they acquire expertise, designers become more and more efficient in coordinating the various aspects that have to be considered for designing the target object. Looking for consistency throughout the design problem solving may allow designers to avoid potential conflicts between choices related to each component.

### 2.4.3. *Scores of usefulness of suggested sources*

Concerning the second experimental phase (see Table 4), whatever the nature of the sources, experienced designers assigned a significantly higher score of usefulness to the various suggested sources than novices: respectively, 3.15 vs. 2.6 ($F(1, 50) = 7.62; p < .01$).

In addition, novices assigned a higher score to intra-domain sources than to inter-domain sources ($F(1, 25) = 7.87; p < .01$). On the contrary, no significant effect was observed for experienced designers.

## 2.5. *Discussion*

The results we obtained in this experiment show important differences in the evocation process according to the participants' level of expertise in design:

- Novice participants evoked fewer aspects about the different sources of inspiration than experienced participants, especially for close and far inter-domain sources.

Table 4
Mean scores of usefulness according to the nature of suggested sources and to the designers' level of expertise

| Nature of sources<br>Designers' level of expertise | Intra-domain | Close inter-domain | Far inter-domain |
|---|---|---|---|
| Novice | 3 | 2.2 | 2.6 |
| Experienced | 3.25 | 3.2 | 3 |

- Novice participants appeared to mainly focus on functional similarities with the target object, whereas experienced designers seem more inclined to also consider structural aspects.
- Experienced designers were able to take advantage of various sources, semantically near or far from the target object, and to adopt and integrate different points of views about the suggested sources.

These results can be related to previous ones in order to better understand differences in evocation processes due to the level of expertise in design. In particular, while engaged in design problem solving, designers *spontaneously* evoked mainly intra-domain sources, whatever their level of expertise (Bonnardel and Marmèche, 2004). The suggestion of potential sources of inspiration appeared to facilitate the evocation of new sources but differences in the nature of the new evoked sources were observed according to the designers' level of expertise (Bonnardel and Marmèche, 2004). Experienced designers evoked mainly inter-domain sources whatever the nature of suggested sources (intra- or inter-domain sources). In contrast, novices evoked mainly intra-domain sources when intra-domain sources were suggested and slightly more inter-domain sources when inter-domain sources were suggested.

Such results suggest that experienced designers have acquired a particular skill consisting of a stronger fluency in the use of analogical reasoning than novices. Therefore, a concrete objective is to support novice designers in developing more powerful evocation processes.

## 3. Toward supporting the evocation process in design

### *3.1. Some methods and techniques for enhancing creativity*

Various methods and training have been developed in order to enhance creativity (Dewulf and Baillie, 1999; Nickerson, 1999). A number of them aim at facilitating the evocation or generation of new ideas. For instance, one of the earliest attempts consisted of the "brainstorming" approach (Osborn, 1963). Such an approach explicitly distinguishes between two stages: idea elicitation and critical evaluation. Brainstorming is intended to be used by groups, but individuals

can do something similar to it by themselves, as is the case when applying the principle of deferred judgment (Parnes, 1963). Finke et al. (1992), in line with their Geneplore model of creative thinking, recommend that individuals generate ideas in the absence of group influence and then submit those ideas to exploration and evaluation in group settings. Thus, brainstorming can be considered as a search process, the target of the search being to generate innovative and useful ideas. However, findings obtained in the areas of decision-making and problem solving emphasized insufficient search as a common failing, even of human expert thinking (e.g., Perkins et al., 1991; Pyszczynski and Greenberg, 1991). In particular, when individuals have acquired expertise in a field, they tend to reproduce what they are used to, or to look for hypotheses in line with their usual findings (see, for instance, Besnard and Bastien-Toniazzo, 1999). Therefore, it appears useful to increase the production of ideas and especially of unusual ideas. It has been the aim of the Productive Thinking Program (Covington et al., 1974), of the CoRT (Cognitive Research Trust) program (de Bono, 1973, 1992), of techniques such as Synectics (Gordon, 1981)…

Though opinions abound about the efficiency of methods and techniques for enhancing creativity, empirical data are often lacking as well as an understanding of the effects of these methods on participants' thinking. Thus, we argue that proposals for enhancing creativity can be derived from experimental results that are, however, related to real-life tasks.

### 3.2. *Operational objectives*

Based on the qualitative analysis we presented in this paper, two operational objectives can be pursued:

1. To support designers, especially novice ones, in taking advantage of inter-domain sources. For instance, providing them with a potential source of inspiration such as a canoe or a wave may show designers that they can take advantage of diverse sources, even if these sources seem very far from the object to design. Therefore, novice designers may realize the heuristic power of taking into account inter-domain sources.
2. To support them in adopting various points of views about sources, whether they are intra- or inter-domain, and not only functional ones, which are the most spontaneously evoked, but also structural, aesthetic, affective sources.

Such objectives could be reached, at least partially, through pedagogical actions during design education (Casakin and Goldschmidt, 1999) or through specific creativity training groups (Dewulf and Baillie, 1999). In addition, the use of computational systems could be particularly useful for providing designers with large database consisting of a lot of pictures or words potentially relevant for creative design tasks (Nakakoji et al., 2000).

### 3.3. Proposals for a computational system supporting creative design

With regard to our results, we argue that a computational system aiming at supporting creativity should include four types of components (see Fig. 1):

- A database consisting of very diverse sources of inspiration, intra- and inter-domain.
- A space of points of view (structural, functional, aesthetic, etc.).
- A diagnostic module for identifying the sources that designers consider, as well as the points of views they adopt, at different steps of the design process.
- An assistance module for providing designers—users of this system—with new potential sources of inspiration or new points of view, or to encourage the designers to integrate these points of view in order to design the target object.

Developing the database of sources of inspiration implies the identification of the various sources, both intra- and inter-domain, that can be relevant for a specific design task. Potentially, an infinite number of sources can be relevant, but a good starting point should be to consider the sources spontaneously evoked by expert designers in the same task—as we did for the cyber-café design problem (Bonnardel and Marmèche, 2001, 2004). Such a database should be then automatically extended and enriched through the use of pre-existing databases providing other objects belonging to the same semantic category as the sources gathered with designers, or to related categories.

For identifying the space of the various points of view (e.g., functional, structural, etc.) that can be adopted for dealing with different types of sources, each point of view could be defined on the basis of a set of terms. For instance, expressions such as "it is useful for…", "it can be used for…" could refer to a functional point of view. These terms and their synonyms would allow the identification of the point of view

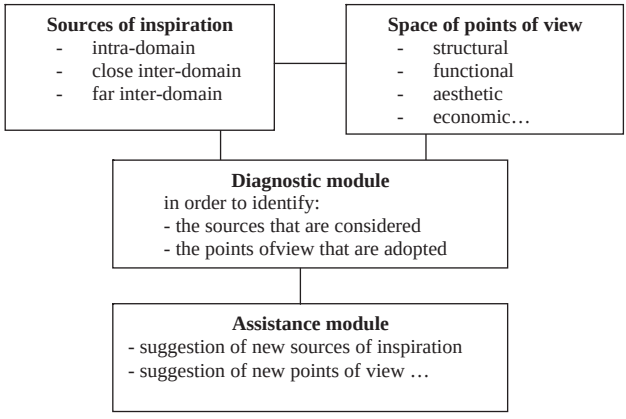


Fig. 1. Modules of a support system for creativity.

adopted on the problem at hand, on the object to be designed or on a current source of inspiration.

The diagnostic and assistance modules would be based on the databases of sources of inspiration and points of view. The envisioned computational system would be built in accordance with a context-aware computing approach (Selker and Burleson, 2000). Therefore, both explicit and implicit interactions would occur between the user (i.e. the designer) and the system, in order to adjust suggestions to the cognitive model of the user.

A first interest of such a computational system would be to allow the identification of the specific thought processes of different designers in order to characterize the inter-individual variability between designers, even between expert designers; and, in addition, to find out some invariants in expert design activities.

A second interest would be to better specify differences between novice and expert designers, through an identification of the different kinds of sources they refer to and the points of view they are inclined to adopt. This diagnostic would focus on the search space considered at a given time by the different designers.

From such a diagnostic, different kinds of suggestions should be given to novice, or even to expert designers:

- To consider sources pertaining to semantic categories different from those spontaneously evoked.
- To adopt different points of view with regard to the evoked sources.
- To coordinate different points of view in order to reach a better integration of the relevant aspects of the object to be designed.

Such suggestions should be delivered at different times of the design process, based upon the evoked or suggested sources of inspiration, as well as upon the considered criteria of analysis of these sources.

Finally, such an assistance to idea generation could be emphasized by designers through "externalizing" (Nakakoji and Yamamoto, 2003), i.e. the creation of external representations which are progressively modified by designers as they reflect-in-action (Schön, 1983).

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