The creative process in design

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Abstract

Society's need for innovation is constantly growing, driven by a demand for new products. To help designers meet this need, we have to fully understand the creative process in design. In this chapter, Bonnardel, Wojtczuk, Gilles and Mazon characterize creative design activities and provide descriptive models of creativity and design thinking. They then describe two complementary studies. In the first one, professional designers had to identify key stages and factors for their process of creative design thinking, via interviews and questionnaires. In the second one, design students were exposed to specific teaching methods, which allows an analysis of aspects of the design process related to divergent/convergent thinking. Bonnardel et al. use these results to highlight components of the creative design process that could be enhanced by particular teaching methods and/or computational systems.

1. INTRODUCTION

Companies and designers face the challenge of coming up with products that are both new and adapted to future users. The process of design thinking therefore requires a degree of creativity. However, the task of imagining and conceiving new products is particularly complex for designers (Bonnardel, 2012; Bonnardel, Forens, & Lefevre, 2016). In order to understand the process of design thinking more clearly, we begin by describing the general characteristics and current models of both creativity and design activities, at the macro and microprocess levels (Section 2). We then describe two studies we carried out: the first with professional designers to determine how they perceive of their own process of creative design thinking (Section 3), and the second with design students to determine how teaching methods based on either divergent or convergent thinking influence certain features of their design thinking process (Section 4). Finally, in the light of these studies, we identify characteristics of the creative design process that could be enhanced by particular teaching and/or computational modalities (Section 5).

2. CHARACTERISTICS AND MODELS OF THE PROCESS OF CREATIVE DESIGN THINKING

2.1 General characteristics of design activities

From a cognitive point of view, design activities can be regarded as problem-solving activities. More specifically, we adhere to Treffinger (1995)'s definition of a *problem* as any 'important, open-ended, and ambiguous situation for which one wants and needs new options and a plan for carrying a solution successfully' (p. 304). Design problems are regarded as *ill structured* or *ill defined* (Eastman, 1969; Simon, 1995), insofar as designers' mental representations are initially incomplete and imprecise. These representations therefore have to be completed through the coevolution of problem and solution spaces (Dorst & Cross, 2001). Moreover, when designers search for a design solution, they frequently engage in an *opportunistic process*, where each new decision is motivated by the one before (Hayes-Roth, 1979; Visser, 1994). As a consequence, the decision process in design results from both top-down and bottom-up processes. It can be multidirectional and occur at different levels of abstraction.

Design problems are also regarded as *open-ended* or *wicked* problems, insofar as they have a large number of possible solutions (Rittel & Webber, 1984). Furthermore, as pointed out previously, in creative (or non routine) design contexts, design solutions must be both *new* and *adapted* to the characteristics of the situation or context, including future users and usages (Bonnardel, 2006, 2012). This twofold requirement directly corresponds to definitions of creativity, which can be viewed as the ability to produce work that is both novel and appropriate (Sternberg & Lubart, 1999). In accordance with this definition, in design situations, we argue that a creative approach (Bonnardel, 2000, 2006) requires both the enlargement of the search area for creative ideas and a focus on the project's constraints. Designers must come up with original products that are quite distinct from existing ones, but which suit and do not destabilize users. Creativity is therefore dependent on both the individual who creates the new products and the environment and society in which these products are created (Csíkszentmihályi, 1999; Lubart et al., 2003).

2.2 Macroprocess of creative design thinking

According to Botella, Nelson, and Zenasni (2016), two approaches can be adopted to describe the creative process. One allows for the description of the different stages of the *macroprocess*, while the other allows for the identification of the mechanisms (or *microprocesses*) involved in the creation of ideas. These two types of description suggest that creativity can be analysed as either one general process or several specific processes, depending on the level of analysis and the characteristics of the individual or context.

At the macro level of the design process, early models described it as being based on *a sequence of stages*. Asimov (1962), for instance, identified three such stages: analysis, synthesis, and evaluation (see Figure 1). *Analysis* corresponds to gathering the relevant information (or preparing the problem) and framing (or (re)formulating) the problem, *synthesis* is associated with the search for an appropriate solution, and *evaluation* can be described as the validation of the proposed solution. If the evaluation stage yields unsatisfactory results, the whole process is repeated. This model was reinterpreted by McNeil, Gero, and Warren (1998), who showed that there is more than one possible sequence for these stages: after evaluation, for instance, the designer can proceed to either the analysis or the synthesis stage.

Bonnardel (2009) compared these models of the design process with models of the creative process, such as those developed by Wallas (1926) and Amabile (1996) (see Figures 2 and 3). For example, Wallas (1926) pointed out the importance of an incubation phase, during which numerous associations are made without any conscious effort on the designer's part. These associations may be followed by some kind of illumination, when an interesting idea is consciously considered. Subsequent models of the creative process added several layers of complexity to this initial proposal. Amabile (1996), for instance, included other stages in the creative process, such as identifying the problem and communicating the final output to others. Mumford et al. (1991) also described a more elaborate sequence of stages (problem construction, information encoding, category search, specification of best-fitting categories, idea evaluation, implementation, monitoring), with many feedback loops between them.

INSERT FIGURES 1, 2 and 3.

Figure 1	Figure 2	Figure 3
Design process by Asimov (1962)	Creative process by Wallas (1926)	Creative process by Amabile (1996)

Designers' activities are usually viewed not as a linear succession of stages, but as an iterative process (as described in Section 2.1), where the mental representation of the (initially incomplete) problem gradually comes into sharper focus as the problem-solving process moves forward (Simon, 1973, 1995). Zeisel (1981)'s metaphor of a spiral is a good illustration of the dynamics of the design problem-solving process and its conceptual jumps between iterative cycles. For his part, Schön (1983) talked about a *reflective conversation* between the designer and external representations of the object to be designed. During this process, designers make unexpected discoveries, which can be positive (results perfectly meeting requirements), negative (emergence of problems interfering with the goals being pursued) or innovative (perception of new directions for creative search). Other models of the design activity include components related to situated cognition. This is, especially, the case of the function-behaviour-structure (FBS) model (Gero, 1998), the analogy and constraint management (A-CM) model (Bonnardel, 2000), and the description of design put forward by Tan and Melles (2010), in line with the opportunistic nature of design activities (see Section 2.1).

These models were recently complemented by analyses and comparisons between different creative domains (Glăveanu et al., 2013), with reference to John Dewey's work (1934). According to this author, action and creativity are brought together by human experience. It is based on the interaction between a person and the environment, and is intrinsically related to human activity with and within the world (for more information, see Glăveanu, 2012). According to Glăveanu et al. (2013), action is a continuous cycle of *doing* (actions directed towards the environment) and *undergoing* (taking in the reaction of the environment). Through these interconnected processes, action can be taken forward so that it becomes a *full* experience.

2.3 Microprocesses involved in creative design thinking

In accordance with the dual criteria of novelty and adaptation to the context, the A-CM model (Bonnardel, 2000, 2006) highlights the roles of two main cognitive processes, which may have contrasting effects and contribute to both divergent and convergent thinking.

1. *Analogical thinking* and, more generally, *associations* can, in certain circumstances (see, for instance, Bonnardel & Marmèche, 2004, 2005), lead designers to open up or extend their search space to new ideas, in line with divergent thinking. Although they can engage in other forms of creative thought (see, for instance, Mumford, 2003), we argue that it is important for designers to establish connections between the design domain (e.g., a mechanical device) and other domain(s) that can provide them with inspiration (e.g., a biological system). Analogical thought can allow designers to transfer the features of one or more sources of inspiration to the design solution being constructed. Final design solutions can therefore result from the combination of several concepts or ideas. Associations can also be useful when designers wish to propose solutions whose features contrast with the source of inspiration and thus break with pre-existing objects, products or entities (Bonnardel, Didierjean, & Marmèche, 2003). However, there is also a risk of *design fixation*. If designers are too focused on sources of inspiration, they may have difficulty opening up

their idea search space (Jansson & Smith, 1991; Chrysikou & Weisberg, 2005). Thus, conditions have been identified that allow designers to benefit from analogical thinking and associations during the process of design thinking (see, for instance, Bonnardel & Marmèche, 2004, 2005).

2. *Constraint management* allows designers to fine-tune their search for ideas. More specifically, we argue that designers' mental representations are shaped by a variety of constraints (e.g. Bonnardel, 2000), which govern their choices and decisions. We can identify several kinds of constraints (see, for instance, Bonnardel, 1999, 2000). Some constraints can be regarded as being either external to the designer, as in the case of *prescribed constraints* derived from a design brief or schedule of conditions, or internal to the designer (referred to here as *constructed constraints*), based on his or her previous experience and preferences. Other constraints (referred to here as *deduced constraints*) can be inferred by designers from an analysis of the current state of the design problem or from the implications of previously defined constraints. These different kinds of constraints can be linked to divergent thinking when they guide designers to look for ideas in a conceptual domain other than the one of the design product being conceived. They can also lead to convergent thinking, insofar as they help designers to assess ideas or solutions, and gradually delimit their search space until they reach a solution that is both new and meets all the various constraints.

According to the A-CM model, analogical thinking (as well as associations) and constraint management interact throughout the design process. They also influence other cognitive processes involved in design thinking, such as constructing mental representations, evaluating solutions, and adopting different perspectives.

This view is in line with Stokes (2007), who holds that implementing constraints reframes the problem and induces a new one for designers to solve. It is also consistent with Kelsey, Medeiros, Partlow, and Mumford (2014), who argue that constraints can generate creative solutions to problems. We believe that creative activities cannot take place (or at least only with considerable difficulty) unless constraints are taken into account, be they internal or external.

Our view is also in line with the GENErate and exPLORE (Geneplore) model (Finke, Ward, & Smith, 1992; Ward, Smith, & Vaid, 1997; Ward, Smith, & Finke, 1999). According to this model, there are two generic phases of creativity:

- a generative phase, in which mental representations, or *preinventive* structures, are constructed;
- an exploratory phase, in which these structures are explored in ways that lead to insights and discoveries.

These stages in the production of creative outcomes are seen as distinct, yet cyclical (Finke, Ward, & Smith, 1992). Moreover, according to the *path of least resistance* described by Ward (1994), creativity is based on the activation of previous knowledge elements and on their re-combination to generate new outputs.

3. STUDY OF PROFESSIONAL DESIGNERS' CREATIVE DESIGN THINKING

3.1 Objective

This first study was conducted to analyze designers' perceptions of their own process of creative design thinking. More specifically, through interviews and questionnaires, we collected data about their perceptions of both their creativity and the stages in their design thinking process.

3.2. Method

3.2.1 Participants

We recruited a sample of 25 professional designers, comprising 19 men and 6 women, with an average of 14 years' experience in design.

3.2.2 Procedure

In line with the themes explored under the CREAPRO ANR contract, we applied a specific research protocol comprising a semi-structured interview and a questionnaire. The construction of the interview guide and the questionnaire were based on the multivariate approach to creativity devised by Sternberg and Lubart (1995) and Lubart et al. (2003). This is a useful approach because it takes both the individual's characteristics and the environmental conditions into account. We therefore considered a variety of factors thought to influence the development of creative potential: cognitive (e.g., intelligence, knowledge), conative (e.g., personality, motivation), emotional, and environmental.

We conducted the *interviews* to analyze the perceptions that designers have of their own process of creative thinking and the stages in their creative process. These retrospective accounts of creative events in design provided by the designers themselves may not have been wholly reliable, but they did give us an overview of the designers' subjective perceptions of their own creative design process. The interviews were conducted individually, and their questions were divided into three phases: (1) general questions that allowed the designers to introduce themselves, say how long they had practiced their profession, and describe the training they had had; (2) questions about their creative productions; and (3) questions related to their process of design thinking-first a general description, then a more detailed one, focusing on what they considered to be their best creative production.

After the interviews, the professional designers were provided with a *questionnaire* that encouraged them to think about the factors described in the multivariate approach. This questionnaire comprised a list of items liable to influence their creativity. In accordance with the multivariate approach, we selected four types of items: cognitive, conative, emotional, and environmental. Participants rated the importance that each item (and its sub-items) had for their creative process on a 7-point Likert-like scale.

- For the cognitive factors, the following sub-items were taken into account: general intelligence, ability to identify, define and redefine a problem, selective encoding, selective comparison, selective combination, divergent thinking, evaluating ideas, flexibility, domain-relevant knowledge, and convergent thinking.
- For the conative factors, the following sub-items were taken into consideration: perseverance, tolerance for ambiguity, individualism, risk taking, emotional stability, agreeableness, extraversion, consciousness, openness to new experiences (openness to dreaming, aesthetics, feelings, actions, ideas, and values), ability to take a step back, humbleness, self-criticism, motivation (intrinsic and extrinsic motivation, motivation to succeed, need for closure) and need to experience emotions.
- For the emotional factors, we probed emotional intelligence, emotional lucidity, ability to identify emotions, ability to regulate emotions, emotional granularity, alexithymia, emotional expressivity, affective intensity, emotional ambivalence, and emotional creativity.
- For the environmental factors, we explored constraints, physical environment, social environment, techniques, finances and important life events.

For each item, we provided a clear definition of the vocabulary we used, so that all the designers would have a similar understanding of the terms we employed.

3.3. Results

After setting out the results of the interviews and questionnaires, we summarize the major stages we identified in the process of design thinking as perceived of by professional designers.

3.3.1 Specific stages based on interviews

To identify the different stages in the creative design process described by the designers during the interviews, we focused on their responses to the question ‘Are there any specific stages in your creative process? Could you name them?’

First of all, we should stress that even though all the designers were able to name the different stages in their creative design process, they produced nonlinear descriptions of their work. We recorded several comments like this one: ‘I do everything at the same time, I have to validate my work by all possible means, I constantly shift from drawings to mock-ups and from mock-ups back to drawings, because each time I find something unsatisfactory, and have to start all over again from the beginning’.

We processed these data by (1) collecting the words used by the designers to describe and name the stages of their creative work, (2) placing them under different headings. We also took account of the order in which these stages were mentioned.

The overall results allowed us to create different headings corresponding to five stages in the process of design thinking (see Table 1): 1) *idea building*, based on documentation, as well as impregnation and analysis of the stimuli present in the environment; 2) *idea developing*, based on sketching and both divergent and convergent thinking; 3) *idea materializing* through mock-ups; 4) *realization or finalizing*, with regard to final constraints; and 5) *presentation to the relevant audience*, such as customers.

Table 1. Stages mentioned by the professional designers during the interviews.

	Number of occurrences
Stage 1	
Having an idea (*intuition, desire, motivation*)	**12**
Impregnation (*observing the environment, collecting experiences*)	5
Reflection (*analysing, thinking about the problem*)	5
Building the brief (*thinking about constraints, listening to the customer*)	3
Documentation (*researching the customer, technology, benchmark*)	**12**
Incubation	1
Eureka	1
Stage 2	
Sketching (*divergent thinking, drawing, shape*	**16**

searching, idea searching)	
Incubation	2
Experimenting (*tests, more accurate drawings*)	3
Convergent thinking (*searching for a concept, associating different constraints*)	**11**
Evaluation leading to choices (*being critical, choosing one or more solutions*)	3
Stage 3	
Mock-up (*exploring materials, visualizing details, validation, 3D*)	**13**
Rectifying (*trials, experimenting, correcting, iterations*)	6
Incubation	2
Stage 4	
Final constraints (*validating with customer, manufacturing constraints*)	10
Finalizing (*deadline, modifications, realization, prototype*)	**17**
Stage 5	
Presentation (*delivery, final product, exposition, presentation to the customer)*	7

3.3.2 Factors based on questionnaires

To identify the main factors involved in the creative design process, we considered the responses given by all the designers to the questionnaires.

Overall results indicated that the designers considered the cognitive factors to be most important factors for their creative process (mean rating = 5.36; *SD* = .75). These were followed by conative factors (*M* = 5.18, *SD* = .57), environmental factors (*M* = 4.95; *SD* = .96) and emotional factors (*M* = 4.13, *SD* = .88).

We also conducted a factor analysis to determine whether any regularities could be observed in the designers' ratings of specific items. We focused on cognitive items, given that they were considered to be the most important ones, and identified three outstanding factors:

- COG1 (*problem-solving* profile), which grouped strongly correlated items (general intelligence, idea evaluation, and convergent thinking) and was negatively correlated with divergent thinking and selective comparison;
- COG2 (*divergent* profile), which grouped divergent thinking, flexibility and domain relevant knowledge, and was negatively correlated with problem identification and selective comparison;

- COG3 (*problem-framing* profile), which grouped selective comparison and the ability to identify, define and redefine a problem, and was negatively correlated with domain-relevant knowledge.

3.3.3 General stages

The data we gathered also allowed us to identify three general stages that the professional designers regarded as particularly important in their process of creative design thinking:

- *Definition and redefinition of the creative problem* (corresponding to the *problem-framing* profile), with a mean rating of 6 on the 7-point scale. The designers explained that they initially consider the constraints provided in the design brief (or schedule of conditions), later supplementing them with others.
- *Openness to aesthetic dimensions, new experiences and new ideas* (corresponding to the *divergent* profile), with a mean rating of 6.43 on the 7-point scale. The designers explained that they draw ideas from other domains and that these ideas can be useful both for understanding the object to be designed and for dealing with the design problem at hand.
- *Self-assessment or reflexive evaluation* (partially corresponding to the *problem-solving* profile), with a mean rating of 6.11 on the 7-point scale. Here, designers evaluate their own creative productions. These self-assessments can be supplemented by external evaluations performed by other persons, especially people who are not involved in the design field.

These three main stages can be related to Botella et al. (2016)'s creative *macroprocess*, in contrast to idea creation mechanisms, which can be regarded as *microprocesses*.

3.4. Discussion

We predicted that the professional designers in our sample would mention some stages in their creative design process more frequently than others, allowing us to identify the nature of their creative macroprocess. Three such stages were indeed identified: (1) definition and redefinition (or *problem framing*) of the creative problem; (2) openness to aesthetic dimensions, new experiences and new ideas (possibly contributing to divergent thinking); and (3) reflexive evaluation (possibly contributing to convergent thinking). In addition, our analysis allowed us to highlight repetitive sequences that took place throughout the design process, similar to those described in the Geneplore model (Finke et al., 1992; Smith et al., 1995; Ward et al., 1999), where the generation of ideas is followed by their exploration. During the *idea generation* stage, designers thought about how to build their own ideas, and chose one or more ideas they wished to develop. To this end, they evoked previous experiences in order to find sources of inspiration while thinking about the problem. This process was based on both analogies and the generation (or management) of constraints, in accordance with the A-CM model (Bonnardel, 2000, 2006). Our professional designers therefore engaged in the co-evolution of problem framing and problem solving described by Dorst and Cross (2001). *Idea development*, when the designers externalized their ideas in the form of sketches, mock-ups or prototypes, in line with the exploration phase of the Geneplore model, characterized by experimenting and convergent thinking, rectifying, and finalizing. In this model, each sequence is repeated until the designer can move on to the next stage, although that is not definitive, as designers often have to go back to the previous stage, in order to rectify unsatisfactory features they have just discovered. The following stage begins with the validated form of the idea (with different levels of detail) developed in the previous stage (choice of an idea, validated mock-up, final prototype). Our findings are also in line with some models of the creative process, such as those developed by Amabile (1996) and Mumford et al. (1991). The *problem identification* or *problem construction* stage, which was described in different ways by designers participating in our study (e.g., desire for a specific theme, detection of a need in the environment, or just a sudden thought), gradually leads (possibly after iterations), either consciously or unconsciously, to *idea evocation*. The *documentation* stage in our description corresponded to the *preparation* stage in Amabile's model, sketching was part of *idea generation*, while mock-ups and finalizing mainly corresponded to the *validation* stage. We also highlighted the importance of convergent thinking in design, which corresponds to the *synthesis* stage in McNeill et al. (1998)'s model. Some designers participating in our study also mentioned a *communication* stage, although not all of our participants considered it to be part of the creative process.

4. STUDY OF STUDENTS' CREATIVE DESIGN THINKING

4.1 Objective and hypotheses

This second study was conducted with design students to determine the influence on their design thinking process of pedagogical methods focusing on either the evocation of ideas (in line with brainstorming) or the management of constraints (Bonnardel, Mazon, & Wotjczuk, 2013; Bonnardel & Didier, 2016). The students were exposed to one out of two types of design project instructions during short sessions and, then, they had to develop their design project.

We hypothesized that training students to produce ideas promotes divergent thinking and, by so doing, evokes still more ideas. By contrast, training them to manage the constraints pertaining to the design project promotes the generation of yet more constraints, which frame the design problem and prompt convergent thinking. We therefore expected these two types of training to have a differential influence on the number of ideas or constraints cited by design students in the early design phase. Moreover, they might also influence the nature of the constraints expressed by participants.

4.2 Two design project-oriented methods

In accordance with the above-mentioned models, and more especially the A-CM model (Bonnardel, 2000, 2006), we developed two project-oriented methods for design students. These shared similar bases, but were each intended to induce a different focus of attention (see Bonnardel, Mazon, & Wotjczuk, 2013; Bonnardel & Didier, 2016).

• The first method was intended to encourage designers to come up with creative ideas, in accordance with some of the stages identified in the previous study, and in line with the brainstorming method developed by Osborn (1963). In order to apply this method, called CQFD, participants had to follow four rules:

- C for *No censorship*, where participants must avoid self-censorship and express all the ideas that come into their heads;
- Q for *Quantity*, where participants have to write all these ideas down;
- F for *Farfelues* (French adjective meaning *wild*, *fanciful* or *unexpected*), where participants have to express even the most madcap or extravagant ideas that spring to mind;
- D for *Demultiplication*, where participants have to use different combinations of all the ideas they have expressed so far to find new ones.

• The second method was intended to encourage designers to take account of and manage the design problem's constraints, in accordance with other steps identified in the previous study. In order to apply this method, called CQHD, participants again had to follow four rules:

- C for *Constraint*, where participants have to list all the constraints related to the problem that come into their heads;
- Q for *Quantity*, where participants have to write all these constraints down;
- H for *Hierarchization*, where participants have to rank the constraints they have listed;
- D for *Demultiplication*, where participants have to use different combinations of all the constraints they have listed to find new ones.

4.3 Experiment

4.3.1 Participants

A total of 32 design students took part in this study. They were all in their first year of a design degree course. Since there is a limited number of students in each class in this specialized area, we asked students enrolled in two different design specialties (and in two different high schools) to take part in our study: half of them had opted for a specialty in spatial design (SD), and half a specialty in product design (PD).

4.3.2 Procedure

Participants were divided into two groups, depending on the design method they were to be exposed to (CQFD or CQHD). Each group consisted of 16 students (8 SD students and 8 PD students). To allocate the students to the CQFD or CQHD group, we asked their usual design teachers to construct pairs of students who were enrolled in the same design specialty and had similar mean scores on design tasks. One student in the pair was then assigned to the CQFD group, and the other to the CQHD group.

The procedure comprised three phases: in the first and third phases, we tested the students to compare their performances before and after training, while in the second phase, all the students tackled the same design task (see below), but it was preceded by one or other of the two design methods.

4.3.2.1 Pre- and posttests

Each design student performed two versions of a test: one administered before the start of the experimental task (pretest) and the other after it (posttest). These pre- and posttests probed both divergent thinking (switching, morphing and fluidity tests) and convergent thinking (e.g., selective combination test). For each of these tests, participants were provided with answer sheets and received both oral and written instructions for performing tasks underlying these tests.

4.3.2.2 Creative design activity

The creative design activity was induced by a design brief provided to all the design students. This brief was defined in collaboration with design teachers, in order to suit students in both specialties, and it consisted in designing a new device to protect pedestrians crossing the road.

The students had 10 minutes to read and understand the schedule of conditions, after which they were asked to read a printed sheet setting out the rules corresponding to each experimental condition (CQFD or CQHD). They were then given 20 minutes to write down all ideas and constraints that came to mind. Finally, they were allowed 90 minutes to represent their design project on A3 sheets and finalize sketches representing the design outcomes.

4.3.3 Data analysis

Part of the data analysis was performed on the ideas and constraints written down by participants, and part was based on the evaluation of participants' creative productions by teachers specializing in creative activities (see Bonnardel & Didier, 2016).

The data analysis allowed us to distinguish between ideas about the urban device to be designed and constraints related to the problem at hand:

- Ideas correspond to concepts that are more or less abstract, and define the *characteristics of the product to be designed*;
- Constraints correspond to *requirements* that the object to be designed has to satisfy. They can either be independent of the designer (*external* constraints) or be generated by the designer him- or herself (*internal* constraints). We made a distinction between three types of constraint (Bonnardel, 1999, 2000): (1) *prescribed* constraints (i.e., external constraints dependent upon the design brief); (2) *constructed* constraints (i.e., internal constraints arising from participants' own experiences or preferences); (3) and *deduced* constraints (inferred by designers from an analysis of the problem solving process thus far or else from the consequences of other constraints).

Three analysts independently analysed the data on the students' proposals. Their results were then compared, and any disagreements were discussed until a consensus was reached.

4.3.4 Results

After setting out the results for the characteristics of the students' design thinking process, focusing on the generation of ideas and constraints, we compare the participants' performances on the pre- and posttests.

4.3.4.1 Results on the students' design thinking

We ran analyses to determine whether (1) the activities performed by the SD and PD students differed significantly, (2) the type of training the students received affected the number of constraints and ideas they produced, and (3) the type of training affected the nature of the constraints that were listed.

• *Impact of design specialties*

Given that the SP and PD students were at the same level in their course and attended similar classes (albeit in different design specialties), we expected them to engage in similar design activities. Analyses of variance (ANOVAs) on the numbers of ideas and constraints produced by the SD and PD students failed to reveal any significant effect of design specialty on the numbers of ideas or constraints they expressed. Moreover, the ANOVAs showed no effect of design specialty on the generation of prescribed, deduced or constructed constraints.

• *Impact of type of training on the numbers of ideas and constraints*

Concerning the influence of type of training (CQFD vs. CQHD) on the numbers of ideas and constraints produced by the design students, results showed that training focusing either on the generation of ideas or on the management of constraints had a significant influence on both the number of ideas and the number of constraints that were produced. In accordance with our hypotheses, students who were exposed to the CQFD method produced more ideas on average (M = 5.44, SD = 3.18) than students who were exposed to the CQHD method (M = 2.19, SD = 2.40), p = .003. Conversely, the CQHD students listed more constraints (M = 16.00, SD = 5.75) on average than the CQFD students ($M = 9.25$, $SD = 3.69$), $p = .002$. Even so, regardless of training method, participants produced more constraints than ideas on average.

• *Impact of type of training on the nature of the constraints*

Concerning the influence of type of training on the nature of the constraints that were cited, an ANOVA revealed a significant effect of type of training on the total number of both prescribed constraints (CQFD = 31, CQHD = 79; $p < .01$), and deduced constraints (CQFD = 37, CQHD = 84; $p < .01$), but there was no significant effect on the number of constructed constraints (CQFD = 80, CQHD = 93).

4.3.4.2 Results on the pre- and posttests

No significant effect of type of training was observed on posttest results (switching, morphing, fluidity and selective combinations). However, the pre- and posttests differed significantly on switching ($p < .01$), with higher mean scores after training than before in both the CQFD (24.33 *vs.* 21) and CQHD (25.33 *vs.* 21.33) conditions. A significant difference was also observed between the pre- and posttests for morphing ($p < .01$), with higher mean scores after training than before in both the CQFD (137 *vs.* 118) and CQHD (136.5 *vs.* 96) conditions.

4.3.5 Discussion

The aim of this second study was to determine the influence of two types of project-oriented design methods (CQFD and CQHD) on students' design thinking process. In accordance with our hypotheses, results showed that the CQFD method prompted students in design to increase the number of ideas they came up with, whereas the CQHD method stimulated them to list more constraints for dealing with the design project. Thus, although participants were only briefly exposed to these two methods, the latter had a differential effect on their creative design thinking process. Students who were exposed to the CQHD project-oriented method seemed to be more engaged in framing (defining and redefining) the design problem at hand than students who were trained in the CQFD method, who produced more ideas and seemed more engaged in solving the design problem. The design project-oriented methods provided to the students in our study therefore appeared to modify the way they tackled the design problem. Our results also revealed that participants were able to adapt their procedures to the rules imposed by the training task, underscoring the flexibility of the creative process. Moreover, the results of the posttest indicated that students' performances improved whichever method they were exposed to.

5. CONCLUSION

Our general objective in this chapter was to contribute to a better understanding of the process of design thinking. To this end, we began by setting out the characteristics of design activities, as well as descriptive models of creativity and design thinking. We then supplemented these descriptions with the results of a study conducted with professional designers to probe their perceptions of their own creative design thinking process. Several stages and factors were highlighted, but we focused on cognitive factors, as these were the factors that the professional designers deemed to be most important. We were able to identify three general stages: (1) definition and redefinition of the creative problem (corresponding to the *problem-framing* profile); (2) openness to aesthetic dimensions, new experiences and new ideas (corresponding to the *divergent* profile); and (3) self-assessment or reflexive evaluation (partially corresponding to the *problem-solving* profile). In view of the importance of these three stages in design thinking, and the nature of the difficulties that can be encountered along the way, it might be possible to support designers during these three stages through human-computer interaction and even human-computer cooperation (Bonnardel & Zenasni, 2010; Burkhardt, & Lubart, 2010; Hewett, 2005). In particular, designers could be provided with computational systems such as TRENDS, which provides users with sources of inspiration in the form of images, or SKIPPI, where thesources of inspiration are provided in word form (Bonnardel & Bouchard, 2014; Bonnardel & Zenasni, 2010). The use of a critiquing expert system could also favour the evaluation of design solutions (see, for instance, Bonnardel & Zenasni, 2010).

We then described a second study that we conducted with design students to analyse the influence on their design thinking process of two methods encouraging them to focus on either idea generation (in line with divergent thinking) or constraint management (in line with both problem-framing and convergent thinking). Results of this second study revealed differential effects on students' creative design thinking process, which were confirmed by the assessment of their creative productions (Bonnardel & Didier, 2016). These results could inform the development of new teaching methods favouring the creative design process.

These two studies complemented each other, insofar as they allowed us to analyse the design thinking processes of both professional designers and design students. These studies yielded results that should contribute to the emergence of new educational and/or computational modalities that favour the creative design process (see, for instance, Bonnardel, 2016).

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References

Amabile, T. M. (1996). *Creativity in context*. Boulder, CO: Westview Press.

Asimov, M. (1962). *Introduction to design*. Englewood Cliffs, NJ: Prentice-Hall.

Bonnardel, N. (1999). L’évaluation reflexive dans la dynamique de l’activité du concepteur. In J. Perrin (Ed.), *Pilotage et évaluation des activités de conception* (pp. 87-105). Paris: L’Harmattan.

Bonnardel, N. (2000). Towards understanding and supporting creativity in design: Analogies in a constrained cognitive environment. *Knowledge-Based Systems*, *13*, 505-513.

Bonnardel, N. (2006). *Créativité et conception: Approches cognitives et ergonomiques* [Creativity and design: Cognitive and ergonomic approaches]. Brussels: De Boeck.

Bonnardel, N. (2009). Activités de conception et créativité: De l'analyse des facteurs cognitifs à l'assistance aux activités de conception créatives. *Le Travail Humain*, *72*, 5-22.

Bonnardel, N. (2012). Designing future products: What difficulties do designers encounter and how can their creative process be supported? *Work, A Journal of Prevention, Assessment & Rehabilitation*, *41*, 5296-5303.

Bonnardel, N. (2016). Propositions de méthodes d’analyse et de modalités d’assistances pédagogique et informatique aux activités créatives. Illustrations dans le domaine du design. In I. Capron-Puozzo (Ed.), *La créativité en éducation et en formation. Perspectives théoriques et pratiques* (pp. 167-.180) Paris: Albin Michel.

Bonnardel, N., & Bouchard, C. (2014). Design, ergonomie et IHM: Etudes complémentaires pour favoriser les activités de conception créatives. In N. Couture, C. Bastien, & T. Dorta (Eds.), *Quelle articulation pour la co-conception de l’interaction? Proceedings of the international conference 2014 Ergonomie et Informatique Avancée Conference - ErgoIA’2014* (pp. 33-40), Toulouse, New York: ACM Press.

Bonnardel, N., & Didier, J. (2016). Enhancing creativity in the educational design context: An exploration of the effects of design project-oriented methods on students’ evocation processes and creative output. *Journal of Cognitive Education and Psychology*, *15*(1), 80-101.

Bonnardel, N., Didierjean, A., & Marmèche, E. (2003). Analogie et résolution de problèmes. In C. Tijus (Ed.), *Métaphores et analogies* (pp. 115-149). Paris: Hermès.

Bonnardel, N., Forens, M., & Lefevre, M. (2016). Enhancing collective creative design: An exploratory study on the influence of static and dynamic personas in a virtual environment. *Design Journal*, *19*(2), 189-203.

Bonnardel, N., & Marmèche, E. (2004). Evocation processes by novice and expert designers: Towards stimulating analogical thinking. *Creativity and Innovation Management*, *13*(3), 176-186.

Bonnardel, N., & Marmèche, E. (2005). Towards supporting evocation process in creative design: A cognitive approach. *International Journal of Human-Computer Studies*, *63*, 442-435.

Bonnardel, N., Mazon, S., & Wojtczuk, A. (2013). Impact of project-oriented educational methods on creative design. *Proceedings of the 31st European Conference on Cognitive Ergonomics - ECCE 2013*, Toulouse, France, article no. 6. New York: ACM Press.

Bonnardel, N., & Zenasni, F. (2010). The impact of technology on creativity in design: An enhancement? *Creativity and Innovation Management*, *19*(2), 180-191.

Botella, M., Nelson, J., & Zenasni, F. (2016). Les macro et microprocessus créatifs. In I. Capron-Puozzo (Ed.), *La créativité en éducation et en formation. Perspectives théoriques et pratiques* (pp. 31-44). Paris: Albin Michel.

Burkhardt, J.-M., & Lubart, T. (2010). Creativity in the age of emerging technology. *Creativity and Innovation Management*, *19*, 160-166.

Chrysikou, E. G., & Weisberg, R. W. (2005). Following the wrong footsteps: Fixation effects of pictorial examples in a design problem-solving task. *Journal of Experimental Psychology: Learning, Memory and Cognition*, *31*, 1134-1148.

Csíkszentmihályi, M. (1996). *Creativity: Flow and the psychology of discovery and invention.* New York: Harper Collins.

Dewey, J. (1934). *Art as experience*. New York: Penguin.

Dorst, K., & Cross, N. (2001). Creativity in the design process: Co-evolution of problem-solution. *Design Studies*, *22*, 425-437.

Eastman, C. M. (1969). Cognitive processes and ill-defined problems: A case study from design. *Proceedings of the 1st International Joint Conference on Artificial Intelligence* (pp. 669-690). Washington, DC.

Finke, R. A., Ward, T. B., & Smith, S. M. (1992). *Creative cognition: Theory, research, and applications.* Cambridge, MA: MIT Press.

Gero, J. S. (1998). Towards a model of designing which includes its situatedness. In H. Grabowski, S. Rude, & G. Grein (Eds.), *Universal design theory* (pp. 47-56). Aachen: Shaker Verlag.

Glăveanu, V. P. (2012). Creativity and folk art: A study of creative action in traditional craft. *Psychology of Aesthetics, Creativity, and the Arts*, *7*(2), 140-154.

Glăveanu, V. P., Lubart, T., Bonnardel, N., Botella, M., de Biaisi, P.-M., Desainte-Catherine, M., ... & Zenasni, F. (2013). Creativity as action: Findings from five creative domains. *Frontiers in Educational Psychology*, *4*, 176.

Hayes-Roth, B., & Hayes-Roth, F. (1979). A cognitive model of planning. *Cognitive Science*, *3*, 275-310.

Hewett, T. T. (2005). Informing the design of computer-based environments to support creativity. *International Journal of Human-Computer Studies*, *63*, 383-405.

Jansson, D. G., & Smith, S. M. (1991). Design fixation. *Design Studies*, *12*, 3-11.

Kelsey, E., Medeiros, P., Partlow, J. P., & Mumford, M. D. (2014). Not too much, not too little: The influence of constraints on creative problem solving. *Psychology of Aesthetics, Creativity, and the Arts*, *8*, 198-210.

Lubart, T., Mouchiroud, C., Tordjman, S., & Zenasni, F. (2003). *Psychologie de la créativité*. Paris: Armand Colin.

McNeill, T., Gero, J. S., & Warren, J. (1998). Understanding conceptual electronic design using protocol analysis. *Research in Engineering Design*, *10*, 129-140.

Mumford, M. D. (2003). Where have we been, when are we going? Taking stock in creativity research. *Creativity Research Journal*, *15*(2-3), 107-120.

Mumford, M. D., Mobley, M. I., Reiter-Palmon, R., Uhlman, C. E., & Doares, L. M. (1991). Process analytic models of creative capacities. *Creativity Research Journal*, *4*, 91-122.

Osborn, A. F. (1963). *Applied imagination: Principles and procedures of creativity thinking*. New York: Charles Scribner's Sons.

Rittel, H., & Webber, M. M. (1984). Planning problems are wicked problems. In N. Cross (Ed.), *Developments in design methodology* (pp. 135-144). New York: John Wiley & Sons.

Schön, D. A. (1983). *The reflective practitioner: How professionals think in action*. New York: Basic Books.

Simon, H. A. (1973). The structure of ill-structured problems. *Artificial Intelligence*, *4*, 181-201.

Simon, H. A. (1995). Problem forming, problem finding and problem solving in design. In A. Collen & W. Gasparski (Eds.), *Design & systems* (pp. 245-257). New Brunswick: Transaction Publishers.

Stokes, D. (2007). Incubated cognition and creativity. *Journal of Consciousness Studies*, *14*, 83-100.

Sternberg, R. J., & Lubart, T. (1999). The concept of creativity: Prospects and paradigms. In R. J. Sternberg (Ed.), *Handbook of creativity* (pp. 3-15). New York: Cambridge University Press.

Tan, S., & Melles, G. (2010). An activity theory focused case study of graphic designers' tool-mediated activities during the conceptual design phase. *Design Studies*, *31*, 461-478.

Treffinger, D. J. (1995). Creative problem solving: Overview and educational implications. *Educational Psychology Review*, *7*, 301–311.

Visser, W. (1994). Organisation of design activities: Opportunistic, with hierarchical episodes. *Interacting with Computers*, *6*, 235-238.

Wallas, G. (1926). *The art of thought*. New York: Harcourt-Brace.

Ward, T. B. (1994). Structured imagination: The role of category structure in exemplar generation. *Cognitive Psychology*, *27*, 1-40.

Ward, T. B., Smith, S. M., & Vaid, J. (1997). Conceptual structures and processes in creative thought. In T. B. Ward, S. M. Smith, & J. Vaid (Eds.), *Creative thought: An investigation of conceptual structures and processes* (pp. 1-27). Washington, DC: American Psychological Association.

Ward, T. B., Smith, S. M., & Finke, R. A. (1999). Cognition. In R. Sternberg (Ed.), *Handbook of creativity* (pp. 189–212). Cambridge: Cambridge University Press.

Zeisel, J. (1981). *Inquiry by design: Tools for environmental behavior research*. Cambridge, MA: Cambridge University Press.