The Impact of Technology on Creativity in Design: An Enhancement?

Nathalie Bonnardel and Franck Zenasni

Technology may be considered as an interface between individuals and the products they create, but we have to determine whether the use of new systems effectively enhance individuals' creative activities. In this paper, we present a new angle of reflection that we illustrate in the field of creative design, since it is a constant challenge for designers to introduce creativity in the projects they work on. The approach we propose is centred on designers' cognitive processes. We argue that both the development of new CAD (computer-aided design) systems and their assessment should be conducted on the basis of a deep understanding of designers' cognitive processes. In accordance with this view, we present three empirical studies that were conducted in order to analyse the impact of new design support systems on designers' cognitive processes. Therefore, the results we present contribute to further our knowledge of whether new CAD technologies effectively facilitate designers' activities and enhance their creativity.

Introduction

In the last decades, developments in technology and computer science have modified the creative potential of each individual. In particular, the democratization of the use of computers and the development of fast internet have allowed large numbers of individuals to access a wide range of informational elements and to use new computational tools. In this paper, we focus on designers and CAD (computer-aided design) tools, since it is a constant challenge for them to introduce creativity in the design projects they work on as well as to satisfy constraints about the object to be designed. Indeed, whatever the domain, final product designs should have some innovative aspects in order to be attractive to customers or future users. However, when faced with a new design problem, designers tend to reproduce solution approaches they used in past designs or to reproduce features of solutions they previously developed or observed. Such a tendency may partly result from the current context of industrial design projects where there is a need to reduce costs and delays, while simultaneously increasing design creativity and quality. Therefore, design science has been oriented towards the development of CAD systems. These systems allow designers to reach precise and appealing external representations of the object to be designed, for instance, through 3D virtual representations of the object (see Figure 1), but the early studies that were conducted on the impact of CAD systems suggested that they exert a negative influence on creative design (Whitefield, 1986). Indeed, designers seemed to be more focused on the use of the computational systems than on the creative design task itself (McCullough, 1996). Moreover, CAD systems usually oblige designers to generate an early precise external representation of the object to be designed and to use highly structured rules, which orients their reflections and does not correspond to their spontaneous process of creation (Scrivener, 1982; Stones & Cassidy, 2007).

In this paper, we argue that the development of new technologies should be dependent on individuals' cognitive processes. More precisely, in the context of creative design, we consider that the development of new CAD systems should be conducted on the basis of a deep understanding of designers' cognitive processes and the difficulties they encounter. Therefore, technology developments should be adapted to designers' cognitive processes instead of requiring users to adapt to new technologies. In addition, we argue that the assessment of new CAD systems should be

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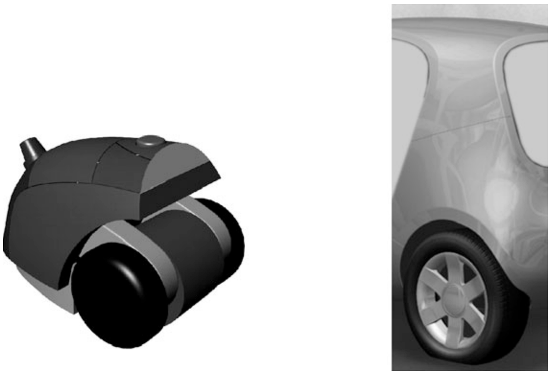

Figure 1. Examples of 3D Virtual Representations of Design Solutions

conducted not only on the basis of heuristic evaluations or ergonomics principles (see, for instance, Norman, 1993; Scapin & Bastien, 1997) but also on the basis of an understanding of designers' cognitive processes while using these new technologies.

To illustrate this approach in the context of creative design, we first describe designers' cognitive activities in order to define directions for the development of CAD systems useful for supporting designers' cognitive processes. Then we present three empirical studies that were conducted to determine whether new CAD systems effectively facilitate designers' cognitive processes.

Understanding Designers' Cognitive Processes

From a cognitive point of view, a main characteristic of creative design activities is that the initial state is 'ill structured' (Eastman, 1969; Simon, 1973, 1995). Indeed, the designers' mental representation is initially incomplete and imprecise. It is only through the problem-solving process itself that designers can complete their mental representations by confronting various points of views and by choosing design options. Thus, the design problem-solving results from a co-evolution of problem and solution spaces (Dorst & Cross, 2001). This specificity of design problems has also been described as based on an iterative dialectic between problem-framing and problem-solving (Rittel & Webber, 1984; Simon, 1995).

During problem-framing, designers refine design goals and specifications and, thus, refine their mental representation of the problem. During problem-solving, designers elaborate solutions and evaluate these solutions with respect to various criteria and constraints, which guide the designers in performing subsequent stages of the design problem-solving (Bonnardel, 2000). Therefore, designers' mental representations evolve until they reach a design solution that is considered as satisfying. In the case of creative design, the solution to be reached has both to be new and to respect certain constraints and criteria. However, when faced with a new design problem, designers may tend to reproduce solution approaches they used in past designs and may not consider alternative and more effective design solutions (Jansson & Smith, 1991; Purcell & Gero, 1992). Thus, it appears crucial *to support the evocation of creative ideas during design activities*.

In addition, designers frequently encounter difficulties in assessing their own design solutions because a variety of criteria and constraints have to be taken into consideration for conducting a precise evaluation. More precisely, if some constraints can result from subconscious processes, showing themselves through apparently 'intuitive' acts, other constraints are the object of a more conscious treatment. Some of these latter constraints result from the activation of certain knowledge elements by designers and are thus dependent on situations they previously experienced (Bonnardel, 2000). Other constraints are defined by designers on the basis of data resulting from the external context of the creative situation, such as constraints specified in the design brief (or in a schedule of conditions) or from constraints associated to points of view adopted by other stakeholders. Indeed, complex design problems require more knowledge than any single person can possess, and the knowledge relevant to a problem is often distributed among stakeholders who have different perspectives and backgrounds (Salomon, 1993; Fischer et al., 2005). Moreover, there are sometimes contradictions among certain criteria and constraints (Bonnardel & Sumner, 1996). Therefore, it seems necessary *to support designers in assessing their own solutions*.

The dynamics of creative design appears also through what is called an 'opportunistic' activity (Hayes-Roth & Hayes-Roth 1979; Visser, 1990, 1994). Design activities are characterized as opportunistic because 'each decision is motivated by one or two immediately preceding decisions, rather than by some high-level executive program' (Hayes-Roth & Hayes-Roth, 1979, p. 381), although it possibly includes hierarchical episodes. This leads to reconsidering previous decisions or postponing certain decisions (Hayes-Roth & Hayes-Roth, 1979; Guindon, 1990; Visser, 1990). This dynamic is facilitated by a process of 'externalization', which corresponds to the creation and modification of external representations of the object to be designed, such as drawings, sketches or 3D virtual representations produced with a CAD system. These representations are useful for the designers themselves as a 'reflective conversation' is established between them and their external representations of the artifact, consisting for instance in drawings (Schön, 1983). It allows designers to reach a better understanding of the design problem and to adopt new points of view about the object to be designed. Externalizations also facilitate communication and the development of shared understanding amongst stakeholders from diverse backgrounds who have to work together throughout the design process (Fischer et al., 2005; Fischer & Giaccardi, 2007). Drawings and sketches are usually intuitive and easy to produce but the objects to be designed are represented in 2D whereas designers need to have different points of view on these objects. In contrast, CAD systems provide the designers and the other stakeholders involved in the design process with precise and appealing representations of the object to be designed, but they require complex and non-intuitive actions for representing these objects. Therefore, it appears suitable to develop *computational systems that would require simple and intuitive actions* to produce 3D virtual representations of the object to be designed.

The Impact of New Design Support Systems on Designers' Activities: Empirical Studies

To facilitate or improve designers' activities, several forms of support can be envisaged:

- design methods to facilitate the process of product development (Araujo, 1996; Schneider & Lindemann, 2005) or to help designers better understand users' expectations and needs (Wharton et al., 1994);
- ergonomic principles or recommendations (e.g., Norman, 1993) and ergonomic criteria (Scapin & Bastien, 1997) to help designers create products or objects that are more adapted to users;
- computational systems that aim at supporting designers at several stages of their activities (Fischer et al., 2005; Maher, Kim & Bonnardel, 2010).

This last form of support seems particularly adapted to professionals. Indeed, due to temporal constraints, it is difficult for them to be engaged in continuing education, which could allow them to learn new design methods and to apply ergonomic recommendations and criteria. In contrast, the introduction in their working environment of design support systems seems particularly convenient because most professional designers use computational systems in their usual activities.

In accordance with this perspective and the necessity to support designers' cognitive processes, we are going to present three empirical studies that aim at determining the impact of the use of new design support systems on designers' activities. In particular, these studies are focused on the use of computational systems for supporting three main cognitive processes involved in creative design: (1) the emergence of creative ideas, (2) the management of constraints in order to assess or evaluate ideas or design solutions, and (3) the externalization of mental representations of the object to be designed. These three ways of supporting designers' activities are presented in the following sections and discussed on the basis of the results of the empirical studies.

Supporting the Emergence of Creative Ideas

According to Ward's structured imagination framework (Ward & Sifonis, 1997; Ward, Smith & Vaid, 1997), people who are engaged in creative or 'generative cognitive' activities have to extend the boundaries of a conceptual domain by mentally crafting novel instances of the concept. Such a view is in line with findings by Ansburg and Hill (2003) who observed that creative thinkers tend to use more 'peripherical' cues, i.e., data not linked directly to the problem. Of relevance is the theory of Conceptual Blending (Fauconnier & Turner, 1998), which proposes that the process of thought involves 'moving' between mental spaces that organize our knowledge of the world. Creativity can be conceived as the combination (or conceptual blending) of two, or more, conceptual spaces. In line with these descriptions, the A-CM model proposed by Bonnardel (2000) highlights the role of two main cognitive processes, which continuously interact during the design activity and can have opposite effects:

- *analogy-making*, which may lead designers to extend or 'open up' their 'research space' of new ideas and thus can lead to creative design solutions;
- the *management of constraints*, which orients design problem solving and allows designers to progressively delimit their research space and assess ideas or solutions until they find a design solution that is both new and adapted to various constraints.

Therefore, such processes contribute to both divergent and convergent thinking (Pereira & Cardoso, 2002). The generative phase of design is thus strongly based on analogical reasoning (Blanchette & Dunbar, 2000; Kryssanov, Tamaki & Kitamura, 2001; Bonnardel & Marmèche, 2004). In this case, the originality of design ideas or solutions may come from the creative distance between the conceptual domain of the object to be designed and conceptual domains from which analogies are extracted. In particular, the more the participants move away from the first evoked ideas or sources (Ward et al., 2002) or propose ideas after having evoked several previous ideas (Mouchiroud & Lubart, 2003), the more their ideas are creative and original. In addition, there is a positive correlation between the number of ideas produced during the design process and the novelty of the design concepts (Srinivasan & Chakrabarti, 2010). However, as the divergent process does not seem easy for designers, it appears necessary to support designers to reach creative ideas and design solutions, as some computational systems seek to do. In line with this view, we describe an empirical study that has just been conducted in order to determine the impact on users' activities of a new design support system, which was developed for stimulating designers to look for new ideas in order to develop creative products: the TRENDS system (Bouchard et al., 2008).

From the Analysis of Designers' Cognitive Processes to the Development of the TRENDS System

The development of the TRENDS system is in accordance with experimental results obtained in studies conducted on cognitive processes developed by both novices and professional designers (Bonnardel & Marmèche, 2004). More precisely, we observed that, contrary to previous research (e.g., Jansson & Smith, 1991; Smith, Ward & Schumacher, 1993; Chrysikou & Weisberg, 2005), it is possible to avoid an effect of 'design fixation', i.e., conformity to examples provided by the experimenter. Indeed, in this previous experiment, we provided novices and professional designers with examples that were not only intra-domain ones (i.e., belonging to the same conceptual area as the object to design) but also inter-domain ones (i.e., belonging to another conceptual area). We asked these participants to solve a creative design task while thinking aloud and we analysed their evocation processes. The results we obtained in this study showed that, contrary to novices, when professionals were provided with inter-domain examples, they evoked many more new sources of inspiration – and especially, new inter-domain ones – than when they were provided with intra-domain examples (for more details, see Bonnardel & Marmèche, 2004). Thus, the suggestion of inter-domain examples stimulated professionals to extend their research space of ideas and, thus, contributes to enhance the evocation of creative ideas.

In line with such results, the TRENDS system was developed by Bouchard et al. (2008) in order to provide designers with examples that can play the role of sources of inspiration (see Figure 2). To use this system, designers have to define some key words they consider relevant according to the object to be designed. Based on this data, the TRENDS system provides the user with images or pictures, which may consist in intra- or inter-domain sources of inspiration.

An empirical examination of the influence of this system on creative output has recently been conducted. In particular, we analysed the effects of the semantic distance between the target field (e.g., that of the object specified in the design brief) and the searched fields corresponding to images provided by the TRENDS system. In accordance with the previous experimental results (Bonnardel & Marmèche, 2004), our main hypothesis was that images provided by the TRENDS system would have an influence on the designers' research space of ideas and, consequently, on their evocation of creative ideas. In addition, because numerous results showed that the cognitive treatment of data is performed differently depending on the participants' level of expertise (see Chi, Feltovich & Glaser, 1981; Adelson, 1984; Wiley, 1998; Chevalier & Bonnardel, 2007), we also expected that the impact of the presentation of images will be different according to the designers' level of expertise.

Method

In this study, we analysed the effect of three kinds of images:

- *Intra-domain images*, which are related directly to the object to be designed. For example, when designers have to create a new car, images that belong to the automotive sector are provided.
- *Near inter-domain images*, which are not related directly to the object to be designed but which share certain functionalities with the object to be designed. Images that belong to the transportation sector (not comprising the automotive sector, which corresponds to the first set of images) would fall into this category.

Figure 2. The Design Environment TRENDS

- *Remote inter-domain images*, which belong to conceptual domains that are not at all related to the object to be designed. For example, images that belong to the product design sector could be provided.

Participants in this study were 48 students in a school of Design (Ecole Axe Sud, Marseille, France): 28 of them were in their first year and, thus, considered as ‘novices’, and 20 were in their final year and, thus, considered as ‘experienced’ participants. During the experiment, both kinds of participants had to imagine that they were employed as a designer in charge of the design of new cars. We gave them a schedule of conditions that specified constraints about a specific car they had to design (e.g., compact, unique, provocative, noticeable, unconventional, fun) as well as about the future client (e.g., urban, new rich, socialite, international, either a man or a woman). Then, depending on the experimental conditions, participants were provided with images (in ‘supported’ conditions) or with no images (in a ‘free’ or control condition). Participants in the ‘images’ condition set were provided with six images obtained through the use of TRENDS. According to the experimental condition, these images were either intra-domain, near inter-domain or remote inter-domain.

All the participants had to design a new car in accordance with the schedule of conditions, without a set time limit and while thinking aloud. To record both designers’ actions and verbalizations, their activities were video-recorded. All the elements they evoked and verbalized were analysed. More precisely, we took into consideration all elements mentioned by participants, which include constraints specified in the schedule of conditions, references to images presented to participants, and ideas evoked for designing the object at hand. The total number of the elements expressed by participants corresponds to what we call the total number of ‘evocations’. Because we were interested in the ideas evoked by designers that can be considered as *creative*, all the ideas expressed by the participants were submitted to a panel of judges. Numerous definitions of creativity highlight the fact that creative ideas or solutions must be both original and adapted to the context (see, for instance, Lubart & Sternberg, 1995). Thus, in this design context, creative ideas should be both original and useful for designing the object at hand. Therefore, we asked judges to assess the ideas with regard to these two criteria and on the basis of a seven-point Likert scale. This allowed us to focus on ideas that had both a level of originality and usefulness better or equal to 3.5, and which were considered ‘creative’ in line with definitions of creativity.

Results

The results we obtained showed no significant effect of expertise level or experimental conditions on the duration of the design task. Thus, all the participants took a similar length of time to perform the creative design task. In contrast, statistical analyses showed a significant effect of the designers' level of expertise on the percentage of creative ideas with regard to the total number of evocations ($F_{(1,46)} = 17.69$; $p < 0.0001$): experienced designers produced proportionally more creative ideas than novices (47% vs 26%, respectively).

In addition, we observed a significant interaction between the experimental conditions and the level of expertise ($F_{(7,40)} = 4.65$; $p < 0.0007$). The presentation of near inter-domain images exerts an opposite effect depending on the designers' level of expertise ($p < 0.0001$): these images enhance the evocation of creative ideas by experienced designers but not by novices. More precisely, for novices, the presentation of both intra-domain and near inter-domain images significantly reduces the evocation of creative ideas in comparison with the 'free' or control condition (respectively, $p < 0.05$ and $p < 0.01$). Only the presentation of remote inter-domain images does not inhibit the evocation of creative ideas by novices compared to the 'free' condition. Moreover, such remote inter-domain images enhance the evocation of creative ideas by comparison with near inter-domain sources.

Discussion

When considering performances in the conditions with images, experienced designers performed best in the 'near inter-domain' condition, whereas novices performed best in the 'remote inter-domain' condition. We suggest that there are two underlying causes of this interaction. First, some of these results are consistent with the 'design fixation' effect that has been described in contexts of design tasks (Jansson & Smith, 1991; Purcell & Gero, 1992). Thus, when designers focus exclusively on materials that are similar to the target domain (the 'intra-domain' images for both groups as well as the 'near inter-domain' for novices), this restricts their search of the problem space, they engage in less divergent processing and, as a result, the emergence of creative ideas is restricted.

In addition, differences between novices and experienced designers in the 'supported' conditions that elicited best performance ('near inter-domain' for experienced designers and 'remote inter-domain' for novices) could be explained by the effects of training. Given that effective product design is often evolutionary rather than revolutionary, it may be that the training that these design students receive led our experienced group to benefit more from images presenting design solutions that are less 'extreme' (and perhaps more functional) than the novice group. This would explain why the experienced group was better supported by 'near inter-domain' images. These images represent a degree of diversity, but also retain strong semantic and functional links to the target domain specified in the design brief.

Therefore, the expertise of the designer and the semantic distance between informational materials (consisting here in images) and the target domain are factors that must be taken into consideration to achieve maximum benefit to the users of such systems.

Supporting the Evaluation of Design Solutions

Beyond the generation of ideas, reaching a creative production requires a stage of management of ideas where one or several ideas (corresponding to elements of design solutions) are evaluated and selected as being the most satisfying solution(s) to a specific creative problem. However, in professional creative areas, such as the design of new products, the evaluation of design solutions is difficult for both experienced and inexperienced designers, because (1) in complex domains, no single person can know all the relevant criteria and constraints, and (2) design solutions must be evaluated from multiple, and sometimes conflicting perspectives.

Domain-oriented design environments have been proposed as computational tools supporting designers to construct and evaluate design solutions. 'Critiquing systems' embedded in these environments support evaluation activities by analysing design solutions for compliance with constraints encoded in the system's knowledge-base (Fischer et al., 1991; Bonnardel & Sumner, 1996). Their main interest is that they allow designers to create the design solution they wish while supporting them in assessing their own solutions. Indeed, the critiquing system performs an analysis of the design solution in progress, it identifies drawbacks of this solution (i.e., incompatibilities between their characteristics and constraints they have to respect), and it provides the user with 'critics' consisting in messages that point out weaknesses of the design solutions. To investigate the impact of such systems, we have designed, built and evaluated a critiquing system with regard to an analysis of designers' cognitive processes (Bonnardel & Sumner, 1996). This system, called VDDE (Voice Dialog Design Environment), was developed for the specific area of phone-based interface design.

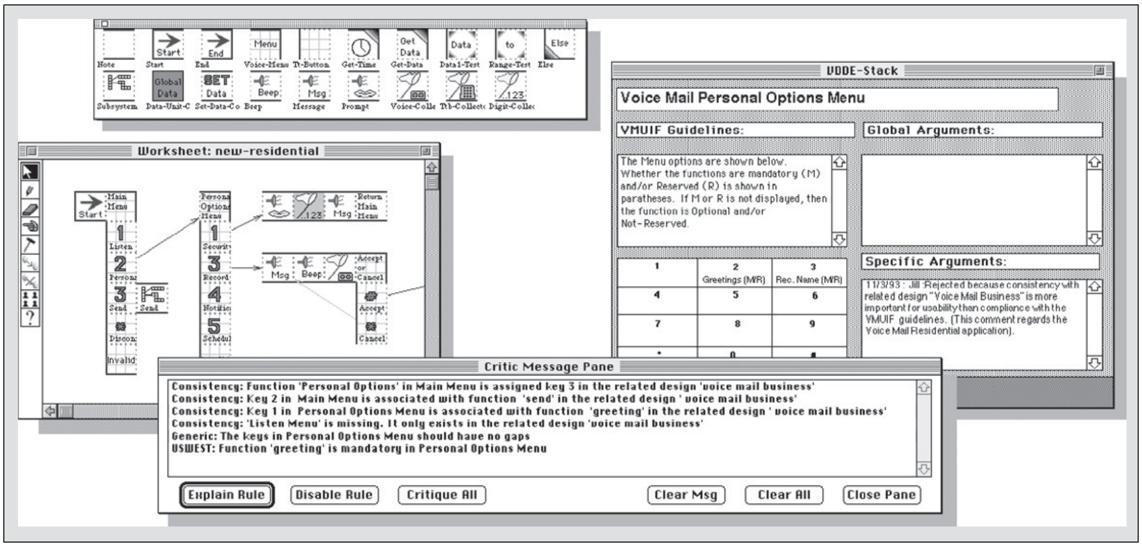

Figure 3. The Voice Dialog Design Environment
Designers select building blocks from the gallery (top window) and arrange them in a worksheet (left window) to create a graphic representation of the audio interface design. A critiquing component analyses the design for compliance with interface guidelines and product consistency. Possible problems are signalled in the critic message panel (lower window). The designer can select a critic message and elect to see the design rationale behind the critic rule, and designers can also add comments to the design rationale in the hypermedia knowledge-base (right window).

From the Analysis of Designers' Cognitive Processes to the Development of the VDDE System

In order to develop a critiquing system adapted to the designers' cognitive processes, we first analysed their traditional design activities through observations and interviews. On these bases, we characterized evaluation processes developed by voice dialog designers and we pointed out the difficulties they encountered. Two kinds of evaluative procedures were identified: an analytical procedure for assessing the solution's features with regard to criteria and constraints, and a comparative procedure for assessing the solution's features by comparison with the features of another solution. The main difficulties these designers encountered appeared to be due to the fact that they had to take into account a huge quantity of evaluative knowledge elements, which were specified in various user interface guidelines (regional, national and international). Moreover, we observed that these designers had also to check internal consistency inside the solution they were developing, and external consistency between the current solution and pre-existing phone-based interfaces. Therefore, they faced a special challenge since their design task was influenced by many conflicting design objectives.

In order to support designers in dealing with these difficulties, we defined functionalities that should be useful for assessing design solutions and the VDDE critiquing system was developed. It contains embedded, knowledge-based computational critics that support evaluation activities by automatically analysing partial design solutions for compliance with constraints resulting from different user interface guidelines. The system plays a role in the design activity by notifying the designer when a potential problem is detected in the design solution (see Figure 3). To understand the impact of this critiquing system on design activities, a study was performed with professional voice dialog designers employed by an American phone company.

Method

Four designers participated in this study. All were experienced in the general principles of user interface design and all had been professionally employed as phone-based interface designers by the same company. However, two of them were considered as highly experienced in the specific design area since they both had 11 years of experience in user interface design. In contrast, the two others had been hired more recently by the company (from one to three years).

All of the participants were familiarized with the VDDE system through the solving of two simple design problems before performing the experimental task. Then, we asked these designers to use this system to perform a design task corresponding to a real project. The requirements for this task were derived from the specifications of a product designed and marketed by another group in the phone company. The designers who participated in this study were thus asked to integrate a new service into an existing voice messaging product while using the VDDE system.

Participants were given 90 minutes to solve the design problem while thinking aloud. Each design session was video-taped and the verbalizations of the designers transcribed. The data analysis was performed by four judges. It focused on the quantity and nature of critiquing messages, called 'critics', presented to participants by the system. In addition, we analysed their consequences on the designers' activities.

Results

The analysis of the designers' activities and verbalizations allowed us to identify reactions common to all designers, as well as specific behaviours depending on the designers' level of experience.

First, in accordance with our expectations and with the main functionality of critiquing systems, all the designers were provided with critics, which lead them to modify their solutions. However, the effect of the use of VDDE is different according to the designers' level of expertise. The less experienced designers were presented with more critics than experienced ones and they modified their solutions in reaction to critics. We also observed that the less experienced designers were able to learn the constraints underlying critics they were provided with. This finding suggests that the VDDE system allows a contextual learning of knowledge in this area.

Concerning the more experienced participants, the effect of the use of VDDE appeared to be also *indirect*. The use of the system leads experienced designers, not only to modify their solutions in reaction to critics, but also to anticipate the presentation of critics. Indeed, they looked for drawbacks of their solutions before graphically representing them on the system, which allowed them to avoid the critics they anticipated being fired. In addition, experienced designers sometimes chose to violate critics, for instance when they identified exceptions to a rule underlying a critic. In these cases, experienced designers recorded in the system their comments on the design rules and the exceptions they noticed, which can allow the system to be evolved.

Supporting Externalization

Given that externalizations are necessary for designers and for other stakeholders (see above), a new computational system, called T'nD – Touch and Design – has recently been developed for supporting activities performed in domestic appliance and automotive design contexts (Cugini & Bordegoni, 2007).

From the Analysis of Designers' Activities to the Development of the T'nD System

The aim of this system is to allow designers to create new products and to represent them in 3D on a computer without requiring complex classical human–computer interactions. Indeed, interactions with this system are intended to mimic physical manual activities and gestures performed by designers and modellers when they develop mock-ups of the products. Towards this end, we conducted observations in naturalistic settings into three companies: Pininfarina (Italy), Alessi (Italy) and Eiger (Spain), which are specialized in automotive design or in the design of domestic appliances. More precisely, we video-recorded gestures of designers-modellers while they were creating mock-ups of the products to be designed at the premises of the industrial partners. We thus gathered 56 hours of videos that were analysed in order to identify repetitive gestures that were performed by the designers-modellers and to examine gestures with respect to their potential for creation and modification of shapes, and to the users' needs and expectations. The results we obtained showed that the modelling process helps the designers to visually imagine the shape of the product to be designed and its different features in a very detailed way. In addition, a distinction was made between 'ergotic' and 'exploratory' gestures. Ergotic gestures correspond to the designer-modellers' gestures when making a shape, while exploratory gestures are used for exploring the shape by hand. On such bases, we defined recommendations for the development of the T'nD system (Bonnardel, Debroise & Poitou, 2005) and this system was developed at Politecnico di Milano (Cugini & Bordegoni, 2007; see Figure 4). Thus, the T'nD system aims at exploiting the existing skills of designers and modellers as well as taking advantage of computational functionalities, for instance by allowing users to easily delete and modify what they previously developed or to access complementary views of the product they are creating.

In complement to the development of this system, we recently conducted an experimen-

Figure 4. The Design Environment T'nD

tal study in order to determine whether this new system allows designers to design and model as efficiently as already existing modelling methods do, i.e., physical modelling and CAD modelling.

Method

In this study, we defined three experimental conditions with respect to the tools used by participants: physical modelling, modelling with a classical CAD system (consisting in the Rhinoceros software), and modelling with the T'nD system.

A total of 30 Masters students in design participated in this experiment. They were randomly assigned to one of the three conditions. These students attended the same kinds of classes and they were considered by their teachers as having a similar level of expertise and skill in physical modelling and CAD modelling.

First, participants were engaged in a phase of familiarization with the modelling tools corresponding to their group. They had 30 minutes to produce a 3D representation of a laptop cover using the assigned modelling tool (CAD, T'nD or physical modelling). All of them were provided with six pictures showing the model of a laptop cover produced by an expert designer from a famous Italian design company (Alessi). They were asked to match the original model as close as possible.

Then, after a five-minute pause, the participants were asked to perform a design task consisting in creating a new computer mouse. During this task, the participants were also allowed to sketch on paper before performing the design task itself. The time allocated to this design task was 30 minutes and the instructions were the same for each group. Participants could ask any questions they wished, both before and during the experiment.

Data gathered during the experiment were video-recorded and comments made by the participants were also recorded. These data have been analysed in order to provide an evaluation of the T'nD system compared with the two other experimental conditions. In particular, two main aspects were taken into consideration: the usability of the T'nD system and the quality of the models created.

Results

Results on the usability were used to improve the prototype (for more details, see Bonnardel & Cugini, 2007). Findings on the quality of the models showed contrasting results. At a first glance, the quality of the models made with T'nD seemed far lower than the quality of models made with CAD or physical modelling. However, a more in-depth analysis, based on reflection lines functionality of the surfaces, was performed on the models created during the first modelling task. This produced more positive results concerning the laptop cover because designs created with T'nD have better quality in terms of surface curvature continuity and surface light reflection. Concerning the second task, participants encountered numerous difficulties in using the T'nD system to perform a creative design task, and they were able to create new computer mice only in the physical modelling and CAD modelling conditions.

Discussion

Although the T'nD project started with the intention to mimic physical manual activities in order to exploit the existing skills of designers and modellers and to allow them to take advantage of knowledge regarding CAD and physical modelling, the application of that knowledge appeared not to be as intuitive as expected. Thus, instead of being focused on the creative task, participants who used the T'nD system were more focused on the use of the new technique, which may appear as a concurrent task to the main creative task.

Therefore, the use of a brand new technique or tool, such as the T'nD system, requires new skills. In the experiment we conducted, participants were given a short training prior to using T'nD, which did not allow them to be sufficiently familiarized with the use of this system for developing creative thinking. Consequently, evaluating the impact of new techniques on creative activities should be performed only after participants are fully familiarized with the use of a new technology.

Thus, although it may seem attractive to use a new technology for performing tasks which would be difficult or impossible with classical technologies, the use of new technologies may require a period of familiarization before allowing users to benefit from the new functionalities offered by such systems.

Conclusion

Based on the studies we presented in this paper, we can consider that new technologies and, especially, new CAD systems may help designers to easily express their creativity as well as to assess their ideas or solutions. In particular, we showed that certain kinds of images provided by the TRENDS system allowed experienced designers to produce creative ideas. A complementary study conducted by Christensen (2010) showed that displaying other kinds of images, about users and products, improves the usefulness of creative designs. We also showed that the use of a critiquing system supported professional designers in assessing their own solutions. Therefore, technologies can contribute to both divergent and convergent processes, which underlie creativity.

In order to go further, we can envision complementary developments to facilitate the activity of designers. A promising direction could be to develop systems that better fit characteristics of the users. For example, such systems could support design students in their training, which would benefit from research that aims at characterizing both students' individual design behaviour and learning style (Bar-Eli, 2005). We can also envision systems for professional designers, which would be adapted to their personality, the points of view they adopt or their creative style. For example some results suggest that tolerance for ambiguity is a personality trait which favours creation and the association of ideas (Zenasni, Besançon & Lubart, 2008). We could also imagine a system which would favour the treatment of ambiguous stimuli in design if we specify to this system that the user, a professional designer or a student designer, does not tolerate ambiguity. A more intelligent system would be able to adapt some specific parts of the creative process to the personality of the creators. Thus, Puccio and Grivas (2009) observed links between individuals' preferences at certain stages of the creative process and their personality traits. For example, they observed that a preference for problem clarification is associated with tendencies to be cautious, careful, analytical, accurate and tactful, whereas a preference for an idea generation stage is associated with attraction to variety. Thus, taking into account characteristics of the user may allow the system to support more efficiently specific stages of the creative process.

Nevertheless, as suggested by the third study we presented, the use of new technologies may need not only some training but also a real period of familiarization with new systems. Otherwise the new computational system may constitute more of a concurrent task than an effective support for users. Thus, it appears necessary to reach a good understanding of requirements for easily using computational systems and to adapt the support provided by systems to the users' characteristics, such as their level of expertise in the domain or their personality. Finally, it is crucial to study the systems' effective impacts on designers' activities in order to identify conditions that allow users to get a real benefit from the use of such systems. In line with such perspectives, computers could become real partners of designers when they perform creative design tasks (Lubart, 2005).

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Nathalie Bonnardel (Nathalie.Bonnardel@univ-provence.fr) is a Full Professor in Cognitive and Ergonomic Psychology at the University of Provence (Aix-Marseille I) and she is a member of the University Institute of France (Institut Universitaire de France, I.U.F.). She is Director of the Department of Cognitive and Experimental Psychology of the University of Provence, Director of the Masters in 'Ergonomics: human factors and engineering of information systems' and in charge of the research team on 'Design, written production and multimedia systems' in the Research Center in Psychology of Cognition, Language and Emotion (PsyCLE).

After a research internship at INRIA (Institut National de Recherche en Informatique et en Automatique), she received a PhD in 1992. From 1992 to 1994, she was a Research Associate at the University of Colorado at Boulder. From 1994 to 2006, she was an Associate Professor at the University of Provence (Aix-Marseille I), where she received an HDR (habilitation or State Doctorate) in 2004. Since 2006, she has been Full Professor in this same university. Her researches focus on cognitive processes involved in creative design activities as well as on computational systems for supporting creative design.

Franck Zenasni (franck.zenasni@gmail.com) received his PhD from the University René Descartes. During his PhD project, he examined relationships between emotion and creativity/divergent thinking. After his PhD, he worked for three years in a medical institute in order to develop measures of quality of life. He is currently research scientist in differential psychology at the University Paris Descartes. His research focuses on (1) the role of emotions in creativity, (2) definition and description of emotional traits and affective style, (3) the impact of these characteristics on cognitive activities, and (4) the evaluation of quality of life.