Applied Ergonomics 83 (2020) 102987

Contents lists available at ScienceDirect

Applied Ergonomics

journal homepage: http://www.elsevier.com/locate/apergo

Brainstorming variants to favor creative design

Nathalie Bonnardel[a,*], John Didier[b]

[a] PSYCLE (Center for Research on the Psychology of Cognition, Language and Emotion), Aix Marseille Univ., InCIAM (Institute on Creativity and Innovations of Aix-Marseille), Aix-en-Provence, France
[b] Department of Art and Technology Teaching, Teacher Training University, Lausanne, Switzerland

ARTICLE INFO

Keywords:
Creativity
Design
Brainstorming

ABSTRACT

The design process in preventive and prospective ergonomic contexts requires creativity. However, user-centered methods are not usually aimed at supporting creative design. We therefore devised two variants of the seminal *brainstorming* technique to favor ideation during design activities. One variant encouraged participants to focus on the evocation of ideas, like the seminal technique, whereas the other emphasized the evocation of constraints related to the design problem. To analyze the effects of these variants on creative design, we conducted three studies: one with future designers (Study 1), one with future generalist teachers (Study 2), and one with future teachers specializing in creative activities (Study 3). Depending on the study, participants were provided with idea evocation instructions, constraint evocation instructions, or no specific instructions. Results allowed us to identify the best conditions for promoting creativity in design, depending on the individual's specialty or the complexity of the design task.

1. Introduction

Creativity is an essential skill in the 21st century (Archibugi et al., 2013; Burnard and White, 2008; Plucker et al., 2011). Today's society therefore has to meet the challenge of satisfying the growing need for creativity and innovation, especially in design activities occurring in *preventive* and *prospective* ergonomics contexts. In these contexts, the main difficulty for designers and ergonomists is to come up with products that are both new and adapted to users (Bonnardel, 2006, 2012). According to Robert and Brangier (2012), *preventive* ergonomics is related to the design of products in response to a client's request, and the focus is on how these artefacts will fit users' current needs and usages. By contrast, *prospective* ergonomics concerns the creation of products that have not yet been identified, meaning that ergonomists and designers have to imagine and anticipate future users' needs, and inject more creativity into their design solutions.

The promotion of creativity is taking on added importance in pedagogical contexts. Creativity needs to be fostered in training and education, in order to produce a creative workforce that is both flexible and competent when tackling complex tasks (McWilliam and Haukka, 2008; Miller and Dumford, 2014; Sternberg and Grigorenko, 2004). Training teachers to teach for creativity is thus becoming increasingly important (Craft et al., 2001; Jeffrey and Craft, 2004).

To contribute to the development of creativity in both schools and the workplace, we devised an approach centered on creative design activities (see Bonnardel, 2000, 2006; Didier and Leuba, 2011). In addition, in this research, our general objective was to identify the conditions favoring creative activities and productions in early design, when participants have to look for design solutions that are both new and adapted to current or future users and usages. To this end, we conducted three complementary studies: one with future designers directly motivated by creative activities (Study 1), one with future generalist teachers who were probably more familiar with subjects requiring little or no creativity (Study 2), and one with future teachers who were motivated by creative activities because they intended to specialize in creative classes (Study 3).

As we wished to identify conditions favoring creativity in design according to individual characteristics and the ergonomics context, a complementary objective was to determine the impact on creative performances of two variants of the brainstorming technique (Bonnardel and Didier, 2016): one focused on the *evocation of ideas* (IE – Idea Evocation), in line with the seminal technique; and one focused on the *evocation of constraints* (CE – Constraint Evocation) related to the design problem. In contrast to the seminal brainstorming technique proposed by Osborn (1953), these studies were conducted not in collective settings, but in *individual design situations*, where these techniques can

* Corresponding author. PsyCLE, Aix-Marseille Université, 29 avenue Robert Schuman, 13621, Aix-en-Provence, France.
E-mail address: nathalie.bonnardel@univ-amu.fr (N. Bonnardel).

https://doi.org/10.1016/j.apergo.2019.102987
Received 29 October 2018; Received in revised form 3 August 2019; Accepted 26 October 2019
Available online 8 November 2019

easily be applied. The results of these three studies would therefore allow us to identify the most appropriate brainstorming techniques for favoring creativity in design. As such, we would enhance current knowledge about the ideation phase that occurs in preventive or prospective ergonomics situations or during design thinking.

2. Creativity in an ergonomic approach

2.1. Ergonomic approach to designing interactive systems

Some authors (e.g., Lallemand and Gronier, 2015) have described an ergonomic approach that can be applied to designing new systems or products in order to favor human-system (or human-machine) interactions and lead to a 'good' user experience. Their approach identifies five important stages: 1) *planning* of the project (e.g., definition of the project and users); 2) *exploration* of the current situation's features (e.g., based on interviews, observations, questionnaires, focus groups); 3) *ideation* to find ideas that are new and also adapted to the design context, users and usages (e.g., with a brainstorming technique or use of the *persona* method); 4) *generation* to develop the ideas (e.g., via storyboarding or development of a mock-up); and 5) *evaluation* of the concrete features of the proposed system, object or service (e.g., through cognitive inspection techniques and user testing).

Each stage of this ergonomics approach can be the object of specific analyses. In the present research, we focused on the *ideation* phase and, more specifically, on techniques favoring the emergence of creative ideas. To better understand how to favor creative design, especially the ideation stage, we describe the characteristics of creativity in design below and evoke methods and techniques that can favor it.

2.2. Characteristics of creativity in design

Creativity is often defined as the ability to generate new solutions that are adapted to the context (Bonnardel, 2000; Lubart et al., 2003). According to Sternberg and Lubart (1995), creativity is a cognitive ability that requires, for instance, knowledge, personality, motivation, and an appropriate environmental context. Creativity is also frequently assumed to rely on both the individual who creates the new products, and the environment and society in which these products are introduced (Csikszentmihalyi, 1999; Lubart et al., 2003; MacKinnon, 1978; Niu and Stenberg, 2001).

Achieving creativity in design requires designers to strike a careful balance, in order to come up with new products that are distinct from existing ones, but do not destabilize users. One of the main characteristics of design activities is that designers are only given a brief description of the product they have to design-usually just its general functionalities and some constraints. Therefore, design problems are regarded as *ill-structured* or *ill-defined*, and it is only by going through the problem-solving process that designers can complete their mental representations (Simon, 1995). Another source of complexity is the fact that design problems can require more or less creativity and have a variety of potential solutions that more or less satisfy different criteria (Simon, 1995).

At the beginning of the design process, concepts and solutions are frequently devised in individual situations and assessed by the designer himself/herself ('reflexive evaluation', Bonnardel, 1999). Design solutions can also be submitted to external judges, in accordance with Csíkszentmihályi (1999)'s systemic model, and later to a more general audience consisting, for instance, of future users (Nelson et al., 2013). Accordingly, in the present study, we asked judges (teachers specializing in creative activities) to assess participants' creative productions on a set of criteria.

2.3. How to favor creativity in design

A number of design methods and ergonomic recommendations have been developed to guide designers and/or ergonomists, by leading them to perform a series of activities intended to move the design process forward. Ergonomic recommendations help them to assess existing-and sometimes future-products or systems, and also provide them with principles and criteria that can be considered during design activities. In addition, certain methods or techniques such as brainstorming, Six Hats, and functional analysis (Chulvi et al., 2012; De Bono, 1970; Jones, 1970; Osborn, 1953), are thought to stimulate creativity in the earlier design phases. In accordance with our research topic, we focused on the brainstorming technique, which Osborn (1953) created to counteract people's tendency to terminate the solution-generating process too early.

The brainstorming technique is classically used in groups and requires a moderator. Sessions therefore have to be carefully planned, which is not always easy, owing to the organizational constraints of real-life situations. Brainstorming is structured by four rules: 1) generate as many solutions as possible; 2) defer judgment about solutions until the end of the generating session; 3) try to come up with original ideas; and 4) combine and build on existing ideas. In the design context, Jiménez-Narváez and Gardoni (2014) noted several variants used as creative techniques in the early design process: 1) *commando brainstorming*; 2) *brainwriting*, in which ideas are written down (VanGundy, 1984); 3) *brainsketching*, in which ideas are drawn (Van der Lugt, 2005); 4) *post-up brainstorming*, based on Post-it notes; 5) *challenge-storming*, which involves working on ideas that generate a jump from existing product paradigms (Swiners and Briet, 2004); and 6) *reverse brainstorming*, used to analyze the causes of the problem (Woods and Davies, 1973). Chulvi et al. (2012) compared the creative outcomes of design sessions during which participants had to use either brainstorming, functional analysis (regarded as the most structured method), or the SCAMPER method (creativity tool for generating or improving ideas for new products and services). Methods based on idea generation yielded more novel outcomes, while the most useful outcomes were achieved with more structured methods. Other methods (e.g., TRIZ; Altshuller, 2004) and certain computational systems can also support designers' creative processes (see Bonnardel and Zenasni, 2010). However, such specific methods may prove complex to apply, and not all stakeholders in the design process necessarily benefit from using computational systems. We therefore argued that one promising way of helping current (e.g., designers or ergonomists) or future professionals (e.g. specialized students) to tackle creative design projects is to expose them to *particular brainstorming techniques that can favor creativity in design.*

3. Brainstorming variants for use in early design

3.1. Rationale for developing new brainstorming techniques

Osborn (1953) originally developed the *brainstorming* technique for the world of advertising, not for the design of new artefacts. One of the main differences between the two is that advertising ideas are required to meet criteria of novelty and unexpectedness, whereas design ideas need to be both *new* and *adapted to (future) users and usages*. Therefore, our general objective was to define and test two brainstorming variants that could be used in early design or in the *ideation* phase of the ergonomics approach described above or during *design thinking* (e.g., Biso and Le Naour, 2017), which is increasingly being used in professional contexts.

These two variants were developed 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 that can have contrasting effects:

1. *Analogical thinking* and, more generally, *idea associations*, can lead designers to extend or open up their search space to new ideas (e.g., Bonnardel and Marmèche, 2005). This process is closely allied to *divergent thinking*, as it allows designers or other stakeholders to

connect the design domain to other domain(s) from which inspiration can be drawn.

2. *Constraint management* allows designers to narrow the focus of their search for ideas. Constraints can be involved in *divergent thinking* - when they guide designers to look for ideas in a different conceptual domain from that of the product to be designed - as well as in *convergent thinking* - by helping designers assess ideas and gradually delimiting their search space until they reach a solution that is both new and meets the various constraints. Different kinds of constraints can subtend designers' mental representations and determine their choices and decisions (Bonnardel, 1999). Some of these constraints are *external* to the designer (*prescribed* constraints derived from the design brief) whereas others are *internal,* either based on the individual designer's previous experience and preferences (*constructed* constraints), or inferred from an analysis of the implications of previously defined constraints (*deduced* constraints).

According to the A-CM model, the processes of analogical thinking and constraint management continuously interact during the design process and contribute to other cognitive processes, such as the gradual construction of mental representations, the assessment of potential solutions, and the consideration of different viewpoints.

3.2. Brainstorming variants

The first variant, involving the *evocation of ideas (IE)*, was designed to encourage participants to come up with creative ideas. It was inspired by the original brainstorming method. Participants had to obey four rules: 1) express all the ideas (however wild or mad) related to the problem at hand that come to mind; 2) write all these ideas down; 3) reject self-censorship; and 4) use different combinations of all the ideas expressed so far to find new ones.

The second variant, involving the *evocation of constraints (CE)*, was intended to encourage participants to evoke and manage the constraints of the design problem. Participants again had to abide by four rules: 1) express all the constraints related to the problem at hand that come to mind; 2) write all these constraints down; 3) arrange the expressed constraints in hierarchical order; and 4) use different combinations of all the constraints expressed so far to find new ones.

These two variants had similar bases, but we hypothesized that they would each induce a different attentional focus among participants, given that they were related to different ways of thinking, and also have an impact on participants' creative productions.

4. Studies in design situations

We conducted three studies to determine whether applying these two brainstorming variants during a design task would influence participants' creative processes and productions.

4.1. Hypotheses and general setting of the studies

Our *first hypothesis* was that both brainstorming variants *favor design problem solving*, but each induces a *different focus of attention*. More specifically, we expected the IE variant to stimulate more divergent thinking, by allowing participants to extend their search space for ideas, and the CE variant to stimulate both convergent and divergent thinking, by leading participants to consider, analyze and manage constraints, which would orient and delimit the search space and thus play the role of current goals (Bonnardel, 2000, 2006).

Following on from this, our second hypothesis was that these variants also influence the *quality* of the creative productions. As assessing creative productions is particularly complex, we asked a panel of professionals (teachers specializing in creative activities) to assess participants' productions on a specific set of criteria.

Each of these studies comprised two complementary phases.

In the *first phase*, participants were provided with a design brief and, depending on the condition:

1) instructions intended to favor IE;
2) instructions intended to favor CE;
3) no instructions (control condition)[1].

In the *second phase*, all the participants' design projects were analyzed anonymously and in random order by panels of judges, according to five criteria: 1) *overall satisfactoriness* of the design project; 2) *'adaptation'*, which corresponds to the suitability of the project relative to the design problem specifications; 3) *feasibility* of the project; 4) its innovative dimension or *'innovativeness'*, which broadly corresponds to newness; and 5) its unexpected dimension or *'unexpectedness',* which reflects a higher degree of novelty. Thus, in addition to the general criterion of overall satisfactoriness, we chose two criteria relating to convergent thinking (adaptation and feasibility), and two relating to divergent thinking (innovativeness and unexpectedness).

4.2. Study with design students

4.2.1. First phase

4.2.1.1. Participants, task and procedure. We recruited 32 design students (16 women) aged 18–20 years ($M = 19$ years). They were all at the end of their first year in a design school in Marseille (France).

These participants were divided into two groups, depending on which brainstorming variant they had to follow (IE or CE). As their design teachers wanted them all to benefit from an ideation technique, it was not possible to constitute a control group (no instruction).

As the participants were future designers, we asked them to perform a creative design task, set in collaboration with their teachers. All of them received the same design brief (or specifications), consisting in designing a universal device to protect pedestrians crossing the road, which would meet the various needs of future users and could be adapted to different urban contexts (see examples of constraints to respect in Fig. 1). As the specific expectations did not correspond to existing urban devices, the brief could be considered to relate to prospective ergonomics.

In the first ideation (divergent) step, participants were given a total of 30 min to read the design problem specifications, together with a printed sheet containing the rules for their condition (i.e. IE or CE instructions), and to write down all their proposals. During the second (more convergent) step, participants had to decide which design project they wished to develop, and were given 90 min to represent it on A3 sheets and finalize their sketches.

4.2.1.2. Data analysis. The data analysis performed during this first phase allowed us to count the numbers of ideas and constraints expressed by participants (for more details, see Bonnardel and Didier, 2016). We considered *ideas* as defining the characteristics of the product to be designed whereas *constraints* defined the requirements the product to be designed had to meet. We analyzed the *fluency of ideas*, based on the number of ideas expressed by participants, and the *fluency of constraints*, based on the number of constraints expressed by participants.

4.2.1.3. Results. We ran an ANOVA to compare the two brainstorming variants (IE vs. CE) on the two dependent variables described above.

Concerning the *fluency of ideas*, the design students who were exposed to the IE instructions expressed more ideas on average ($M = 5.44$, $SD = 3.18$) than those who were provided with the CE instructions ($M = 2.19$, $SD = 2.40$), $F(1, 28) = 10.8$, $p = 0.003$.

Concerning the *fluency of constraints*, the design students who were provided with the CE instructions expressed more constraints on average ($M = 16.00$, $SD = 5.75$) than those in the IE group ($M = 9.25$, $SD = 3.69$),

The universal urban device should comply with the following constraints:
- to protect pedestrians crossing the road,
- to fit users' various needs,
- to allow simultaneous moves of two persons,
- to limit pedestrians' fear of accident risks,
- to be adaptable to any road configuration.

Fig. 1. Extract of constraints prescribed in the design brief.

F (1, 28) = 14.92, $p = 0.002$.

Therefore, in accordance with Hypothesis 1, the two brainstorming variants led participants to adopt a *different focus* on the design problem. Although both ideas and constraints were evoked whatever the experimental condition, depending on the brainstorming variant, participants were stimulated to develop evocation processes that were centered more on ideas or on constraints.

4.2.2. *Second phase*

4.2.2.1. Participants and procedure. We asked 16 judges to assess the design students' drawings of their projects (see example in Fig. 2), according to the criteria described above.

4.2.2.2. Results. To test our hypotheses on the influence of the brainstorming variant (IE vs. CE), we ran statistical analyses on the scores awarded by the judges to the design students' productions (see Table 1). Kendall's tau coefficient showed no significant difference between the judges on their evaluations of the students' productions ($r_\tau = 0.004$, $p = 0.59$).

We first ran an ANOVA to determine whether the type of brainstorming variant had a significant effect on assessments of the design students' productions but no significant difference was observed. We then performed a principal components factor analysis that allowed us to project the scores, for each participant's drawing with regard to four variables (adaptation, feasibility, innovativeness, unexpectedness), in a smaller subspace of dimensions. It appeared that these scores could be reduced to two factors (F1 and F2) since innovativeness and unexpectedness loaded on F1 (respectively −0.913373855 for innovativeness and −0.942182905 for unexpectedness), while adaptation and feasibility loaded on F2 (respectively 0.862740172 for adaptation and 0.900081093 for feasibilty). With regard to the topics of these variables, F1 was considered as related to divergence, and F2 as related to convergence.

Finally, a linear regression was performed with the F2 scores as the explained variable, and the brainstorming variant as the explanatory variable. On this basis, in accordance with Hypothesis 2, we observed that the brainstorming variants affected the judges' scoring of the participants' productions: participants who followed the CE instructions achieved a higher convergence score than participants provided with IE instructions ($\beta = 0.25$; $t = 2.95$; $p = 0.006$). Nevertheless, there was no significant difference on the divergence score. Thus, the design students appeared to benefit more from instructions that led them to evoke and manage constraints related to the design problem (CE) than from instructions that led them to evoke ideas (IE), when they had to come up with projects that were both new *and* adapted to the design problem.

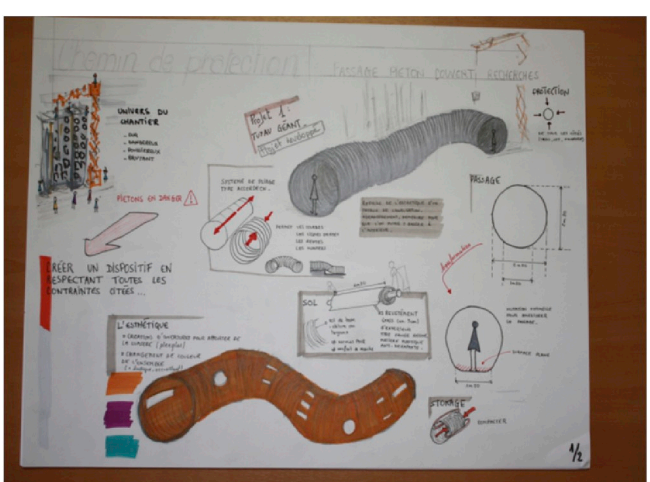

Fig. 2. Example of the drawings produced by the design students.

4.3. *Study with future generalist teachers*

As the participants in the second study were future generalist teachers, they were assigned a simpler design task that they would be able to use later on with their students or pupils. This task did not require a high level of creativity but involved developing a new object for a specific use and allowed participants to exhibit *expressive* creativity (Taylor et al., 1957; cited in Rouquette, 1973).

As the design task was easier than in the previous study, we observed that, after producing a few sketches, participants directly set about designing and realizing their creative productions in accordance with the design brief. We therefore do not present any results for the first phase of the study.

4.3.1. *First phase*

4.3.1.1. Participants, task and procedure. We recruited 34 future generalist teachers, all women, aged 18–45 years (mean = 20 years). They were in their second year of teacher training, and during their internship, they learn to conceive and realize technical objects with their future pupils. The study took place during seminars on the didactics of creative and manual activities.

Participants were divided into three groups: IE ($n = 12$), CE ($n = 12$), and control (no instructions given; $n = 10$).

All these participants received the same design brief (see examples of constraints to respect in Fig. 3) and were asked to design and produce a keying made of felt padded with fleece, using the materials made available to them (fleece, felt, thread, needle, feathers) (see example of production in Fig. 4).

The 12 participants in the IE condition and the 12 in the CE condition were given a total of 30 min to read the design brief together with the instructions corresponding to their brainstorming variant (IE or CE) and possibly write down all their ideas. They then had 60 min to represent their design project on A3 sheets and finalize their sketches using pens of different colors.

The 10 participants in the control group had 90 min to read the design brief and to make and represent their design project.

4.3.2. *Second phase*

4.3.2.1. Participants and procedure. The participants' productions were again assessed by 16 judges (different from those in Study 1), according to the same criteria as before.

4.3.2.2. Results. We ran an ANOVA to determine whether the type of brainstorming variant had a significant effect on the criteria taken into

Table 1
Judges' scoring of the design students' productions.

	Conditions	Overall satisfactoriness	Adaptation	Feasibility	Innovativeness	Unexpectedness
Mean	IE	3.20	3.27	3.17	2.95	2.86
	CE	3.31	3.35	3.46	2.91	2.80
Standard deviation	IE	1.05	1.03	1.04	1.14	1.16
	CE	0.988	0.935	1.02	1.03	1.07

The keyring should comply with the following constraints:
- to be easy to handle
- to fit in a pocket or bag
- to be of shop quality (which in this context means a good quality invoice)
- to be sturdy and longlasting (to withstand frequent daily use)
- to have a metal ring for the keys and be solid.

Fig. 3. Extract of constraints prescribed in the design brief.

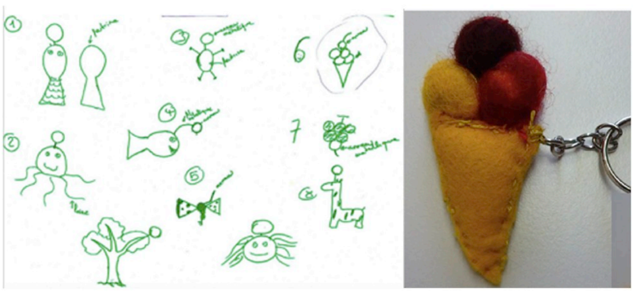

Fig. 4. Example of the sketches and objects produced by the future generalist teachers.

account to judge the future generalist teachers' productions (see Table 2). Kendall's tau coefficient showed no significant difference between the judges on their evaluations of the students' productions ($r_{\tau} = 3.7^{E}$-4, $p = 0.96$).

The productions of the future generalist teachers provided with the IE instructions were judged to be significantly *more satisfactory* than those of participants in the CE condition (IE: $M = 3.31$, $SD = 0.6$; CE: $M = 3.13$, $SD = 0.5$; $p = 0.002$). In addition, the productions of the participants in the CE condition were judged to be significantly more satisfactory than those of controls (CE: $M = 3.31$, $SD = 0.6$; control: $M = 2.94$, $SD = 0.8$; $p = 0.005$).

The productions of the IE group were also judged to be significantly *more innovative* than those of the CE group (IE: $M = 2.94$, $SD = 0.8$; CE: $M = 2.65$, $SD = 0.8$; $p = 0.001$). In addition, the productions of the CE group were judged to be more innovative than those of the control group (CE: $M = 2.65$, $SD = 0.8$; control: $M = 2.28$, $SD = 0.6$; $p = 0.01$).

However, we observed no significant differences on either adaptation or feasibility.

In accordance with Hypothesis 2, we again showed that the brainstorming variants influenced features of the participants' productions. However, in contrast to the previous study, the future generalist teachers appeared to benefit more from the instructions encouraging them to evoke ideas (IE) than from those encouraging them to evoke and manage constraints (CE). Moreover, some benefits were observed with the CE instructions relative to the control condition.

4.4. *Study with future teachers specializing in creative activities*

This study was conducted among future teachers who intended to specialize in creative and manual activities, and who were therefore potentially more interested in performing creative tasks than future generalist teachers. These teachers were receiving postgraduate on-the-job training intended for generalist teachers or for members of the creative professions (designers, engineers, craftspeople, seamstresses, mechanics, sculptors) who wish to teach creative activities in mainstream school in French-speaking Switzerland. These participants had therefore all received professional training. As in the previous study, they were asked to perform a design task that they would be able to use later on with their students or pupils. We again observed that, after producing a few sketches, these participants directly set about designing and realizing their creative productions in accordance with the design brief. We therefore do not present results for the first phase of the study.

4.4.1. *First phase*

4.4.1.1. Participants, task and procedure. We recruited 17 (14 women) future teachers specializing in creative activities aged 25–50 years ($M = 33$ years). They were being trained to teach handicrafts and creative textile activities in French-speaking Switzerland.

Participants were divided into three groups: IE ($n = 6$), CE ($n = 6$), and control ($n = 5$).

All these participants received the same design brief (see examples of constraints to respect in Fig. 5) and were asked to design and produce a model for a new kind of Advent calendar using the material made available to them (different types of paper, colored cardboard, tools for cutting cardboard) (see example in Fig. 6). As in the previous study, although this design task did not require a high level of creativity, it did involve developing a new object for a specific use and allowed

Table 2
Judges' scoring of the future generalist teachers' productions.

	Conditions	Overall satisfactoriness	Adaptation	Feasibility	Innovativeness	Unexpectedness
Mean	IE	3.31	3.309	3.64	2.94	2.93
	CE	3.13	3.308	3.47	2.65	2.58
	Control	2.94	3.06	3.68	2.28	2.25
Standard deviation	IE	0.6	0.6	0.6	0.8	1
	CE	0.5	0.9	0.6	0.8	0.9
	Control	0.8	0.7	0.7	0.6	0.7

The Advent calendar should comply with the following constraints:
- to be sturdy enough to handle,
- to be suitable for a school context,
- to have parts that open and close,
- to reflect a clearly identifiable symbolism (sign function),
- to serve the purpose for which it is intended.

Fig. 5. Extract of constraints prescribed in the design brief.

participants to exhibit *expressive* creativity.

The six participants in the IE condition and the six in CE condition had 30 min to read the design brief and the instructions corresponding to their brainstorming condition (IE or CE), and possibly write down all their ideas. They then had 60 min to represent their design project on A3 sheets and finalize their sketches using pens of different colors.

The five participants in the control group had 90 min to read the design brief and to make and represent their design project.

4.4.2. Second phase

4.4.2.1. Participants and procedure. The design projects produced by the specialist students were assessed by 10 judges, according to the same criteria as before.

4.4.2.2. Results. We ran an ANOVA to determine whether the type of brainstorming variant had a significant impact on assessments of the future specialist teachers' productions (see Table 3).

In accordance with Hypothesis 2, the productions of the future specialist teachers provided with IE instructions were judged to be significantly:

- *more satisfactory* than those of both the CE group (IE: $M = 3.16$, $SD = 0.6$; CE: $M = 2.65$, $SD = 0.6$; $p = 0.006$) and the control group (control: $M = 2.8$, $SD = 0.6$; $p = 0.04$);
- *more adapted to the design problem*, compared with those of the CE group (IE: $M = 3.68$, $SD = 0.7$; CE: $M = 3.18$, $SD = 0.6$; $p = 0.007$);
- *more feasible*, compared with those of the CE group (IE: $M = 4.05$, $SD = 0.4$; CE: $M = 3.5$, $SD = 0.6$; $p = 0.003$);
- *more innovative* than those of both the CE group (IE: $M = 2.8$, $SD = 0.7$; CE: $M = 2.33$, $SD = 0.8$; $p = 0.011$) and the control group (control: $M = 2.36$, $SD = 0.8$; $p = 0.013$).

Unexpectedness was the only criterion where no significant difference was observed.

Therefore, in accordance with Hypothesis 2, we observed that both brainstorming variants influenced the nature of the productions of future teachers specializing in creative activities. As in Study 2, these participants benefitted more from instructions encouraging them to evoke ideas (IE) than from instructions encouraging them to evoke constraints related to the design problem (CE). Participants also benefited from the CE instructions relative to the control condition.

5. Discussion, limitations and perspectives

5.1. Main findings and interpretations

The results of the three studies we conducted showed that each brainstorming variant led participants to adopt a *different focus of attention*. More precisely, in the first study, the IE instructions led participants to express more ideas than the CE instructions did, whereas the CE instructions led participants to express more constraints than the IE instructions did, in accordance with Hypothesis 1.

In addition, in all three studies, these brainstorming variants influenced the nature of the participants' creative productions, in accordance with Hypothesis 2. However, the judges' assessments showed that the conditions required to enhance creative performances depended on the participants' specialties and/or the complexity of the design task. The design students, who had to perform a complex design task related to prospective ergonomics (conceiving a new urban device), benefitted more from the instructions encouraging them to analyze the constraints (CE), whereas the future generalist and specialist teachers, who had to design simpler objects they could subsequently use with their pupils, benefitted more from the instructions encouraging the generation of ideas (IE).

The differences observed between these participants may be explained by the training they were receiving. Owing to the content of their training, and maybe also to their motivation to perform creative activities, design students may spontaneously adopt divergent thought processes. Thus, to balance their spontaneous thought processes, it may be useful to encourage them to focus more on the constraints related to the design problem, which is what the CE instructions did. By contrast, future generalist teachers may be more familiar with activities that require the application of knowledge and rules. They may therefore spontaneously adopt convergent thought processes, as these are required in numerous teaching disciplines. Accordingly, they may benefit more from IE instructions leading them to look for large numbers of unfamiliar ideas, and enabling them to open up their search space and adopt more divergent thought processes than in *spontaneous* situations (or control conditions). Concerning the future specialist teachers, who

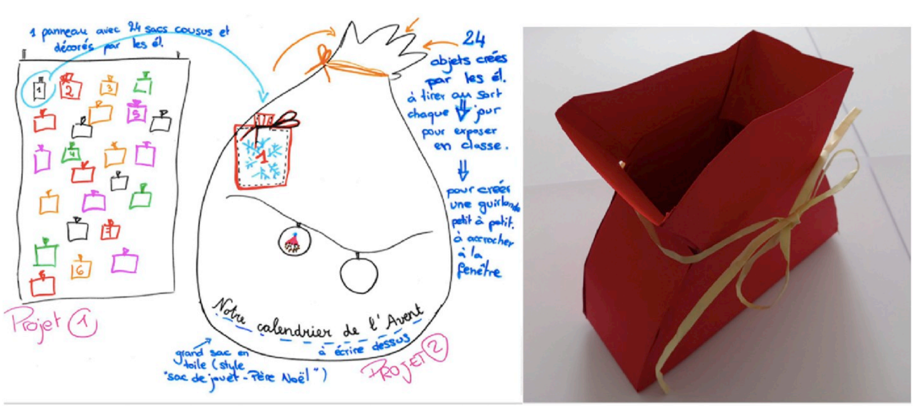

Fig. 6. Example of the sketches and objects produced by the specialist students.

Table 3
Judges' scoring of the future specialist teachers' productions.

	Conditions	Overall satisfactoriness	Adaptation	Feasibility	Innovativeness	Unexpectedness
Mean	IE	3.16	3.68	4.05	2.80	2.87
	CE	2.65	3.18	3.50	2.33	2.72
	Control	2.8	3.36	3.82	2.36	2.66
Standard deviation	IE	0.6	0.7	0.4	0.7	0.5
	CE	0.6	0.6	0.6	0.8	0.6
	Control	0.6	0.6	0.5	0.8	0.7

may have been more motivated to perform creative activities, we observed similar results, even though their background differed from that of future generalist teachers. Based on the results of these three studies, we suggest adapting the brainstorming technique to participants' specific features, notably to compensate for their spontaneous thought processes when they have to come up with creative solutions that are both new and adapted to the context.

Another interpretation of these results relates to the complexity of the design task that participants had to perform in each study. The task given to future designers required them to take complex constraints into account (e.g. to limit pedestrians' fear of accident risks), and it may have been difficult to find ideas that satisfied these constraints. Thus, when participants directly evoked ideas, as they did with the IE instructions, their ideas and creative productions may have been less satisfactory than when participants first reflected on the design problem's constraints, as was the case with the CE instructions, before engaging in the evocation of ideas. Thus, complex design activities, and possibly those related to prospective ergonomics, may benefit from the use of a brainstorming technique that focuses on constraints related to the design problem. By contrast, simpler design tasks, such as the ones given to future teachers, may be efficiently performed with a brainstorming technique that leads participants to directly evoke ideas for the design problem.

5.2. *Limitations*

The studies described here present some limitations. First, the number of participants in each study was quite small (32 in Study 1, 34 in Study 2, and 17 in Study 3). It should, however, be noted that our participants were enrolled on specialist courses with small numbers of students, and we worked with all those available in each of these fields. Moreover, as some of our results were significant, our findings contribute to a better understanding of the effects of the two brainstorming variants, and can therefore lead to suggestions for applying these techniques in the case of preventive or prospective contexts or design thinking situations.

Second, participants were relatively young (around 19 or 20 years) in Study 1 (future designers) and Study 2 (future generalist teachers). However, these participants were engaged in specialized training and acquiring experience in their respective fields. By contrast, the participants in Study 3 (future teachers specializing in creative activities) were older (around 33 years) and all of them had received professional training prior to this postgraduate program, as they were either former generalist teachers or had worked in a creative profession.

Third, owing to the experimental settings, each design session lasted (at least) a total of 90 min, whatever the experimental condition and area of specialization. Thus, none of the three studies allowed us to observe the effects of instructions on design conditions in the longer term. Nevertheless, although this duration was obviously shorter than that of real-life design projects, it was in accordance with realistic design projects that may be set during specialist training. In addition, all the experimental design sessions were structured in two steps, beginning with a divergent period (leading to the evocation of ideas or constraints, depending on the brainstorming variant) followed by a convergent period (leading to the selection of a design project that was represented or realized). This encouraged participants to engage for a short time in processes that may take place over longer periods in real-life contexts. We therefore argue that these design projects are useful for training future specialists.

Fourth, it seems important to return to the kind of design problems that participants were set. The design problems given to the future teachers in Studies 2 and 3 focused on the design and implementation of a relatively simple artefact, compared with the design problem that future designers in Study 1 had to tackle. In Studies 2 and 3, the constraints focused exclusively on functional and aesthetic aspects of the artefact, whereas in Study 1, they were also related to ergonomic aspects related to pedestrian protection and users' perception of accident risks. It would be interesting later on to analyze the effects of IE and CE brainstorming techniques for complex design problems that require more knowledge (e.g., in economics, science and/or technology), as can be the case in professional contexts.

5.3. *Perspectives*

We found that the type of brainstorming instruction (IE or CE) modified the way in which the design problem was tackled. Therefore, it appears possible to act upon participants' creative abilities and stimulate either divergent or convergent thinking, depending on participants' needs. However, several complementary studies will be necessary to fully understand when and how to apply these brainstorming variants in order to favor creative design activities.

First, we plan to analyze the use of brainstorming variants in design activities performed by ergonomics students involved in the design of new products (or services) to fit future users' needs.

Second, it would be extremely worthwhile to supplement this research with a study conducted in professional real-life contexts (e.g., with professional designers or ergonomists in charge of projects related to prospective ergonomics). In this case, there would be fewer participants than in the present studies, but the professionals would be involved in design projects over a longer period than in the experimental studies, thereby increasing the ecological validity of the findings.

Third, we plan to determine whether it is possible to allow participants to adapt their brainstorming technique to the ongoing creative design process and/or their own characteristics, depending on their training or *creative profile*. For instance, a tool such as the Creative Profiler (developed at LATI, Paris Descartes University) can contribute to identify individuals who spontaneously adopt more divergent processes or, on the contrary, more convergent processes. Thus, depending on the participants' characteristics, it might be possible to suggest that they use a brainstorming technique focused on either CE or IE.

To conclude, this research illustrates the extent of the opportunities we have to help students and professionals come up with ideas (products or systems) that are both new and adapted to expectations across a range of fields.

Acknowledgements

We are very grateful to all the design students, generalist teachers, and teachers specializing in creative activities who took part in our studies. We are also very grateful to Thomas Arciszewski, Nicolas Bonzon and Nicolas Pichot, as well as to the anonymous reviewers for their constructive advice and suggestions.

This research was partially supported by the CREAPRO French National Research Agency contract (grant no. ANR-08-CREA-038) and by the Aix-Marseille University Foundation.

References

Altshuller, G.S., 2004. 40 Principes D'innovation. A. Seredinski, Paris.

Archibugi, D., Filippetti, A., Frenz, M., 2013. The impact of the economic crisis on innovation: Evidence from Europe. Technol. Forecast. Soc. Chang. 80, 1247–1260.

Biso, S., Le Naour, S., 2017. Design Thinking. Malakov, Dunod.

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

Bonnardel, N., 2000. Towards understanding and supporting creativity in design: Analogies in a constrained cognitive environment. Knowl. Based Syst. 13, 505–513.

Bonnardel, N., 2006. Créativité et conception: Approches cognitives et ergonomiques. Solal/Paris: De Boek, Marseille.

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., 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. J. Cogn. Educ. Psychol. 15 (1), 80–101.

Bonnardel, N., Marmèche, E., 2005. Towards supporting evocation process in creative design: a cognitive approach. Int. J. Hum. Comput. Stud. 63, 442-435.

Bonnardel, N., Zenasni, F., 2010. The impact of technology on creativity in design: an enhancement? Creativ. Innov. Manag. 19 (2), 180–191.

Burnard, P., White, J., 2008. Creativity and performativity: Conterpoints in British and Australian education. Br. Educ. Res. J. 34 (5), 667–682.

Chulvi, V., Mulet, E., Chakrabarti, A., López-Mesa, B., González-Cruz, C., et al., 2012. Comparison of the degree of creativity in the design outcomes using different design methods. Journal of Engineering Design 23 (4), 241–269. https://doi.org/10.1080/09544828.2011.624501.

Craft, A., Jeffrey, B., Leibling, M. (Eds.), 2001. Creativity in Education. Continuum, London, New York.

Csíkszentmihályi, M., 1999. Creativity: Flow and the Psychology of Discovery and Invention. Harper Collins, New York.

De Bono, E.D., 1970. Lateral Thinking. Harper & Row, New York.

Didier, J., Leuba, D., 2011. La conception d'un objet: Un acte créatif. Prism 15, 32–33.

Teaching creatively and teaching for creativity: Distinctions and relationships. In: Jeffrey, B., Craft, A. (Eds.), Educ. Stud. 30 (1), 77–87.

Jiménez-Narváez, L.M., Gardoni, M., 2014. Developing design concepts in a cloud computing environment: creative interactions and brainstorming modalities. Digit. Creativ. 25 (4), 295–312. https://doi.org/10.1080/14626268.2013.858750.

Jones, J., 1970. Design Methods: Seeds of Human Futures. Wiley-Interscience, New York.

Lallemand, C., Gronier, G., 2015. Méthodes de design UX. 30 méthodes fondamentales pour concevoir et évaluer les systèmes interactifs. Editions Eyrolles, Paris.

Lubart, T., Mouchiroud, C., Tordjman, S., Zenasni, F., 2003. Psychologie de la créativité. Armand Colin, Paris.

MacKinnon, D.W., 1978. In: Search of Human Effectiveness: Identifying and Developing Creativity. Creative Education Foundation, Buffalo, NY.

McWilliam, E., Haukka, S., 2008. Educating the creative workforce: new directions for twenty-first century schooling. Br. Educ. Res. J. 34 (5), 651–666.

Miller, A., Dumford, A., 2014. Creative cognitive processes in higher education. J. Creat. Behav. 50 (4), 282–293.

Nelson, J., Buisine, S., Aoussat, A., 2013. Anticipating the use of future things: towards a framework for prospective use analysis in innovation design projects. Appl. Ergon. 44 (6), 948–956.

Niu, W., Sternberg, R.J., 2001. Cultural influences on artistic creativity and its evaluation. Int. J. Psychol. 36 (4), 225–241.

Osborn, A.F., 1953. Applied Imagination: Principles and Procedures of Creative Thinking. Charles Scribner's Sons, New York.

Plucker, J.A., Waitman, G.R., Hartley, K.A., 2011. Education and creativity. In: Runco, M.A., Pritzker, S.R. (Eds.), Encyclopedia of Creativity. Elsevier, pp. 435–440.

Robert, J.-M., Brangier, E., 2012. Prospective ergonomics: Origin, goal, and prospects. Work, A Journal of Prevention Assessment and Rehabilitation 41, 5235–5242.

Rouquette, M.-L., 1973. *La Créativité, Que Sais-je* ? PUF, Paris.

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

Sternberg, R.J., Grigorenko, E., 2004. Successful intelligence in the classroom. Theory Pract. 43 (4), 274–280.

Sternberg, R.J., Lubart, T.I., 1995. Defying the Crowd: Cultivating Creativity in a Culture of Conformity. Free Press, New York.

Swiners, J.-L., Briet, J.-M., 2004. L'intelligence créative au-delà du brainstorming. Maxima Editeur, Paris.

VanGundy, A.B., 1984. Brainwriting for new product ideas: an alternative to brainstorming. J. Consum. Mark. 1 (2), 67–74.

Taylor, D.W., Berry, P.C., Block, C.H., 1957. Does group participation when using brainstorming facilitate or inhibite creative thinking? Tech. Report no. 1 Yale University, Office of Naval Research, Yale.

Van der Lugt, R., 2005. How sketching can affect the idea generation process in design group meetings. Des. Stud. 26 (2), 101–122.

Woods, M.-F., Davies, G.-B., 1973. Potential problem analysis: a systematic approach to problem prediction and contingency planning – an aid to the smooth exploitation of research. R D Manag. 4 (1), 25–32.