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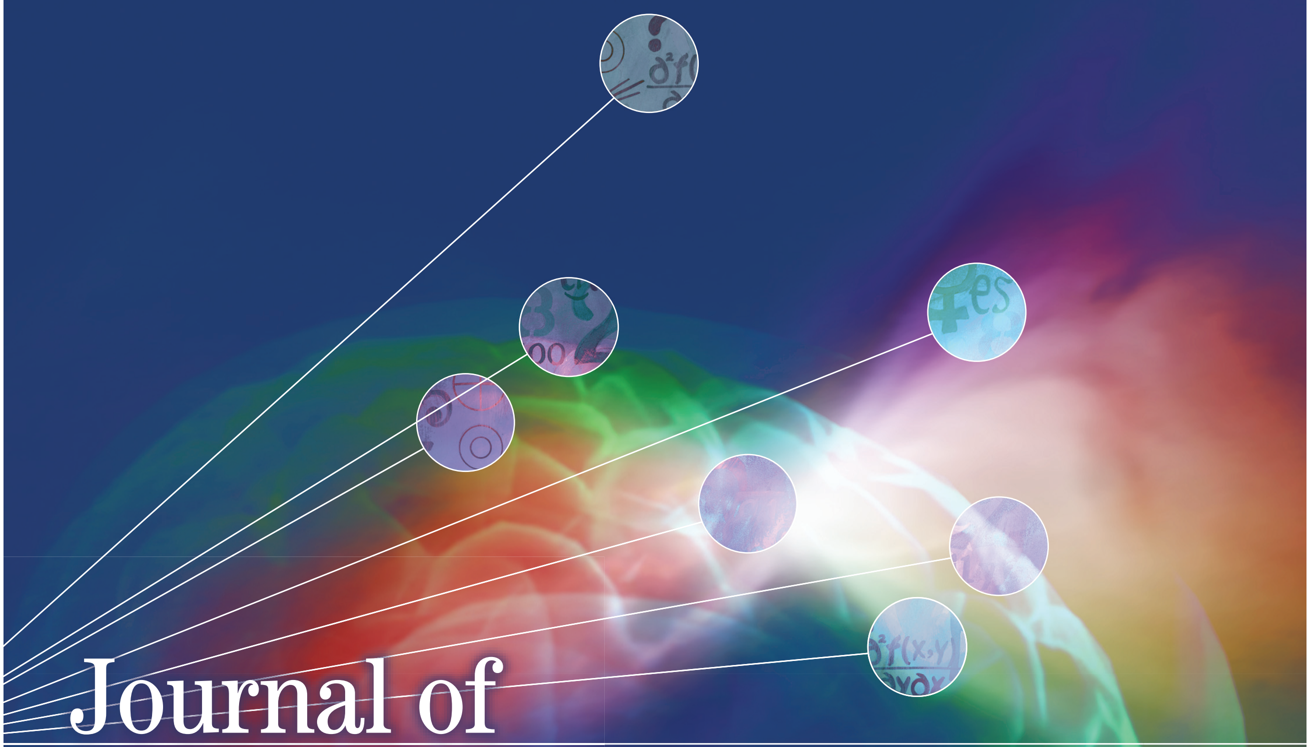

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Enhancing Creativity in the Educational Design Context: An Exploration of the Effects of Design Project-Oriented Methods on Students' Evocation Processes and Creative Output

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One of the challenges in today's society is to satisfy the growing need for creativity and innovation, especially in design contexts, where designers have to come up with products that are both *new* and *adapted* to their users. Although designers' professional experience is crucial, we consider that their creative skills can be nurtured in design schools. We therefore explored the effects of two types of design project-oriented methods, which were operationalized as specific courses offered to design students. As our objective was to determine the impact of this training on creativity, we looked at both the students' evocation processes and their creative output. In the *first* of two studies, 32 design students had to perform the same creative design task, but half of them received training based on brainstorming principles and the other half training based on constraint management. Here, we focused our analysis on the students' evocation processes. In the *second* study, we asked 16 teachers specializing in creative activities to assess the students' output according to different criteria. These two studies showed that the two types of training had a differential impact and allowed us to explore relationships between constraints and ideas in creative design.

Keywords: creativity; education; creative design; evocation process; creativity assessment

One of the challenges in today's society is to satisfy the growing need for creativity and innovation. In the aftermath of the economic crisis, these skills are becoming a priority for academics, industries, and policymakers (Archibugi, Filippetti, & Frenz, 2013). Accordingly, many leaders from all walks of life now stress the importance of being able to solve problems creatively (Plucker, Waitman, & Hartley, 2011). This is

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especially true in design contexts because companies must regularly bring out new products for consumers or users to stay competitive. Consequently, one challenge for designers is to come up with design solutions and define products that are both *new and adapted* to future users (Bonnardel, 2000, 2012). These expectations for designers' activities are in line with definitions of creativity, which is commonly defined 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 requires (Bonnardel, 2000, 2006) the enlargement of the search area for creative ideas and a focus on the project's constraints. Thus, looking for creativity in design requires *a balance*: 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 developed (Csikszentmihalyi, 1999; Lubart, Mouchiroud, Tordjman, & Zenasni, 2003). Creative design situations present a challenge for designers. Although professionals can use classic design methods and ergonomic recommendations (e.g., Norman, 1988; Scapin & Bastien, 1997), which are useful in most run-of-the-mill design contexts, these methods and recommendations are of limited use when the design project requires a greater degree of creativity. Designers can also potentially use creative techniques, such as the TRIZ method (Altshuller, 2004; Altshuller, Zlotin, Zusman, & Filatov, 1989) or the challenge-storming method (Swiners & Briet, 2005), or else computational systems to support their creative processes (see, for instance, Bonnardel & Zenasni, 2010). Nevertheless, the impact of such specific creative methods and systems may remain limited because they can only be applied to specific types of design project. We therefore argue that one promising way of helping future designers tackle creative design projects is to expose students in design schools to particular educational methods. In this case, another challenge is to train design students—and thus future professional designers—to produce creative designs. Thus, our objective was to help determine how creativity in design can be enhanced through training dispensed in educational contexts. More specifically, in the study we performed, we analyzed the impact of two design project-oriented methods that are intended to encourage design students to adopt a particular perspective:

- The first is centered on the evocation of ideas, as is the case during brainstorming (which is frequently used in design areas), thereby possibly favoring divergent thinking.
- The second is centered on the management of constraints related to the design project at hand, thereby possibly favoring convergent thinking.

To justify the teaching of these design project-oriented methods, we begin by presenting the main characteristics of design activities, we describe several creative design models, and we evoke the difficulties involved in training students, and more specifically design students, to be creative. Second, we set out our general objective and describe the first study we performed, where 32 design students were all given the same creative design task, but half of them received training in line with brainstorming principles and the other half training based on constraint management. After providing the results of our analysis of the effect of type of training on students' evocation processes, we describe the second study, which was designed to analyze the effect of training on students' creative output. This output was rated by

16 teachers specializing in creative activities on a range of criteria. In the light of our results, we discuss the impact of these two kinds of educational design project method on creativity in design.

DIFFICULTIES IN DESIGN ACTIVITIES AND IN TEACHING CREATIVE DESIGN

Difficulties Encountered in Design Activities

From a cognitive point of view, creative design can be regarded as a problem-solving process, in that no solution can be directly applied to resolve it.

One difficulty is that designers are only provided with a brief description of the product they have to design: just the product's general functionalities and some constraints. Therefore, at the outset, designers have only an incomplete and imprecise mental representation of the design goal. Thus, design problems are regarded as *ill-structured* or *ill-defined* (Eastman, 1969; Simon, 1973, 1995). Only by going through the problem-solving process itself can designers complete their mental representations. Therefore, the design problem-solving process has been described as involving the coevolution of problem and solution spaces (Dorst & Cross, 2001). Valkenburg and Dorst (1998) distinguished between framing the problem (exploring the design task) and framing the solution (developing solutions). In addition, the construction and gradual refinement of the designer's mental representation occurs in interaction with the elaboration of external representations or sketches of the design product (Bonnardel, 2006; Demailly & Lemoigne, 1986; Schön, 1983; Simon, 1995).

Another kind of difficulty arises from the fact that design problems are also *open-ended* (Fustier, 1989). Indeed, they admit various potential solutions, all of them satisfying criteria or constraints to varying degrees, in a context in which there are no definite criteria for assessing these solutions (Fustier, 1989; Simon, 1973, 1995). This difficulty is also related to the fact that design solutions are both assessed by the designers themselves, through a "reflexive" evaluation process (Bonnardel, 1999), and by external judges, in accordance with the systemic model developed by Csikszentmihalyi (1999). Indeed, although design solutions are frequently developed in individual situations and assessed by the designer himself or herself all along the design problem solving, these design solutions are later submitted not only to external judges, who are considered as specialists in the design area, but also to a more general audience consisting of future users of the product. Concerning the self-assessment by designers themselves, each designer benefits from his or her own previous background and experiences, which underlie both the construction of mental representations of the design problem at hand and the adoption of specific viewpoints associated to criteria and constraints considered during the evaluation of design solutions (Bonnardel, 1999). Therefore, each designer constructs his or her own mental representation of the design problem and refers, at least partly, to his or her own criteria for assessing the design solutions. Concerning the assessment by external judges, Csikszentmihalyi's (1999) approach points out the fact that creativity is constructed through an interaction between the individual and a social system in which individual productions are judged by a *field* (made up of a group of persons or institutions—*gatekeepers*—who control a particular domain by assessing and selecting those ideas and productions that should be included in it), and then either rejected or accepted into a *domain*. Thus, creativity is determined not only by the originality of an individual's production but also by the degree to which this production is accepted and deemed to be creative by the field. This model suggests that to succeed with a creative production, an author or a designer should be familiar with the judges' requirements and values to satisfy them. However, the main difficulty is that even specialists (or *gatekeepers*) in a given field as well as teachers in this field do not know, at least consciously, all the criteria they take into account for assessing creative productions. Indeed, according to Norman (2004), design can be perceived at different levels because human responses are determined by various factors. Some of them are external to the judge, controlled by advertising or brand image; some others come from the judge's own experience. Following studies of emotion, Norman suggested that there are three different levels of approach to design: visceral, behavioral, and reflective. The visceral level results from the genetically determined, simplest reactions to the sensory information coming from the environment (e.g., when a product is perceived as pretty, this judgment comes from the visceral level). The behavioral level neither depends on appearance nor on rationality; it focuses on usability, function, understandability, and physical feeling. The reflective level covers the territory of the message and the meaning of the product; thus, this reflective perception of design is influenced by the judges' self-image and their belief of "what is right."

Moreover, Norman (1988) noticed that the same product can be perceived in a totally different light by the designer and its user. Indeed, designers' interpretations are influenced by their professional creative experience, or by their knowledge of their specialist area, whereas users base their interpretations on their experiences of use and on the opinions either of other users and, sometimes, of domain gatekeepers. To complement this idea, Wojtczuk and Bonnardel (2011) found out that the way in which specific criteria impacted the overall design assessments is different depending on the judges' different profiles. These findings are in line with Glăveanu (2010), who suggests that creativity, as well as its assessments, are rooted in the social and cultural context of participants.

A last kind of difficulty is related to the fact that being creative during design activities implies, for designers, *taking risks*. Especially, results from a poor design activity are critical: Difficulties using the new product may lead to its being abandoned, and users may make mistakes. The consequences of these errors may be serious and even fatal. For instance, the design of inadequate user interfaces, products, workstations, or services may have dramatic consequences. Moreover, there are economic risks for companies if the new products do not meet their users' needs, abilities, and usages.

Models of Creativity and Creative Design

Given the dual criteria of novelty and adaptation we have highlighted for creative design, several models of creativity can contribute to a better understanding of creative design activities. The first models of creativity to be developed featured a rather orderly and simplified succession of stages because it was the case in the well-known model of creativity proposed by Wallas (1926). Models of the design process, such as the ones proposed by Asimov (1962) or McNeill, Gero, and Warren (1998) also conceive the design process as a series of stages (see Bonnardel, 2009), comprising "analysis" (corresponding to both problem preparation and problem [re]formulation), "synthesis" (corresponding to the generation of design solution) and "evaluation" (of design solution). As Lubart et al. (2003) noted, early concerns with the creative process (and, according to us, in the case of the design process too) resulted primarily in stage models and generated sustained arguments about the characteristics of each stage. By contrast, more recent theories have shifted the focus to the microlevel dynamics of creativity, albeit conserving a predominantly cognitive perspective. For instance, the geneplore model (Finke, Ward, & Smith, 1992; Ward, Smith, & Finke, 1999; Ward, Smith, & Vaid, 1997), corresponding to the combination of the words *GENErate* and *exPLORE*, identifies 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 et al., 1992).

If we consider creative design in particular, these models of creativity as well as the dual criteria of novelty and adaptation to the context are in accordance with the analogy and constraint management (A-CM) model (Bonnardel, 2000, 2006). As its name suggests, this model highlights the roles of two main cognitive processes: analogy and constraint management. These two processes may have contrasting effects, and they contribute to divergent and convergent thinking.

1. *Analogical thinking* can encourage, in certain conditions (see, for instance, Bonnardel & Marmèche, 2004, 2005), designers to extend or open up their search space to new ideas—a process that is closely associated with divergent thinking. Although other forms of creative thought are used (see, for instance, Mumford, 2003), we believe that during creative design, it is important for designers to connect the design domain (e.g., a mechanical device) to some other domain(s), from which inspiration can be drawn (e.g., a biological system). For instance, analogical transfer is useful when there is a degree of similarity between the source and the target domains (or the relations in those domains) and where that similarity allows the designer's reasoning to span the domains (Forbus, Gentner, & Law, 1994). We also believe that analogical thinking can be useful when designers wish to find solutions that include features that contrast with the source of inspiration, for instance, when designers explicitly want to propose ideas or concepts that break with preexisting objects, products, or entities (Bonnardel, Didierjean, & Marmèche, 2003). Connecting two (or more) domains can also make new topics easier to understand, facilitating the discovery, development, evaluation, and exposition of knowledge (Holyoak & Thagard, 1995). However, one of the difficult challenges is finding a plausible source, especially when the search space is large, the relationship to the target is not obvious, and the differences are blatant. Moreover, in certain cases, designers can also be exposed to a *design fixation* effect, when they are too much focused on the source or example and therefore have difficulty opening up their idea search space (Chrysikou & Weisberg, 2005; Jansson & Smith, 1991). Thus, conditions that allow designers to benefit from analogical thinking in creative design situations have been explored regarding the cross-domain or interdomain (further refined

to distinguish between far vs. close interdomains) or near domain or intradomain nature of the stimuli (see, for instance, Bonnardel & Marmèche, 2004, 2005). Moreover, because of the ill-defined characteristic of design problems, connecting the design domain to other domains can occur at various moments all along the design activity and final design solutions frequently result from the combination of several concepts or ideas.

2. *Constraint management* allows designers to give focus to their search for ideas, and we believe that different kinds of constraints (Bonnardel, 1999) underlie designers' mental representations and determine their choices and decisions. First, constraints can be linked to divergent thinking when they guide designers to look for ideas in another conceptual domain than the one of the design product to be conceived but they also lead to convergent thinking, as they help designers to assess ideas or solutions, and gradually delimit their search space until they arrive at a solution that is both new and meets the various constraints. Several kinds of constraints can be described (see, for instance, Bonnardel, 1999, 2000): either external (*prescribed constraints* derived from a design brief or schedule of conditions) or internal to the designer, based on each designer's previous experience and preferences (*constructed constraints*). They can also be joined by other constraints that are inferred by designers from an analysis of the current state of the design problem or from the implications of previous defined constraints (*deduced constraints*).

According to the A-CM model, the processes of analogy thinking and constraint management continuously interact during the design process and contribute to other cognitive processes, such as the progressive construction of mental representations (as described earlier), solution evaluations, and the consideration of various viewpoints.

This view is directly in line with Stokes (2007), who considers that the implementation of constraints restructures the problem, favoring its ownership, and induces a new problem for participants to solve. Moreover, we agree with Kelsey, Medeiros, Partlow, and Mumford (2014), who consider that different constraints can be expected to generate creative resolution problems, and we argue that creative activities cannot occur (or, at least, only with considerable difficulty) without taking constraints into account, be they external or internal.

Training (Design) Students to be Creative?

As pointed out by Glăveanu et al. (2013), despite the general consensus that more creativity is needed in the education system (Makel, 2009), researchers have been slow in designing highly effective programs for enhancing creative expression (see Fasko, 2000–2001). Creativity has thus been a longstanding subject of debate in educational psychology (Smith & Smith, 2010). Several authors have pointed out that creativity occupies a conflictual position in many classrooms (see, e.g., Beghetto, 2010; Plucker, Beghetto, & Dow, 2004). Although psychologists have long viewed the development of creative potential as a key educational objective (Vygotsky, 1967/2004), it remains a challenge for educators. Researchers have identified various barriers that make creativity particularly difficult in the classroom, including convergent teaching practices and teachers' attitudes, and the difficulty of assessing creativity (Beghetto, 2010). The convergent approach to teaching, or the initiate, respond, and evaluate (IRE) pattern (Mehan, 1979), usually corresponds to the default option in classrooms and is taught in interactions between teachers and students. Another issue concerns the relationship between creativity and learning. In most educational contexts, learning is viewed as being separate from the development of creative thinking, whereas a more complementary view is needed. Thus, the objectives of teachers could be to develop both students' creative potential and their knowledge of academic subject matter. This view would be in accordance with Guilford (1950), who noted that "a creative act is an instance of learning" (p. 446), as well as Vygotsky (1967/2004), who described a "double, mutual dependence" (p. 17) between the creative imagination and learning experiences (Beghetto, 2010). However, some individualistic accounts of creativity place their emphasis on *inner* attributes that are hard to train (see Plucker et al., 2004). Although some elements of personality and motivation are highly important for creativity (see, for instance, Amabile, 1996, as well as Lubart et al., 2003), analyses performed by Scott, Leritz, and Mumford (2004) showed that training designed to influence participants' personality, to make them more creative, had rather weak effects. In addition, according to some authors, real-life experiences are correlated with imagination and creativity (see Archambault & Venet, 2007). Therefore, although (design) students may benefit from few previous experiments, it may be difficult for them to produce creative ideas. Thus, developing methods for enhancing creativity—and creative design—can be regarded as a challenging objective in today's society.

Teachers' assessment practices also have a major influence on creativity in the classroom, in that they signal to students what is valued and important. Although assessing performances based on convergent thinking appears relatively easy, assessing students' creativity (as well as creativity in general) remains a very complex task and can be a challenge for teacher training. Various creativity assessment methods and techniques are currently available (see, for instance, Kaufman, Plucker, & Baer, 2008), but these are mainly used for research purposes. In addition, teachers' perceptions and, more generally, judges' perceptions of what creativity is in a given domain may depend on their own backgrounds and viewpoints (Wojtczuk, 2014; Wojtczuk & Bonnardel, 2011).

In the case of educational approaches to design, teachers' attitudes tend to favor the development of students' creative potential, but most of the earlier mentioned difficulties remain. For instance, design teachers acknowledge difficulty assessing creative output. Nevertheless, the training of design students should promote a mix of cognitive and creative skills, as well as practical skills. With this in mind, the *design-realization-socialization* approach (Didier, 2015; Didier & Leuba, 2011) models the process for producing objects that allows for the development of both cognitive and conative skills in a problem-solving context. According to this theoretical model, the design activity constitutes a phase of analysis and research that allows students to anticipate the product's manufacturing process. Theoretical approaches are based on three distinct timescales: design, realization, and socialization (Figure 1). The design activity, in which these are directly involved, allows students to reflect on the product's characteristics and future use, as well as its usability and socialization (e.g., issues about where this product will be received and used by users), when introduced in a specific context.

The part of the loop located in the upper part of this model (see Figure 1) represents an artistic approach oriented to the product's sign function. This could bring more focus to

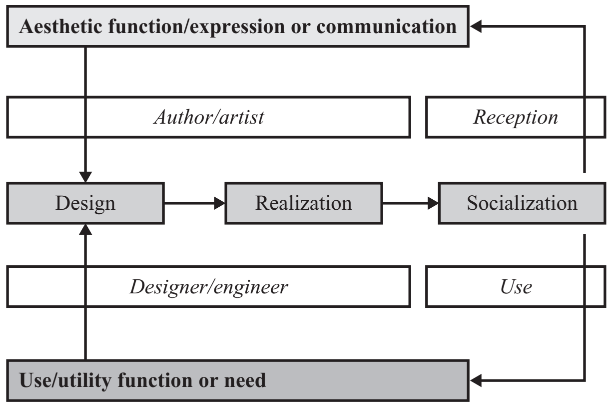

FIGURE 1. The *design-realization-socialization* approach.

the designer's interdomain analogy search. The use of divergent thinking leads the designer or design student to make use of symbolic thinking, cognitive flexibility, risk-taking, and single perspective in his or her search for ideas in the same field. Conversely, the lower part of the loop in this model is related to an engineering-oriented approach, which could favor the search for intradomain, structured and hierarchical ideas, while nonetheless having a positive impact on the search for new ideas that are appropriate to the situation.

Moreover, we argue that design project-oriented methods can help to develop creativity in context. The cognitive operations induced by the design activity promote the development of abilities such as analysis, anticipation, the construction of mental representations, and problem solving throughout a contextualized creative process aimed at reaching solutions that are both new and adapted to the situation (Bonnardel, 2000, 2006). Moreover, asking students to participate in concrete design-oriented projects can contribute to develop their divergent thinking. Although this kind of thinking is seldom promoted in classical educational contexts (Lubart et al., 2003), it constitutes a key stage in design activities, allowing the individual to find new ideas to elaborate solutions adapted to the design problem at hand. As pointed out in the A-CM model (Bonnardel, 2000, 2006), the selection of an idea regarded as relevant is therefore based on both the needs and constraints related to the product to be designed. This cognitive operation requires convergent thinking to consider and combine all the parameters relating to the product. Therefore, we believe that students who are involved in design-oriented projects can develop transversal abilities that may also prove useful in other disciplinary fields: learning strategies, anticipation, creative thinking and decision making, as well as communication and collaboration when several stakeholders are involved in the design situation.

Although practical skills are mastered over long timeframes, through day-to-day practice (Kolko, 2011), we believe that it may be possible to teach certain cognitive skills. Several studies have reported positive effects of short training sessions, such as workshops, on participants' creative capabilities (Scott et al., 2004). These effects have mainly been demonstrated for problem-solving training (Parnes, 1967), as well as for training based on divergent thinking, such as brainstorming (Osborn, 1963). Thus, in the present research, we argued that even short training sessions can have an influence on both the creative processes and creative output of students. To test this general hypothesis, we performed two studies to analyze the impact of two kinds of training: one focused on students' evocation processes, the other on their creative output.

STUDY 1: EFFECTS OF DESIGN PROJECT-ORIENTED METHODS ON STUDENTS' EVOCATION PROCESSES

Objective and Hypotheses

The objective of this first study was to determine whether design project-oriented methods associated with short-term training have an effect on the creative processes of design students. More specifically, we explored the effects of two types of design project-oriented methods corresponding to two kinds of training: one based on idea finding, the other on constraints related to the design project. We hypothesized that training centered on the evocation of ideas can favor divergent thinking and thus the evocation of more ideas. By contrast, training centered on the management of constraints applying to the design project can favor the generation of more constraints, framing the design problem and encouraging convergent thinking. Thus, these two kinds of training should have a differential influence on the number and nature of the proposals (ideas or constraints) expressed by design students in the early design phase. More specifically, we predicted that participants trained with the first method would express more ideas than participants trained with the second method and conversely those trained with the second method would express more constraints. In addition, the nature of the constraints expressed by participants might differ according to the training they had followed.

These methods were applied during an experimental study conducted in a real-life educational setting with students on a design course. Half the participants were trained with the first method and half with the second method. After describing these two kinds of methods in greater detail, we describe the experiment itself and the results we obtained.

Two Design Project-Oriented Methods

In accordance with the earlier mentioned models, and more especially the A-CM model, we developed two project-oriented methods for design students.

- The first one was designed to stimulate designers to come up with creative ideas and was inspired by the brainstorming method developed by Osborn (1963). It was chosen because this method is frequently used in real-life design contexts. To apply this method, called *CQFD*, participants had to obey four rules:
  - C, as in *Censure*, or more precisely, "no censorship," since self-censorship must be rejected and participants must express all the ideas that come into their heads
  - Q, as in *Quantity*, where participants must write all these ideas down
  - F, as in *Farfelues* (French adjective meaning wild, crazy, or unexpected), where participants must express even the wildest or maddest ideas that spring to mind
  - D, as in *Demultiplication*, where participants must use different combinations of all the ideas they have expressed so far to find new ones

- The second method we developed for this study was intended to stimulate designers to take into account and manage the constraints of the design problem. To apply this method, called *CQHD*, participants again had to abide by four rules:
  - C, as in *Constraint*, where participants must express all the constraints related to the problem at hand that come into their heads
  - Q, as in *Quantity*, where participants must write all these constraints down
  - H, as in *Hierarchization*, where participants must arrange the constraints they have expressed in hierarchical order
  - D, as in *Demultiplication*, where participants must use different combinations of all the constraints they have expressed so far to find new ones

These two methods are built on similar bases, but we guess that they will each induce a different focus of attention. As pointed out in the hypotheses, we assumed that these methods are related to two different ways of thinking, in that the first one is intended to stimulate divergent thinking, by allowing designers to extend their search space for ideas, whereas the second one is intended to stimulate convergent thinking, by allowing designers to take into account and manage constraints, which delimit and orient the space of research and can thus play the role of current goals (Bonnardel, 2000, 2006).

Experiment

Participants. There were 32 design students who took part in this study. They were all in the first year of a design degree course. This number of participants may seem quite small, but in this specialized area, the number of design students in each class is limited (about 16 students per class). We therefore asked students enrolled in two different design specialties, and enrolled in two different high schools to take part in our study: Half of them had chosen a specialty in spatial design (SD), and half a specialty in product design (PD). Because all the students engaged in a design specialty participated, in the same time, in this study, they could not be aware of the activities of other students.

Procedure. Participants were divided into two groups, depending on the training method that they were going to receive (CQFD or CQHD). Each group comprised 16 students (8 SD students and 8 PD students). The same experimenters went in each of the classes (corresponding to SD or PD specialty), in the absence of the usual teachers (these last ones only presented the experimenters to the students and then left them). They stayed in each of the classrooms until the students completed the design task and put back them their proposals written on a specific sheet and the drawings representing their design projects (see examples on Figure 2). Because the design students were provided with either the CQFD or the CQHD instructions (described earlier), written on a specific sheet, the role of the experimenters was quite limited.

The study took place over 2 days, with a 2-hr training session on each day. Both groups (CQFD or CQHD), enrolled in a same specialty, underwent their training at the same time. Each student attended both training sessions, each featuring the training method to which he or she had been assigned. For defining the composition of each groups of students, who were provided with the CQFD or the CQHD instructions, we asked their usual teachers in design to construct paired groups of students: two design students (enrolled in a same specialty) who obtained similar usual means in design tasks were assigned to each of the groups (CQFD or CQHD).

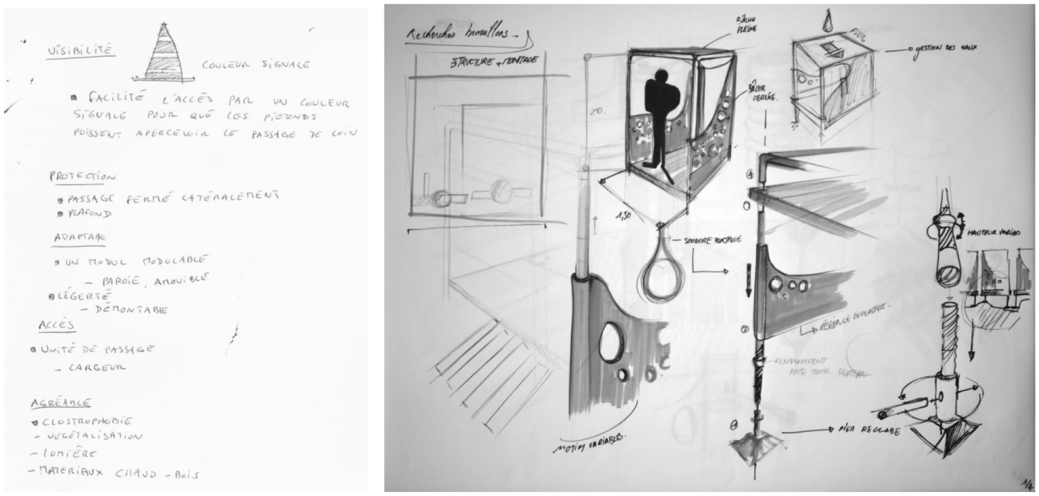

FIGURE 2. Examples of proposals written by a design student (on the left) and of a graphical production (on the right).

The task described here was performed during the second day to be able to observe a potential effect of the training methods.

All the students were provided with the same design brief (see "experimental task" in the following text) and given 10 min to read and understand the schedule of conditions. They were then invited to read a printed sheet setting out the rules corresponding to each experimental condition, after which they were given 20 min in which to write down all the proposals that came into their heads (see left part of Figure 2). Finally, they had 90 min to represent their design project on A3 sheets and finalize sketches representing the design outcomes (see right part of Figure 2).

Experimental Task. The design brief was defined in collaboration with three design teachers so that it would be suitable for students in both specialties. In addition, to provide these students with an ecological and project-oriented task, we chose a task that was proposed for a design competition. This task was performed during the time scheduled for teaching courses. It consisted in designing a new device for an urban environment, more specifically, a universal device to protect pedestrians crossing the road that could be adapted to different urban contexts.

Data Analysis. The data analysis was performed on the proposals written down by participants during the 20 min they had to express whatever they wanted about the design project. These proposals were analyzed to distinguish between ideas about the urban device to be designed and constraints related to the problem at hand as well as to establish distinctions between the different kinds of constraints (see in the following text).

Ideas may result from cognitive processes, such as analogy-making or the selective combination of previous features, and they correspond to concepts that are more or less abstract, and which allow participants to define the *characteristics of the product to be designed*.

Constraints define *requirements* that the object to be designed has to satisfy. They can be independent of the designer (*external* constraints) or else can be generated by the designer him- or herself (*internal* constraints). As we described in the theoretical part of this article, we distinguished three kinds of constraint (Bonnardel, 1999, 2000): (a) *prescribed* constraints, that is, external constraints that depend on the design brief and which correspond to explicit problem requirements; (b) *constructed* constraints, that is, internal constraints that are based on participants' own experiences or preferences; and (c) *deduced* constraints, which are inferred by designers from an analysis of the current state of problem solving or from the consequences of other constraints.

To avoid ambiguities about the data attributed to these categories, three analysts independently performed the data analysis. Their results were then compared. A satisfactory degree of agreement was first reached (0.90), and the remaining hesitations were raised based on a discussion until a consensus between the analysts.

Results

We ran analyses to determine (a) whether there were any significant differences between the activities performed by the SD and PD students, (b) whether the type of training affected the numbers of proposals (constraints and ideas) produced by the participants, and (c) whether it affected the nature of constraints produced by the participants.

Influence of the Design Specialties? Because the SP and PD students were at the same course level and attended similar classes (although in different high schools), we expected them to perform similar design activities. We therefore began by checking that there was no significant difference between the SD and PD students.

More specifically, we performed an analysis of variance (ANOVA) on the numbers of ideas and constraints produced by the students in each design specialty. No significant effect was observed concerning either the number of ideas they expressed, $F(1, 28) = 2.3$, $MSE = 7.83$, $p > .05$, *ns*, or the total number of constraints they expressed, $F(1, 28) = 0.184$, $MSE = 24.43$, $p > .05$, *ns*.

In addition, we compared the nature of the constraints expressed by the SD and PD students. The ANOVA showed no effect of design specialty on the generation of prescribed constraints, $F(1, 28) = 0.121$, $MSE = 4.12$, $p > .05$, *ns*, the generation of deduced constraints, $F(1, 28) = 0.412$, $MSE = 6.15$, $p > .05$, *ns*, or the generation of constructed constraints, $F(1, 28) = 0.205$, $MSE = 7.5$, $p > .05$, *ns*.

We therefore observed no effect of design specialty on the numbers of ideas or constraints, whatever their nature.

Influence of type of Training on the Number of Proposals. We then tested the hypotheses about the influence of type of training (CQFD vs. CQHD) on the number of proposals expressed by the design students. More specifically, we first distinguished between proposals expressing ideas for the design problem and proposals referring to the project's constraints.

An ANOVA revealed a significant effect of type of training on the production of ideas, $F(1, 28) = 10.8$, $MSE = 7.83$, $p = .003$, and on the production of constraints, $F(1, 28) = 14.92$, $MSE = 24.43$, $p = .002$. In accordance with our hypothesis, 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 ($M = 2.19$, $SD = 2.40$; see Figure 2). Conversely, the CQHD students proposed more constraints ($M = 16.00$, $SD = 5.75$) on average than the CQFD students ($M = 9.25$, $SD = 3.69$; Figure 3). Nevertheless, independently of the training method, the total number of constraints proposed by the participants was higher than their total number of ideas.

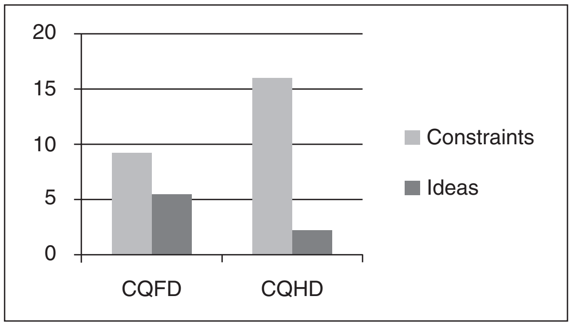

FIGURE 3. Mean numbers of constraints and ideas produced according to the type of project-oriented method.

A Pearson correlation coefficient also revealed a negative correlation between ideas and constraints ($r = -.486$, $p = .01$). To probe these results further, we analyzed the nature of the constraints expressed by the design students, with regard to the training they had followed.

Influence of Type of Training on the Nature of Constraints. An ANOVA showed a significant effect of type of training on the total number of prescribed constraints, $F(1, 28) = 18.6$, $MSE = 3.86$, $p < .01$, CQFD = 31, CQHD = 79, and on the total number of deduced constraints, $F(1, 28) = 11.6$, $MSE = 5.94$, $p < .01$, CQFD = 37, CQHD = 84. However, no significant effect was observed on the generation of constructed constraints, $F(1, 28) = 0.746$, $MSE = 7.1$, $p > .05$, *ns*, CQFD = 80, CQHD = 93.

In addition, Pearson correlation coefficients showed a positive correlation between prescribed and deduced constraints ($r = .572$, $p < .01$), a positive correlation between deduced and constructed constraints ($r = .376$, $p < .05$), a negative correlation between prescribed constraints and ideas ($r = -.554$, $p < .01$), and a negative correlation between deduced constraints and ideas ($r = -.421$, $p < .05$). No significant correlation was found neither between prescribed constraints and constructed constraints nor between constructed constraints and ideas.

Discussion

The aim of the first phase of our research was to test hypotheses about the impact of the two types of project-oriented methods, operationalized as training methods, on the production of ideas and constraints by design students. More specifically, we expected the CQFD training method, which focused on the evocation of large numbers of ideas—the wilder the better—to stimulate the design students to increase the number of ideas they came up with. We also expected that the training method focused on taking into account and managing constraints (CQHD method) would stimulate design students to analyze, hierarchize, and develop constraints related to the design brief (i.e., prescribed constraints). In addition, we expected this method to stimulate students to infer new constraints from the design problem-solving context and to supplement external constraints with internal ones related to their own viewpoints and preferences, thereby increasing the total number of constraints taken into consideration for dealing with the design project.

Results showed that *training focused either on the emergence of ideas or on the management of constraints influences the numbers of ideas or constraints produced by design students*. These results confirmed our expectations and hypotheses and demonstrated the efficiency of the two types of training we developed, in that they led to differentiated behaviors. We also observed that, regardless of the training method, the total number of constraints proposed by participants was higher than the total number of new ideas. Therefore, design problem framing seems to take up a substantial proportion of designers' activities, especially during the early design stage, as was the case in this study. Moreover, the process of evoking ideas is possibly more difficult than the evocation of constraints, and the generation of ideas may require several constraints to be taken into consideration, possibly combining them at a certain stage of design problem solving.

In addition, the results we obtained showed that the processes that lead to the emergence of ideas or allow constraints to be managed are not mutually exclusive, even when design students are exposed to different training methods. Participants who were encouraged to produce new ideas also produced constraints, albeit fewer in number than those evoked by the other group of students. Similarly, participants who had to focus on constraints were also able to express new ideas. Thus, the type of training appears to modify the way in which design problems are tackled, but our results revealed that participants were able to adapt their procedures to the rules imposed by the training task, underlining the flexibility of the creative process.

The analysis of the correlations between ideas and constraints, as well as between the three kinds of constraints (prescribed, deduced, and constructed), allowed us to explore the relationships between constraints and ideas and to reflect on the mechanisms that allow designers to switch from taking constraints into account to evoking ideas. In particular, we observed that the more design students generated prescribed constraints, the more deduced constraints they proposed ($r = .572^{**}$), whereas the more design students generated prescribed and deduced constraints, the fewer ideas they proposed ($r = -.554^{**}$ and $r = -.421^{*}$). Thus, our results show that the students who were trained with the CQHD project-oriented method were more focused on the management of constraints and seemed more engaged in framing the design problem than students who were trained with the CQFD method, who proposed more ideas and seemed more engaged in solving the design problem. However, it is important to note that the training methods did not exert a significant effect on constructed constraints, which are based on designers' own experiences or preferences.

Therefore, our results tend to show that the type of project-oriented method influences the production of ideas and constraints, as well as the creative design process itself. Indeed, the type of training also seems to have an effect on the coevolution of the problem and solution, by focusing designers' attention on either framing or solving the design problem. The dynamics of the design activities also seem to be influenced by the generation and propagation of the different types of constraints, which subtend the emergence of ideas.

STUDY 2: EFFECTS OF DESIGN PROJECT-ORIENTED METHODS ON STUDENTS' PRODUCTIONS

Objective and Hypotheses

Supplementing the previous study, the objective of this second one was to determine whether the project-oriented methods (CQFD vs. CQHD) influence students' output. As pointed out in the "Difficulties Encountered in Design Activities," it appears difficult to determine who should be the relevant judges to assess creative productions. Nevertheless, because our research takes place in an educational context, we asked teachers specializing in creative activities to evaluate the students' drawings representing their design projects. These participants had first to globally assess the design students' productions to express a general level of satisfaction, then to rate them on four specific criteria. These criteria were in line with the usual definitions of creativity (Amabile, 1996; Lubart, 1994; Runco & Charles, 1993; Sarkar & Chakrabarti, 2008) and with descriptions of convergent versus divergent thinking processes while suiting in a design area. More precisely, two criteria were in line with convergent thinking (adaptation or compliance to the design brief and the feasibility of the design project) and two others were in line with divergent thinking (innovative and unexpected dimensions of the design project).

Consistent with hypotheses formulated in the first study, we hypothesized that training centered on the evocation of ideas (CQFD) favors design solutions (or design projects) that will obtain higher ratings related to divergence than those produced in the CQHD condition. By contrast, our second hypothesis was that training centered on the management of constraints related to the design project at hand (CQHD) favors design solutions (or design projects) that will obtain higher ratings related to convergence than those produced in the CQFD condition.

Participants

There were 16 teachers specializing in creative activities (different from usual teachers of the design students) who assessed the 32 projects produced by the design students. These teachers had been trained to develop the creativity of pupils in compulsory education through the design and production of technical objects in the classroom. As part of their instruction in creative activities, these teachers had undergone training combining theoretical perspectives from the psychology of creativity, ergonomics, work psychology, and professional didactics. In parallel, they had attended practical seminars led by design professionals (designers, architects, stylists). In this context, we believed that this jury was particularly well qualified and suited for assessing the design students' productions.

Procedure

The 32 design projects to be assessed by this jury were blended into four different groups to avoid a halo effect. The participants' identity was not disclosed to the judges nor was any information about the design conditions.

Students' output was rated on 5-point scales ranging from *weakly* (*adjective*) to *strongly* (*adjective*). The questionnaire was developed using five criteria: (a) general satisfaction with the project, (b) adaptation to or compliance with the design brief, (c) feasibility of the design project, (d) innovative dimension, and (e) unexpected nature of the project.

Results

Influence of the Design Specialties? We performed linear regressions to determine whether the design specialty of students (SP or PD) had an influence on the ratings attributed by the judges to the students' design projects represented on their drawings. Several linear regressions with the design specialty as explanatory variable did not show any significant results,

TABLE 1. Saturation of the Principal Component Factor Analysis of the Four Types of Ratings Obtained by Design Projects After Rotation

Variables	F1 (Divergence Factor)	F2 (Convergence Factor)
Adapted	−0.229527218	**0.862740172**
Feasible	−0.122189856	**0.900081093**
Innovative	**−0.913373855**	0.253622303
Unexpected	**−0.942182905**	0.149710518

nor with each of the criteria as explained variables, nor with convergent or divergent factors (see explanations in the following text).

Influence of Type of Training on Ratings Attributed to the Design Projects. We also performed several statistical analyses to test hypotheses about the influence of the type of training (CQFD vs. CQHD) on the ratings attributed by judges to the students' design projects.

Concerning the general level of satisfaction with the project, the drawings performed by students who followed the CQHD training obtained slightly higher ratings than drawings developed by CQFD students (M[c] and $= 3.3031$, $SD = 0.98$ for students trained with CQHD method, versus $M = 3.1969$, $SD = 1.0467$, for students trained with CQFD method), but this difference was not significant, $t(510) = -1.18$, $p = .24$; *ns*. We did not observe either significant difference because of the kind of training, regarding the ratings attributed by judges according to each of the other criteria.

However, a principal components factor analysis was performed to project the ratings obtained by each design project regarding the following variables: (a) adapted to the design brief, (b) feasible, (c) innovative, (d) unexpected, in a more reduced subspace of dimensions. A scree plot analysis showed that the ratings of the four variables can be reduced to two factors: F1 and F2. The *innovative* and *unexpected* variables saturate on F1, whereas *adapted* and *feasible* variables saturate on F2 (Table 1). Thus, we decided to consider F1 as a factor related to divergence and F2 as a factor related to convergence.

Then, a linear regression with the factorial ratings in F2 as explained variable and the type of training as explanatory variable revealed that the students who followed the CQHD training obtained higher score of convergence than students who performed the CQFD training, $\beta = 0.25$, $t(30) = 2.9573$, $p = .006$.

Therefore, contrary to our first hypothesis, a training centered on the evocation of ideas (CQFD) did not appear to lead to higher ratings related to divergence. However, in accordance with our second hypothesis, a training centered on the management of constraints (CQHD) allowed the students to propose design projects that obtained higher ratings related to convergence than the ones produced in the CQFD condition.

GENERAL DISCUSSION

Discussion on the Results of the Two Studies

Results from the *first study* showed that the type of project-oriented method (or training) modifies the way in which design problems are tackled, but they also revealed that design students are able to adapt their procedures to the rules imposed by the training task, underlining the flexible nature of the creative process. Whatever their specialty (SD or PD), students who were trained with the CQHD project-oriented method appeared to be more focused on the management of constraints and more engaged in framing the design problem than students who were trained with the CQFD method, who proposed more ideas and seemed more engaged in solving the design problem. However, although the type of project-oriented method exerted a significant effect on the generation of prescribed and deduced constraints, we did not observe a significant effect on constructed constraints, which are based on participants' own experiences or preferences.

Consistent with these results, in the *second study*, we observed no significant effect of the specialty in design (SD or PD) on the ratings attributed by judges to the students' design projects, whatever the criteria. In line with the first study, we observed again an effect of the type of project-oriented method (or training), but it appeared to be significant only for the CQHD method: The students who followed this training proposed design projects that obtained better ratings related to convergence than design projects developed in the CQFD training context. In addition, it is important to note that these higher performances related to convergence occurred without being to the detriment of the level of general satisfaction of the projects, nor of ratings related to divergence.

To pursue the discussion about the *role of constraints in creative design*, as described earlier, we distinguished between constraints related to the design brief (*prescribed constraints*), constraints that are inferred by design students or designers during the design problem-solving process (*deduced constraints*), and constraints that are determined by each designer's or student's experiences and preferences (*constructed constraints*). Although a significant effect of training method was observed, in the first study, on the two first kinds of constraint, this was not the case for constructed constraints, which may play a specific function in creative design. This last kind of constraint may allow designers or design students to establish relationships between their knowledge and experiences and the other kinds of constraints, to introduce personal orientations and sources of inspiration into the search for ideas. Therefore, we argue that they may lie at the core of creativity and may play the role of *preinventive structures* in accordance with the Geneplore model (Finke et al., 1992). As previously pointed out, according to this model, creativity is based on both generative and exploratory processes. If we refer to this model for interpreting design activities, we can consider that during the generative phase, the designer would generate several *preinventive structures*, which correspond to mental representations that are often incomplete. This generative phase is mainly based on the association of prescribed constraints and constructed constraints, which contributes to the construction of mental representations and, thus, to the framing of the design problem. During the second exploratory phase, the preinventive structures are interpreted, elaborated, assessed and structured, and thus explored in ways that lead to insights and discoveries. For the participants in our study who were trained with the CQFD project-oriented method, the generation of constraints and preinventive structures may have led directly to exploratory processes and thus to creative ideas, as these students engaged more rapidly in the solving of the design problem. By contrast, students who were trained with the CQHD method initially focused on framing the design problem (as shown by the generation of more constraints), before engaging in solving the design problem (which would explain the lower number of ideas).

Moreover, during the first study, we observed a significant effect of training method on prescribed constraints, in favor of students who were trained with the CQHD method, and this result was consistent with the main result of the second study, which showed that students who were trained with the CQHD method developed design projects that achieved higher ratings related to convergence. It is important to remind that although these students took into account more constraints (result of the first study) and were able to apply them to propose design projects that were judged as having a higher score of convergence than those of students trained with the CQFD method, their drawings obtained similar ratings concerning general satisfaction and divergence (results of the second study). Therefore, the CQHD project-oriented method appeared to enhance the ability of design students to engage in framing the design problem, without being to the detriment of either the level of general satisfaction of the students' output or ratings related to divergence.

Complementary Analyses and Studies

To deepen our understanding of the impact of the two design project-oriented methods, we envision conducting *complementary studies* to the present research. First, we could determine whether longer cognitive training sessions, possibly across a longer training period (e.g., a semester), are more efficient at enhancing students' creativity. Second, we could base the choice of training method on tests performed by the design students beforehand. For instance, students who did not spontaneously express numerous and/or various creative ideas could be trained with the CQFD method, whereas students who did not take into account numerous and/or various constraints could be trained with the CQHD method. This would allow us to determine the impact of each of these methods on students' individual performances based on tests performed before and after the training sessions.

Third, we could analyze the impact of a more complex training method based on factors complementing the two processes taken into account in the present research. For instance, the cognitive factors we considered here could be combined with conative and emotional factors. This combination of factors would be in accordance with the multivariate approach to creativity (see, for instance, Lubart et al., 2003). In this case, we could postulate that enhancing the different factors has a cumulative effect, leading to more creative performances. Finally, we could study the influence of training methods according to the participants' level of expertise in design and thus conduct a similar study with professional designers. Indeed, previous studies (Bonnardel & Marmèche, 2004, 2005) have shown that more experienced students and professional designers are more sensitive to the presentation of stimuli and environmental factors intended to enhance the evocation process.

Relationships Between Education and Professional Activities in Design

As pointed out in this article, one of the challenges in today's society is to satisfy a growing need for innovation, while at the same time coming up with new products that meet users' needs, capabilities, and usages. Because such creative design activities appear difficult (Bonnardel, 2012), we chose to focus on ways of favoring creativity in design, not in the workplace but upstream, by providing project-oriented training for design students. Education in the field of design is becoming increasingly oriented toward work, but tasks in the classroom are not usually aimed explicitly at enhancing creativity (Fasko, 2000–2001). In line with several models of creativity and creative design, we focused on two cognitive processes that play a major role in creativity and which were associated with two project-oriented educational methods. These methods were operationalized with two kinds of training that encouraged the design students in our study to adopt a particular perspective:

- One centered on the evocation of ideas, as is the case during brainstorming, and we showed that it allows design students to produce more ideas than the students exposed to the other method but their design projects were not associated to better ratings related to divergence.
- One centered on the management of the constraints related to the design project at hand, and we showed that the method based on this process allowed the design students to produce more constraints than the students exposed to the other method and, it allowed them to produce design projects that obtained higher ratings related to convergence, without any negative impact on their level of general satisfaction or on ratings related to divergence.

In addition, as illustrated by results of the first study, finding new ideas appeared difficult and, in particular, more difficult than defining constraints. Thus, training students to exploit relationships between constraints, knowledge, and ideas could be a useful addition to the teaching approaches currently used in design schools. Applying project-oriented training in specific cognitive abilities could be of considerable benefit, especially at this stage of training, where future designers learn their future working habits and cognitive strategies. Moreover, we can envision offering similar kinds of educational methods to professional designers through lifelong learning as well as advise them to use computational design environments in their professional activities. This way, we would observe the increasing interpenetration of the worlds of work and education in society, which should help designers come up with new products that are adapted to their users and meet expectations in the design field.

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