Creativity Support Systems:
A Systematic Review of the Literature

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***Abstract*: As part of the innovation process, creativity has become a critical dimension for organizations that wish to maintain their competitiveness. In order to foster the creativity potential within organizations, processes and systems need to be designed and integrated so that all stakeholders can participate in a coordinated and timely fashion, and despite the various dispersion levels that may separate them. Although many tools are already available on the market or being tested, a significant gap still exists between those products and the creativity process that they are supposed to support. To truly respond to the need for creativity in a distributed environment, it is suggested that the entire process be re-examined and understood so that future Creativity Support Systems can fill real needs. This paper is a systematic review of the literature on existing digital tools dedicated to creativity. A thorough examination of over 49 digital tools is also carried out, providing the foundation for defining high-level specifications for emerging Creativity Support Systems that would better support collaboration diversity throughout the creative process.**

Highlights

- **Creativity positioning for creative support systems**
- **Systematic review of the creative support systems**
- **Qualitative and quantitative analysis of the creative support system characteristics**
- **Prospective proposals of creative support system specifications**

Keywords: creative support system; creativity method; remote collaboration; creative problem solving; creativity process; computer-assisted creativity.

I. Introduction

In today's globalized competitive context, organizations need to maintain their competitiveness by regularly generating new ideas, new products or services, and new processes. Globalization also necessitates remote collaboration and extensive use of digital devices. From the perspective of the innovation process, numerous factors influence the generation of value and novelty for a company. A trend that confirms and combines innovation and remote collaboration is the increase in open innovation strategies and the associated platforms (i.e., OpenIdeo,[1] Dell IdeaStorm,[2] etc.). This article focuses on digital systems that support creativity during innovative initiatives and, more specifically, innovation approaches that involve teams, such as creative workshops.

[1] OpenIdeo: https://openideo.com/
[2] Dell Idea Storm: http://www.ideastorm.com/

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Devising an entire system that supports creativity and can be part of the innovation process is a complex problem that involves different research fields. Adraiz-Villanueva et al. (2011) identified four separate groups of studies, each of which has a different underlying goal: (1) to determine how creativity is associated with personal characteristics (personality traits, cognitive ability); (2) to examine the cognitive and social processes that are involved in creativity; (3) to foster ideational creativity by means of computer tools; and (4) to identify the environmental factors that nurture or inhibit creativity.

In this paper, we investigate how to implement a creative approach by relying on computer tools, while taking into consideration environmental factors and the cognitive and social processes that are at play in creative contexts. Through a systematic literature review, we also emphasize that the domain of digital systems dedicated to creativity is an incomplete one (Bonnardel and Zenasni, 2010; Shneiderman, 2007), as we describe some of the field's strengths and weaknesses (Grant and Booth, 2009). Ultimately, this paper aims to describe current relevant contributions as a step in defining future research avenues. High-level specifications and scenarios are proposed based on a typical creative process and specific collaboration settings.

As a starting point, creativity and innovation will be examined in general. Then, highlight the collaboration settings and the process definition that serve as the basis for designing a support system will be highlighted.

II. Overview on Creativity and Some Associated Concepts

Some of the themes introduced previously will be briefly expanded on to give readers a better understanding of the assumptions underlying the present approach.

- Innovation vs. design vs. creativity

Innovation, defined as the acceptance and widespread use of a new product, process, or service, conveys the notion of success and of perceived value from various economic actors (e.g., customers), as well as differentiation from existing solutions (Tidd and Bessant, 2009). It is also considered as a process (e.g., search-select-strategy-implementation) and as a necessary mind set to produce novelty. From the perspective of innovation *as a process,* it is quite common for creativity to be considered as a component of innovation (Tidd and Bessant, 2009; Damanpour and Aravind, 2012; Boly, 2008).

Like innovation, *creativity* can be seen from different perspectives: some authors would describe it as a mind-set, others as a process, and some as a result. Several definitions have been proposed in the literature. In a problem-solving context, the most common definition of creativity is the ability to achieve a new and adapted production of concepts (Lubart, 2003), or the ability to produce something original and appropriate to a context (Howard et al., 2008). In other words, creativity is a balance between concept novelty and usefulness (Puccio and Cabra, 2012) or appropriateness (Zeng et al., 2011; Howard et al., 2008) that is achieved by using existing knowledge (Ogot and Okudan, 2007).

These definitions of creativity have a lot in common with the concept of *designing* a solution. In this case, there are three relevant interpretations of 'design': design as a tangible outcome (Von Stamm, 2008), design as a creative activity (Von Stamm, 2008; Warr and O'Neill, 2005), and design as a process of transforming information into outcomes (Von Stamm, 2008). The third definition, which is the most commonly used according to Von Stamm, can be defined as a ‘conscious decision-making process by which information (an idea) is transformed into an outcome, be it tangible (product) or intangible (service)’ (Von Stamm, 2008, p. 17). Von Stamm also suggests that creativity takes place within the design process. From this perspective, design *as a process* can be divided into three different types: *conceptual design,* in which concepts are generated to fulfil an objective; *embodiment design,* which is the structured development of the selected concept; and *detailed design,* which precisely defines every individual element of the outcome (Von Stamm, 2008). Thus, it appears that conceptual design concerns the generation of ideas/concepts, while embodiment design and detailed design concern creativity in the generation of new technical solutions.

In many cases, the distinction between innovation, design and creativity is blurred for the benefit of an overall process. For example, Von Stamm (2008) would argue that innovation is composed of the creativity process plus the (successful) implementation of the idea in the form of a product, process or service. On the other hand, other authors consider implementation to be part of the creativity process. This view suggests that the innovation and design processes do overlap. Based on the experience of the authors concerning creative session facilitation, the implementation will be considered as the stakeholders’ concern and so not be considered as part of the creative process.. However, a link will be made between conceptual design and creativity. As highlighted by Howard et al.’s (2008) review, there is a slight difference in the scopes and the concepts considered, but design remains a creative process which is generally applied to domain-specific problems (e.g., engineering).

- Influencing factors

Beyond the issue of defining creativity, multiple directions have been proposed to scientifically investigate the creativity domain. Studies of creativity are generally structured on three different levels: individual, collective (team) and organizational (Mumford, 2011). The third perspective is often considered to constitute innovation rather than creativity according to Damanpour and Aravind (2012), but this does not change the interactions between levels and how the different influential factors are classified.

- At the individual level, the influential factors most often cited include domain-specific expertise, motivation and cognitive abilities (Damanpour and Aravind, 2012). Cognitive abilities include ease with open-ended problems, personal cognitive processes established to generate ideas, and even experience and personal history. These factors can be further subdivided into three classes: dynamic systems, which group factors that empower a person to do creative activities (motivation, personality, intelligence, thinking style and creative behaviour); foundation systems, which refer to factors that support the execution of creative activities (education level, organizational environment, domestic economy and material conditions); and resource systems, which describe the resources needed during a creative process (knowledge, information, and design technology and computer support tools).
- From the collective perspective, the focus is on interactions between individualities and how they affect creativity. According to Glăveanu (2010), social creativity is more than constraints on individual creativity. Creativity is social, as ‘its mere nature is relational since it could not exist outside of cultural resources and dialogical relations’ (Glăveanu, 2010, p. 88). Regarding social influence, three main elements may explain the loss of creativity: production blocking, which means waiting for one’s turn to talk; evaluation apprehension, which is the fear of sharing a worse

idea than other people; and free riding (also known as social loafing) which refers to one member of the creative group becoming lazy and relying on the others (Ray and Romano, 2013; Warr and O'Neill, 2005). From this perspective, collective creativity implies the confluence of intelligence, personality, domain knowledge and social influences.

- As for the organizational perspective, influential factors include the process and the environment provided by the organization or social structure, but also its culture, its available knowledge and the ability to create motivation. Other elements associated with organizational structure have also been studied to determine the nature of their impact on innovation and creativity (Damanpour and Aravind, 2012), such as communication (internal or external), actors' specialization, technical knowledge resources and numerous other factors that impact specific innovation approaches.

Many factors have overlapping effects on these three perspectives. For instance, problem formulation is often seen as influencing the personal cognitive process, the collective understanding, and the organization's choice of creativity methods (Lubart, 2003).

- Collaboration

Since creativity is social and organizational in nature, it is closely related to the notion of collaboration. Two aspects are usually examined when considering collaboration in relation to creativity: (1) traditional co-located collaboration, where all actors are in the same place at the same time; and (2) remote collaboration, which implies virtual teaming, whereby members do not often interact in person due to distance or time lags, and thus can only communicate with information and communication technologies (Nemiro, 2004).

The literature clearly shows that distributed projects are more challenging than traditional projects. It introduces new variables such as 'physical and geographic separation among teams, social and cultural differences among people, time zone differences, etc. which impact communication and collaboration, problem solving, trust, and several other factors that influence project success' (da Silva et al., 2010, p. 87). In the case of remote collaboration, virtual platforms are vital to ensure communication among team members. This can be achieved synchronously, as in natural communication, which implies that people need to be connected at the same time regardless of the time lags that exist between them. It can also be achieved through asynchronous communications, whereby a delay between the transmission of the information and its receipt occurs (e.g., e-mails).

How communication is processed greatly influences the success of collaboration, even when different modes (synchronous and asynchronous) are deployed (Nemiro, 2004). In addition to communication, other determining factors come into play when collaboration among team members is required. Learning preferences (Nemiro, 2004), creative styles (Ray and Romano, 2013) and the characteristics of the work process being used are some examples of important factors to consider in qualifying a creative collaboration as successful or otherwise.

- Creative/innovative process

As presented above, *process* is often referred to at the various levels of analysis: individual, collective and organizational. From the individual point of view, the creative process mainly represents the cognitive process. This does not mean that external factors are not considered, but the process is mainly centred on

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individuals. Historically, the creation of ideas and artefacts was mostly considered to be the domain of individuals, as described in the Helmholtz-Poincaré-Getzels (Lubart, 2003) and Wallas (Ogot and Okudan, 2007) models. These models introduced the concepts of *incubation* and *insight*, which are based on 'individuality, insight and outstanding ability' and give 'an elitist and essentialist account of creativity' (Glăveanu, 2010, p. 81). The individual creative process is considered to be a non-linear process that describes the creation of knowledge by individuals, whether it is influenced by techniques acquired with personal experiences or uncontrolled (Gero and Kannengiesser, 2004). On the other hand, the collective creative process is a collaborative process that is influenced by the context and the environment. The passive elements of *incubation* and *insight* are replaced by an active phase: idea generation. From a passive to an active approach, creativity is transformed into something that can be forced through creativity methods, as in the case of brainstorming (Osborn, 1963). This level defines the creativity methods applied by the group. It focuses on how and what information is exchanged. From the point of view of the organization, the creative process is a managerial tool that gives it an overall view of creativity. It is certainly the most documented approach, although it originates in the field of psychological research rather than management. An overall stepped description is adapted to managerial use, but these creative processes are descriptive than operational.

Numerous creative processes are described in the literature (Salerno et al., 2015; Sawyer, 2012; Seidel, 2011; Howard et al., 2008; Nemiro, 2004); most of them describe a linear series of steps. According to Massaro et al. (2012), all these process models can be classified in six main approaches: creative problem solving, lateral thinking, appreciative inquiry, design thinking (re-engineering), synectics, and inventive problem solving (TRIZ and similar approaches). Each of these approaches applies to various specific contexts, including the type of information input required and the expected results, but ultimately they aim to guide people to be creative individually and/or collectively in order to solve problems. Though each approach follows its own process, there are basically two main standpoints characterizing these approaches. Some approaches, such as TRIZ and lateral thinking, suggest exploring a 'design space' (also called 'conceptual space') by means of heuristics (general rules) (Martin et al., 2012; Yilmaz et al., 2011). These approaches are systematic, like the theory of constraints (Stratton and Mann, 2003). Much less structured approaches such as creative problem solving (CPS) advocate letting the natural flow of ideas emerge. CPS is a collection of methods (VanGundy, 2008; Michalko, 2006; Aznar, 2005) that are based on different cognitive mechanisms, such as association (brainstorming methods), analogy, projection, metaphor, oneiric methods such as daydreaming, and several others that can be qualified as 'intuitive methods' (Mohan et al., 2012). In its simplified form, TRIZ can also be considered as a creativity method that can be applied in a CPS process.

Much attention has been paid to the CPS process, which is made up of three recursive phases: problem analysis, ideation and evaluation (Howard et al., 2008). Some models include implementation as a fourth step, even though it relates to innovation more broadly, rather than specifically creativity (Zeng et al., 2011; Von Stamm, 2008). Problem analysis initiates the process, allowing people to define the 'problem space'. The aim of this step is to understand the problem, gather and reorganize information and then finally frame the problem by reformulating it. The second step is 'the production of original mental images and thoughts that respond to important challenges' (Puccio and Cabra, 2012, p. 195) by applying a variety of (creative) methods. In order to sustain idea generation, in the third step the idea is assessed according to a set of criteria specified earlier in the process (goal definition), with the aim of developing workable solutions. The last stage is the implementation of the selected ideas. In this paper, these steps

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will be the basis for a high-level consideration of the creative process, as opposed to the operational level, which describes creativity methods or activities (Browning et al., 2006).

According to numerous studies of the creative and innovation processes (Salerno et al., 2015; Sawyer, 2012; Seidel, 2011; Howard et al., 2008; Nemiro, 2004), representing creativity into steps is certainly the simplest approach, but human relations are anything but linear. No two projects follow the same path in terms of creative steps and creative activities; there is not just one path. Still, representing creativity as a process has some advantages. Defining the steps and activities in the creative process enables one to identify the influencing factors and the actors who take part in each step (Gabriel et al., 2014). It can be valuable for managing the creative process. The difficulty is specifying the recursive approach to the process. A model that is intended to structure a digital system dedicated to creativity should consider different alternative creative processes in order to remain flexible.

III. Creativity Support Systems

There is a wide range of approaches to support creativity by means of digital devices. Lubart (2005) classified these approaches in four metaphorical categories: a creativity support can be considered as a *coach* (gives advice and helps to implement and apply techniques); as a *pen pal* (provides support for collaboration); as a *nanny* (monitors the work's progress and provides a framework); or as a *colleague* (the computer generates its own ideas and solutions). Each of these classes represents a specific approach to creativity via digital devices and introduces specific issues and vocabulary.

a. Different kinds of systems

In this section, some examples of systems that fit into Lubart's four categories will be presented. One of the most documented systems is called Gi2MO.[3] It can be considered as a collaboration support tool or *pen pal* as it allows the different actors in a creative approach to collect and share information. It can also monitor the progress of the approach in light of an idea's life cycle (Westerski, 2013). This system is especially oriented towards idea management, which is a 'rising industry sector that delivers software for collecting and organizing input from people regarding innovations for products or services' (Westerski, 2011, p. 1). 'The goal of the Idea Management Systems (IMS) is to build tools for assessment of the collected ideas and selection of the best ones to implement' (Westerski, 2011, p. 1). Gi2MO makes it possible to collect the ideas of a 'distributed community' and put them on a feed as a social network. Once an idea is collected and on the feed, it is possible to up-vote or down-vote it and make comments. The idea manager/administrator also has access to advanced features, such as presenting the similarity and relationships between ideas .[4,5] Another, more modest, example of an IMS is the system called '48h Innovation Maker',[6] which is actually a dedicated platform that supports a creative international competition called 48h to Generate Ideas®. In this case also, the basic concept is to collect an idea, which is structured and characterized with a title, a description, and a sketch. The difference in terms of idea structure is the use case that completes the description of the idea, as well as a preliminary evaluation of the idea's strengths and weaknesses and the knowledge needed to implement it. Once a user suggests an idea, the administrator can assign it to a category of idea.

[3] http://www.gi2mo.org/
[4] IdeaStream similarity: https://www.youtube.com/watch?v=i-ca2sP8QJs
[5] Gi2MO relationship visualizer: https://www.youtube.com/watch?v=uwvIZn0mqjE
[6] http://www.48h-innovation-maker.com/?language=en

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Most systems that support collaboration are known as Group Support Systems (GSS), Computer-Supported Cooperation Work (CSCW) or Single Display Groupware (SDG). ‘The process of collaboration support can be divided into two parts: communication and coordination. Communication is subdivided into explicit communication and information gathering. […] Coordination consists of shared access and transfer’ (Gutwein, 2013, p. 15). Most advanced systems will sort information according to project phase and collaboration phase. As described above, there are two distinct modes of collaboration: co-located, where all the users are in the same place, and remote, where actors are separated by time or space and constitute a virtual team (i.e., kind of social network). Most systems permits asynchronous communication through news feeds, synchronous chat, and the sharing of various documents. They may also provide videoconference functionality. In a co-located context, systems tend to involve the use of many digital devices (wall display, interactive tabletop, interactive whiteboard, camera, mobile device, etc.); two examples are iLounge (Sundholm et al., 2004) and iRoom (Gutwein, 2013). The idea is to provide an environment that allows the members of a working team to work individually, in subgroups or collectively. To this end, all devices are connected so everyone’s data can be accessed and modified either on individual devices or collectively on collective devices (interactive whiteboard or interactive tabletop). SDG refers to such collective devices, where the team is gathered around the device, working on it together. ‘Interactive tabletops enable fully collaborative work, engendering diverging conversations, idea exploration and information sharing equally amongst the group members’ (Jones et al., 2011, p. 156). In a creative context, ‘the interactive tabletop serves as the platform on which six to eight participants generate and organize the majority of the content, i.e. creating of Postit notes, labeling groups’ (Jones et al., 2012, p. 2). Collaboration systems are not specific to creativity; they can be used for any task that requires communication and coordination. They do not provide specific assistance with creative activities unless they are combined with assistant systems, as described below.

Similarly to Computer-Assisted Design (CAD) software, some systems are specifically designed to help with the application of creativity methods. By analogy, they are called Computer-Assisted Creativity (CAC) systems or Creative Support Tools (CST) (Bao et al., 2010). The principle is to select a creativity method and provide all the information and assistance needed to ease its application, including dedicated forms, a database and data processing. Such a system can provide assistance with a wide range of activities. The most commonly assisted method may be brainstorming, which is so common that it accounts for a subcategory of CAC: Electronic Brainstorming Systems (EBS) or E-Brainstorming. One example of such a system is Firestorm (Clayphan et al., 2011), which is a four-user interactive tabletop system that collects ideas or keywords and displays them on a spiral at the centre of the screen. These systems tend to counteract the main weaknesses of ‘pen and paper’ brainstorming, namely group pressure, social loafing and production blocking (Gutwein, 2013; Puccio and Cabra, 2012). Some tools are dedicated to defining the subject of a brainstorming exercise, such as Momentum (Bao et al., 2010). This web-based system ‘generates a series of textual prompts based on a given brainstorm topic’ (Bao et al., 2010, p. 1234). Group members respond individually to the prompts with text messages or pictures before the brainstorming session and these responses are used as ‘seed ideas’ at the beginning of the session. Although brainstorming is the best-known creativity method and has been widely studied, it is not the only method targeted by assistance tools. The inventive problem solving method called TRIZ is also the subject of active research and support efforts. Tools can be found on the Internet that enables to quickly assist the resolution of a problem by defining the specifications that must be improved and the specifications that

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should be maintained. [7] TRIZAquisition (Zanni-Merk et al., 2011, p. 324) is a more advanced tool, designed to 'accompanying the expert in the development of an inventive design study, from problem formulation to the proposal of solution concepts'.

The digital system seen as a *colleague* corresponds to a system that becomes actively involved in the creative task and is able to suggest new ideas to humans. This corresponds to the computational creativity approach (Boden, 2009; Wiggins, 2006). It involves the application of the Artificial Intelligence (AI) to model human creativity. Creativity is considered as a conceptual space (Boden, 2009), even as a complex conceptual space, which means that 'enumeration of that […] space, especially when guided by heuristics, can be a valid simulation of human creativity' (Wiggins, 2006, p. 221). The result of this simulation can be very interesting. 'There are three forms [of creativity]: combinational, exploratory, and transformational. All three can be modeled by AI—in some cases, with impressive results. […] Whether computers could "really" be creative isn't a scientific question but a philosophical one, to which there's no clear answer' (Boden, 2009, p. 23). The effect of the introduction of AI into creativity support is not necessarily to generate ideas instead of the human team members. It can also introduce a cognitive model of creativity (López-Ortega, 2013) to provide better assistance with creative tasks, regardless of the typology and orientation of the system (collaboration, progress monitoring or method assistance). For example, CACDP (Liu et al., 2011) integrates cognitive considerations into the design of a system that assists with the application of TRIZ.

To support the complexity of creativity, considering only one category of tools is not sufficient. The same is true of creativity support schools suggested by Shneiderman (2007): structuralist, inspirationalist and situationalist. 'Structuralists believe people can be creative if they follow an orderly method. […] Inspirationalists argue that breaking away from familiar structures elicits creative solutions. […] Situationalists recognize that creative work is social' (Shneiderman, 2007, p. 25). The richest approach entails considering all these schools at the same time to provide complete support. This is what Voigt et al. (2012) suggest in their overview of different systems, in which they introduce the concepts of Creative Support System (CSS) and Creativity-Intensive Process Support System (CPSS). These types of systems are respectively defined as a 'class of information systems encompassing diverse types of IS that share the purpose of enhancing creativity' (Voigt et al., 2012, p. 153) and 'a framework for flexible process support that classifies existing approaches to process modeling and supports the introduction of IT support in CIPs [Creativity Intensive Processes] based on the level of structure and the intensity of creativity.' (Voigt et al., 2013, p. 229).

b. Literature review methodology

As it has been introduced, there are numerous digital support approaches dedicated to creativity. The objective of this review is to determine what kind of support these systems provide and which technologies they deploy to do that. The intent is to cover the main elements described in the research field of creativity in terms of the different phases covered (problem analysis, ideation, idea evaluation) and the different creativity methods assisted by the digital system. As creativity is also collaboration, the observations also focus on different modes of collaboration and the digital devices used to apply them.

- Search terms

[7] TRIZ 40: http://www.triz40.com/TRIZ_Fr.php

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The keywords associated with these two themes – collaborative creativity support systems and creative problem-solving systems – are presented in Table 1. The Population-Intervention-Comparison-Outcomes-Context (PICOC) structure described by Kitchenham and Charters (2007) was not strictly followed, although our approach is largely inspired by theirs. These keywords were defined by the research question in different groups of words. Then these groups were extended by keywords encountered in a preliminary review of the creativity literature, plus some synonyms. The research terms were created by joining synonyms and groups using the Boolean operators OR and AND, and by using wild cards like *.

	Keyword group 1	Keyword group 2	Keyword group 3
Collaborative creativity support systems	Collaboration Virtual team Distant collaboration Work group Groupware Open	Creativity Creativity workshop Creativity challenge Creative design Innovation Ideation Brainstorming Creative design method Preliminary design Early stage innovation	Support Support tools Support system System Data systems Data support Devices Tools Software Application Tabletop Wall display Interactive surface Computer support Computer-aided Interactive whiteboard Electronic
Creative problem-solving systems	Creativity Innovation Creative problem solving Creative Brainstorming Design Ideation	Electronic System Support system E-brainstorming Computer-aided	

Table 1. Keywords used for each theme

- Materials

The documents considered in this review are essentially limited to journal articles and conference proceedings, although official work reports might also be included. A system was included in the review if it was cited in one of the documents. A search for documents focused on two themes: collaborative creativity support systems and creative problem-solving systems. The main databases used in this review were Web Of Science and EI Compendex. We extended the search to some articles that were cited in the first batch of articles if they were likely to provide additional details about a system. All the articles were written in English. No start and end dates were set on the search; because it concerned digital technologies, even the older papers did not date back very far in the past. The only criterion for rejecting a reference was the quantity of information. If information was missing concerning the criteria observed, the system was not considered in the review.

- Criteria

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The collection of information for the system review was structured according to three categories: *general information, technical features* and *creativity features*:

- *General information* constitutes all the elements that make it possible to identify the system. It includes the name of the system, the associated university if any, the years and the commercial orientation (i.e., systems from academic or research work vs. commercial systems). The presence of commercial systems in the review was due to the information collection method: a system that is mentioned in an article is not necessarily the subject of research; it may be, for example, the support for a psychology experiment.
- *Technical features* describe the technology used, the nature of the information exploited, the need for registration, and the specific graphical interface according to the role. Based on the descriptions in the literature, devices were limited to one of the following possibilities: web service, interactive tabletop, computer software, interactive whiteboard, mobile/individual device, wall display, augmented object, digital sketching instrument, and interactive floor. Unlike the other devices mentioned, web services are not physical devices. It is important to make this distinction, as it implies that system functionalities are accessible from any device that is connected to a network. The nature of the information processed by the system is a meaningful element as it enables one to determine the different possible uses in the domain of application. This criterion identifies what kind of input is possible with the system: plain text, images, sketches, or graphics. For instance, a system has to consider text, sketches and even pictures in the case of embodiment or detailed design. Another element that was evaluated was the necessity to log in to a system to use it. This feature is important from a technical point of view as it means that the authors of information input into the system can be identified. It is related to another element: the differentiation of the user's role. The prerequisite is to identify users and their roles in the creative process and adapt the graphical user interface accordingly. The last indicator concerning nonspecific features was the use of any principle of 'gamification'.
- *Creativity features* relate to the determination of the phases covered by the creative process but also the methods supported by the system and its collaboration settings. The creative process in its simplest approach can be considered as a process comprising four iterative phases: problem analysis, ideation, idea evaluation and implementation (Zeng et al., 2011). The evaluation of this indicator involves not the phase explicitly covered but primarily the associated activities. This means that, if the system covers some evaluation activities, it will support the evaluation phase overall. Concerning collaboration features, the collaboration setting of a system is described by several different indicators which attempt to describe the system's physical and conceptual limits.
    - The first one is an indicator concerning the physical use of the system: for example, is it something used by one or more people on the same device?
    - The second indicator concerns the system's collaboration functionality. In other words, it differentiates systems that are designed to be used by one person but are in fact used collectively from systems that are designed for collaboration. The collaboration may be physical, where several persons use the same device, or virtual, where everyone has their own device and is able to exchange information.
    - The dimension of collaboration in virtual teams is characterized by the third criterion: remote collaboration.
    - A fourth indicator is the temporality of the communication, which determines whether the activity on a system must be synchronous or whether users can act asynchronously.

Independently of the above-mentioned elements, the different creativity methods supported by the systems were freely recorded due to the wide variety of methods.

c. Overview of creativity support tools

According to the methodology described above, of the 75 systems cited in the literature, only 49 were accompanied by enough information to be considered in this review. Table 2 presents an extract of the information collected about the systems considered here. They all have different approaches to supporting creativity. For instance, Computer-Assisted Creativity systems such as Calico (Mangano and van der Hoek, 2012) and IdeaVis (Geyer et al., 2012) simplify the formalization of ideas and participants' contributions by using natural expressions such as sketches or diagrams (e.g. UML); TRENDS can even provide assistance with inspiration by broadcasting images (Setchi and Bouchard, 2010). The methodology also generated references to systems that impact some factors of creativity but whose focus is unrelated to creativity per se. These systems were not included in the review.

References	Name	Digital device	Collective/ Individual	Collaborative	Remote collaboration	Phase covered	Nature of the assistance
(Brocco et al., 2011)	360°	Web service	Individual	Yes	Yes	Ideation	IT systems to support open creativity
(ERPI, n.d.)	48h Innovation Maker	Web service	Individual	Yes	Yes	Ideation	Collect the ideas of different teams that are working on the same subject.
(McCaffrey and Spector, 2011)	AhaNets	Computer software	Individual	No	No	Problem analysis, ideation, evaluation	Define the subject by redefining techniques, analyse the unexplored features of a solution
(Brade et al., 2011)	BrainDump	Computer software	Individual	No	No	Problem analysis, ideation, evaluation	Information gathering and organizing (cluster)
(Gutwein, 2013; Hilliges et al., 2007)	BrainStorm	Interactive table, wall display	Collective	Yes	No	Ideation, evaluation	Support co-located collaborative creativity
(Liu et al., 2011)	CACDP	Computer software	Individual	No	No	Problem analysis, evaluation	Requirements analysis, design problem analysis, design problem solving, solutions management
(Mangano and van der Hoek, 2012)	Calico	Interactive whiteboard	Collective	Yes	No	Problem analysis, ideation	Support designers sketching on the interactive whiteboard
(Warr and O'Neill, 2007; Sugimoto et al., 2004)	Caretta	Sensing board (interacts with physical objects), projector, and PDA	Collective	Yes	No	Ideation	Integrate personal and shared spaces to support face-to-face collaboration
(Bellandi et al., 2012)	Catalyst for Collaborative Innovation (C4CI)	Web service	Collective	Yes	Yes	Ideation	Pervasive, intelligent environment that can proactively stimulate collaboration between innovation team members
(CogniStreamer, n.d.)	CogniStreamer	Web service, computer software	Individual	Yes	Yes	Problem analysis, ideation, evaluation	Support the idea management process, stimulate collective creative minds
(Bhagwatwar et al., 2013)	Creative virtual environment	Computer software	Individual	Yes	Yes	Ideation	Immersive environment to interact with remotely located persons and brainstorm
(Vattam et al., 2011)	Dane	Web service	Individual	No	No	Problem analysis, ideation	Interactive knowledge-based design environment, provides access to a design case library containing Structure-Behaviour-Function (SBF) models of biological and engineering systems
(Schmitt et al., 2012; Buisine et al., 2012)	DiamonSpin	Tabletop	Collective	Yes	No	Ideation	Graphical interface to support brainwriting and mindmapping
(Warr and O'Neill, 2007)	Envisionment and Discovery Collaboratory	Interactive tabletop, physical object, ultrasonic sketching tools	Collective	Yes	No	Problem analysis, ideation	Support social creativity by creating shared understanding among various stakeholders, contextualizing information to the task at hand, and creating objects-to-think-with in collaborative design activities
(Clayphan et al., 2011; Gutwein, 2013)	Firestorm	Tabletop	Collective	Yes	No	Ideation, evaluation	Tabletop computer interface has the potential to support idea generation by a group using the brainstorming technique
(Gutwein, 2013)	GADjet	Tabletop	Collective	Yes	No	Ideation	Interactive meeting table based on a multitouch surface which should transfer the technological advantages of a normal working place to the working area of a whole group
(Wang and Ohsawa, 2013)	Galaxy + ideaGraph	Computer software	Individual	No	No	Ideation	Support the dynamic process of idea discovery
(Westerski et al., 2010)	Gi2MO	Web service	Individual	Yes	Yes	Ideation, evaluation	Set up Semantic Web technologies in the environment of Idea Management Systems

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References	Name	Digital device	Collective/ Individual	Collaborative	Remote collaboration	Phase covered	Nature of the assistance
(ThinkTank, n.d.; Yuan, 2008)	ThinkTank	Web service, complete digital environment	Collective	Yes	Yes	Ideation, evaluation	Collaborative structure for the way people work together; transform process performance and create culture of innovation and engagement
(S. Jones et al., 2011)	Ide Rummet (the idea room)	Web service	Individual	Yes	Yes	Ideation	Asynchronous distributed collaborative idea generation platform
(Wang et al., 2010)	Idea Expander	Computer software	Individual	Yes	Yes	Ideation	Tool to support group brainstorming by intelligently selecting pictorial stimuli based on the group's conversation
(Huang et al., 2007)	Idea Storming Cube	Web service	Collective	Yes	Yes	Ideation	Game-based collaborative creativity support system to support creative thinking and help a user form a perspective-shift thinking habit
(Chakrabarti et al., 2005)	Idea-Inspire	Computer software	Individual	No	No	Problem analysis, ideation	Software for automated analogical search of relevant ideas from the databases to solve a given problem
(Forster et al., 2010)	IdeaStream	Web service	Individual	Yes	Yes	Ideation	Chat communication on computer-supported idea generation processes
(Geyer et al., 2011; Geyer et al., 2012)	IdeaVis	Custom tabletop, wall display, Anoto digital pen	Collective	Yes	No	Ideation	Novel approach for supporting co-located sketching sessions
(Warr and O'Neill, 2005; Warr and O'Neill, 2007; Streitz et al., 1999)	i-Land	Augmented object, interactive wall, interactive tabletop, computer chair	Collective	Yes	Yes	Problem analysis, ideation, evaluation	An interactive landscape for creativity and innovation
(Gutwein, 2013; Sundholm et al., 2004)	iLounge	Interactive whiteboard, tabletop, computer software	Collective	Yes	Yes	Problem analysis, ideation	Support co-located collaborative work
(KPMG Innovation Factory, 2014; Bellandi et al., 2012)	PIT Idea Management Software	Computer software, web service	Individual	Yes	Yes	Ideation	Built-in social intelligence ensures that all relevant knowledge within the organization is captured to create great ideas
(WeListen Business Solutions, n.d.; Bellandi et al., 2012)	InnovationCast	Web service	Individual	Yes	Yes	Ideation, evaluation, implementation	Pose challenges, capture and evolve ideas and work collaboratively on opportunities and projects, to translate investments in innovation into value
(Gutwein, 2013; A. Jones et al., 2011)	iRoom	Interactive whiteboard, tabletop, computer software	Collective	Yes	No	Ideation	Create a collaborative environment for complete civil engineering teams
(BIBA, n.d.)	Laboranova	Web service	Individual	Yes	Yes	Problem analysis, ideation, evaluation	Team building, information gathering, idea formalization, evaluation
(Gardoni et al., 2005)	MICA-graph	Web service	Individual	Yes	Yes	Ideation	Graphical formalization of the idea (prototype)
(Herrmann and Nolte, 2010)	ModLab + SeeMe	Interactive tabletop, web service, smartphone	Individual & collective	Yes	No	Ideation, evaluation	Special facilitation collaboratory (ModLab) where laptops and a large interactive screen can be linked to produce collaborative modelling
(Gutwein, 2013; Bao et al., 2010)	Momentum	Web service	Individual	Yes	Yes	Problem analysis	Tool that elicits topic-oriented responses prior to a group brainstorming session
(Friess et al., 2012)	Not named	Tabletop, web service, smart phone	Individual & collective	Yes	No	Ideation, evaluation	Generic model for creativity-technique-based problem-solving processes and discussions (group), collaboration and interaction on multi-touch tabletop displays

References	Name	Digital device	Collective/ Individual	Collaborativ e	Remote collaboration	Phase covered	Nature of the assistance
(PatentInspiration, n.d.)	PatentInspiratio n	Web service	Individual	No	No	Problem analysis, ideation	Intelligent data mining tool to leverage the creative performance of engineers and innovation managers
(Hartmann et al., 2010)	Pictionaire	Interactive tabletop	Collective	Yes	No	Ideation	An interactive tabletop system that enhances creative collaboration across physical and digital artefacts. It offers capture, retrieval, annotation and collection of visual material
(Yuan and Chen, 2008)	SILA + CBDS	Computer software	Individual	Yes	Yes	Ideation, evaluation	Environment where an inference mechanism of a Semantic Ideation Learning Agent (SILA) that performs idea associations and generation can learn and share knowledge
(A. Jones et al., 2011)	TATIN	Interactive whiteboard, tabletop	Collective	Yes	No	Ideation	Increase the creativity of brainstorming meetings, and help make the group's output more effective
(A. Jones et al., 2011)	Tatin-Pic	Interactive whiteboard, tabletop, smartphone, web service	Individual & collective	Yes	Yes	Ideation	A multi-modal collaborative work environment for teams performing preliminary design
(Hailpern et al., 2007)	TeamStorm	Tablet PC, wall display	Individual & collective	Yes	No	Ideation	Collaborate by providing mechanisms to integrate tablet- or PC-based input on a large display in front of a group of designers
(van Dijk and Vos, 2011)	Traces	Interactive floor	Collective	Yes	No	Ideation	Save the 'traces' (intermediate artefacts) of creativity, build a consensus/common imaginary between participants
(Setchi and Bouchard, 2010)	TRENDS	Computer software	Individual	No	No	Ideation	Software tool that supports the inspirational stage of design by providing various sources of inspiration
(Zanni-Merk et al., 2009)	TRIZAcquisitio n	Computer software	Individual	No	No	Problem analysis	Assistance with elementary knowledge acquisition, problem formulation, knowledge structuring or problem reformulation
(Lopes et al., 2009)	USE (Uplift Seek Engine)	Web service	Individual	No	No	Ideation	System that can lead creative professionals on an individual brainstorm by using images to relate semantic concepts
(Alvarez and Su, 2012)	Virtual Reality Mechanism Design Studio (VRMDS)	Virtual reality and computer software	Individual	No	No	Ideation	Rapid 3D modelling and prototyping
(Tan et al., 2010)	VisuaPedia	Web service	Individual	Yes	Yes	Ideation	Generate and collect data on creativity, knowledge contribution and sharing as well as the context in which people network to build their social capital
(Ardaiz-Villanueva et al., 2011)	Wikideas + creativity connector	Web service	Individual	Yes	Yes	Ideation, evaluation	Enhance creative skills, especially the generation of ideas and originality in university students
(Gutwein, 2013)	WordPLay	Tabletop	Collective	Yes	No	Ideation	Interactive tabletop platform for finding and organizing ideas in a group.

Table 2. Digital creativity supports mentioned in the literature

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- <u>Creativity phases supported</u>

Table 3 shows that the great majority of the CSS studied support only one phase (65%); 78% of this subsample is dedicated to the ideation phase. For 16% of the systems, the scope was not clearly determined. Overall, the supports that exclusively cover the ideation phase represent nearly half of those listed in Table 2. Nevertheless, this also means that 35% of the supports are designed to support more than one phase of the creativity process. The most covered pair of phases are ideation and evaluation; concretely, this means that the support receives the ideas and then displays a map that is automatically or manually generated. Four CSS that cover more than two phases were also identified: CogniStreamer (CogniStreamer, n.d.), i-Land (Streitz et al., 1999), InnovationCast (WeListen Business Solutions, n.d.), and Laboranova (BIBA, n.d.). It is interesting to note that very few of the surveyed articles focused on the detailed study of problem analysis and evaluation.

No. of phases covered	Phases	Number of supports (total: 49)	Proportion of category (%)	Proportion of total (%)
1 (65%)	Problem analysis	2	6	4
	Ideation	25	78	51
	Evaluation	0	0	0
	Implementation	0	0	0
	Undetermined	5	16	10
2 (27%)	Problem analysis and ideation	2	15	4
	Problem analysis and evaluation	3	23	6
	Ideation and evaluation	8	62	16
3 (8%)	Problem analysis, ideation and evaluation	3	75	6
	Ideation, evaluation and implementation	1	25	2

Table 3. Phases of the creativity process covered by the supports

- <u>Collaboration settings and tools</u>

Most of the digital supports listed in this review (78%) were designed to allow collaboration between users/participants, as Table 4 shows. More than half of these collaborative creativity supports (55%) were designed to support remote collaboration. However, according to Table 5, a majority of them are limited to individual-to-individual remote collaboration. The systems that do not support remote collaboration but are still considered to be collective systems provide functionalities to enable a group of participants to interact locally, such as interactive tabletops or a mix of individual and collective devices such as smartphones and interactive tabletops.

Collaboration	Number of CSS	Remote collaboration	Proportion of category	Proportion of total (%)
Yes	38 (78%)	Yes	21 (55%)	43
		No	17 (45%)	35
No	11 (22%)			22

Table 4. Collaboration capabilities of CSS

Remote collaboration	Number of CSS	Use	Number of supports	Proportion of category (%)	Proportion of total (%)
Yes	21 (43%)	Individual	16	76	33
		Collective	5	24	10
		Both	0	0	0
No	17 (35%)	Individual	0	0	0
		Collective	12	71	24
		Both	5	29	10

Table 5. Remote collaboration capabilities and use of collaborative systems

- Use of the system

Table 6 shows that more than half of the supports are designed for individual use. This may be due to the historic heritage of creativity, which was originally seen as an individual activity. More recently, creativity has been considered to be collective as well. The interest in brainstorming has even led to the production of supports that exclusively manage the collective dimension. Finally, a balance appears, with the existence of CSS that make it possible to switch between personal and collective spaces. The present review found only five CSS that respect this balance between individual and collective conceptual spaces: Caretta (Sugimoto et al., 2004), ModLab + SeeMe (Herrmann and Nolte, 2010), Tatin-Pic (A. Jones et al., 2011), TeamStorm (Hailpern et al., 2007), and the unnamed system proposed by Friess et al (2012).

Use	CSS	Total (%)
Individual	27	55
Collective	17	35
Both	5	10

Table 6. Global distribution of modes of using CSS

- Technologies dedicated to the system and their use

All of the CSS considered in this review are supposed to be designed to work on synchronous collaboration. This means that collaborators have to be connected and work at the same time, which represents a difficulty when collaborators are in different time zones. The evolution from an individual to a shared space is intimately related to technological evolution. The popularity of personal computers is decreasing, whereas the reliance on personal devices such as smartphones and tablets is increasing, as revealed by company adoption (Deloitte, 2011). Group devices such as interactive whiteboards and interactive tabletops confirm this trend of creating a mixed digital environment.

According to Table 7, the most widely used type of technology is the web service, which makes it possible to access the information on various web-enabled devices such as tablets, smartphones, personal computers, and even interactive tabletops. Web services are also used to centralize information and allow each device to exchange data on a single web platform. As the backbone of a system that supports creativity, it seems normal that this kind of technology is most popular, given its flexibility.

To gain a better understanding of the use of technology, the details in Table 8 are useful. The individual supports used, which represent half of the systems in the present review, are mainly based on web services. This is because a significant proportion of these individual supports are remote collaboration systems. Among creativity support systems that are exclusively intended for collective use, interactive tabletops are the most widely used. In the case of complete environments, the most popular are again interactive tabletops, in association with interactive whiteboards or other accessories: BrainStorm (Hilliges et al., 2007), Envisionment and Discovery Collaboration (Warr and O'Neill, 2007), ThinkTank (ThinkTank, n.d.), IdeaVis (Geyer et al., 2012), i-Land (Streitz et al., 1999), iLounge (Sundholm et al., 2004), iRoom (A. Jones et al., 2011), and Tatin (A. Jones et al., 2011). It is not surprising that all five of the systems that are designed to integrate individual and collective use are based on smartphones or tablets (PDAs for the oldest experiments) for individual input and interactive tabletops or whiteboards for collective input.

Support technology	Number of supports that use it	Proportion of total (%)[a]
Web service	22	45
Interactive tabletop	17	35
Computer software	11	22
Interactive whiteboard	7	14
Mobile/individual device	5	10
Wall display	4	8
Augmented object	3	6
Digital sketching instrument	2	4
Interactive floor	1	2

Table 7. Distribution of the types of technology used by collaborative CSS

[a] Percentages do not add up to 100 because some supports use more than one technology.

Use	Number of supports	Device used	Number of supports that use the device	Proportion of category (%)
Individual	27 (55%)	Computer software	9	33
		Web service	15	56
		Both	2	7
Collective	17(35%)	Interactive tabletop	13	76
		Interactive whiteboard	6	35
		Web service	3	18
		Wall display	2	12
		Computer software	2	12
		Digital sketching instrument	2	12
		Physical object	2	12
		Interactive floor	1	6
Both	5 (10%)	Mobile/individual device	5	100
		Interactive tabletop	4	80
		Web service	3	60
		Wall display	2	40
		Interactive whiteboard	1	20
		Physical object	1	20

Table 8. Detailed distribution of types of technology according to the use orientation of the support

In contrast to what it was expected at the beginning of this review, a significant number of digital supports are dedicated to positively improving and assisting the creative process. These systems are described with many different names. In general, these terms are not explicitly defined according to their scope, materials or approach. It is even less likely that there will be an overall description of their potential relationships with each other. In terms of functionalities provided, most of these systems are designed to provide assistance with brainstorming in a co-located collaboration. Others assist in managing the overall process. Ultimately, none of these systems respond totally to all the different specifications observed, namely supporting co-located and remote creative collaboration, respecting individual and collective conceptual space, and covering problem analysis, ideation and evaluation phases. Several of these systems meet some of these specifications. Five supports are designed for both co-located and remote collaboration: C4CI (Bellandi et al., 2012), ThinkTank (ThinkTank, n.d.), Idea Storming Cube (Huang et al., 2007), iLounge (Sundholm et al., 2004), and i-Land (Streitz et al., 1999). Likewise, five supports cover both individual and collective conceptual spaces: Tatin-Pic (A. Jones et al., 2011), ModLab (Herrmann and Nolte, 2010), TeamStorm (Hailpern et al., 2007), Caretta (Sugimoto et al., 2004), and the unnamed system from Friess et al. (2012). As for the phases covered in the process, most systems focus on ideation; this is no doubt due to decades of promotion of divergent thinking and ideation in the literature (Puccio and Cabra, 2012). However, there is now a trend to extend the study of creativity support beyond ideation. Only four supports cover all three of the expected phases: CogniStreamer (CogniStreamer, n.d.), i-Land (Streitz et al., 1999), Laboranova (BIBA, n.d.) and InnovationCast (WeListen Business Solutions, n.d.). As it is shown in the experimentation with Momentum (Bao et al., 2010), getting participants involved upstream of ideation results in a faster and more in-depth start to a creative workshop. If creative approaches were considered from a strategic, comprehensive perspective, all the specifications discussed here could be satisfied. The current research project focuses on the further application of this insight.

IV. Towards a Comprehensive Creativity Support System

As described in the introduction, the design of digital systems that support creativity in local and remote collaboration involves various fields. This review highlights the fact that existing systems are not multifunctional: they do not support the entire creative process or the different modes of collaboration (co-located and remote, synchronous and asynchronous). Instead, each one supports only a limited number of creativity methods. Without entering into detail on design methodologies and rules for creating software, and specifically CSS, this section will present some use typologies (based on collaboration and communication).

The design of such digital systems can take different perspectives as a starting point: the phases of the creative process, the roles of the different users, the collaboration settings, or the different devices used. Of course, all these perspectives are interdependent. Given that the aim of this article is not to present the detailed system requirements and architecture of a CSS, some of the CSS perspectives will be presented according to the two main perspectives: creative process and collaboration settings.

- Features according to the creative process

As seen previously, most current systems are dedicated to supporting specific creativity methods during the ideation phase. These systems are useful, but they would be even more useful if they were used coherently. Coherence affects all the phases of the creative process, which should be considered as non-linear.

Problem analysis, the first phase of the creative process, represents an opportunity to create coherence. Although the conclusion of the present review is a poor support of this phase, in some papers give it more importance and described it in more depth with sub-steps, such as the six steps dedicated to problem analysis in the creative product design method (Liu et al., 2011) According to a guideline for formalizing the problems (MacLellan et al., 2013), several factors can be extracted at this stage, such as orientation of the creative approach, the expectations in terms of results, and the nature of the problem to be solved. Depending on these elements, relevant creativity methods can be suggested and coherently planned by applying facilitation rules from experiences of creative session facilitators. A methodological approach can help to formalize the problem, the context and the subject. As a prelude to the ideation phase, avenues for exploration would automatically be defined with semantic analysis; in addition, it would facilitate the determination of the evaluation criteria for the evaluation phase.

The ideation phase involves the application of the different creativity methods selected during the previous phases. The application of the method depends on the collaboration setting. This review has presented several examples that suggest how creativity methods can be supported in different collaboration settings. The most difficult aspect is designing support for a large number of different creativity methods. Every time a user enters data in the system during the ideation phase, it should be considered as an idea, regardless of its state of advancement.

Different approaches can be applied in the evaluation phase. The evaluation method can produce qualitative (clustering ideas according to themes) and quantitative (assigning a score according to a criterion) results. It is difficult for humans to correctly evaluate large numbers of ideas. The ideal system should be both automatic and manual, meaning that it would prepare a selection of ideas to ease the work of the human who is evaluating them; the ideas should be related to the person's expertise or interests.

This automatic processing will be done with the (semantic) analysis of the information generated by problem analysis. Evaluation processed by humans would be facilitated with evaluation cards also based on the information from the problem analysis.

- Features according to collaboration settings

Three different types of configurations have been identified: collaboration of dispersed individuals, rather like current open innovation platforms; collaboration of remote teams; and co-located collaboration. The first two settings can be considered synchronously and asynchronously, while the last can only be synchronous or else it will be equivalent to a remote setting. These different configurations are summarized in Table 9.

		Collaboration		
		Co-located	Semi-remote	Remote
Communication	Synchronous	- Storage of the knowledge generated - Use of adapted devices according to activities - Individual and collective creativity methods support	- Storage of the knowledge generated - Use of adapted devices according to activities - Individual and collective creativity methods support - Chat, videoconference, news feed	- Storage of the knowledge generated - Limited device access - Individual creativity methods support - Chat, videoconference, news feed
	Asynchronous	X	- Storage of the knowledge generated - Use of devices according to activities - Individual and collective creativity methods support - News feed, recommendation system	- Storage of the knowledge generated - Limited device access - Individual creativity methods support - News feed, recommendation system

Table 9. Suggestions for different collaboration settings

Co-located collaboration setting is the closest approach to the basic ‘paper and pencil’ case. Instead of using sticky notes and easel pads, the group will alternatively use collective devices such as interactive whiteboards and interactive tabletops for collective activities (visualization, consensus and information sharing) and individual devices such as laptops, smartphones and tablets for personal activities (information research, personal mapping, model creation, drawing or submitting ideas).

Collaboration in semi-remote teams (virtual teams) raises the issue of creating a collaboration synergy. In both synchronous and asynchronous cases, the focus will be on the sharing and visualization of information through devices, whether individual or collective. Although an overly high degree of formalization in terms of collaboration impedes creativity, success depends on some formalization (Nemiro, 2004; da Silva et al., 2010). The emphasis should be on communication and organization to permit group awareness and the creation of common representations of the problem. In this case, support will be provided by individual methods, involving various communication technologies (Nemiro, 2004), and inspiration sharing via a recommendation system. In organizing the creative approach, special attention should be paid to managing synchronized videoconferences.

Collaboration in remote teams is a mix of local and remote collaboration, as local teams have their own work methods but need to remain in communication with remote teams. So the same devices will be used as in co-located settings but they must be adapted to avoid any misunderstandings in communication. This means integrating a recommendations system in the tools so that everyone is aware of related ideas generated by other teams. In terms of planning, time to do videoconference and explore the information generated must be managed. Shared times need to be planned and managed with objectives and time limitations to limit time wasting.

The functionalities expected of a CSS relate to the definition of the overall process and the actors' interactions: defining which activities apply and how to organize them to enable collective creativity while respecting to individuals, providing assistance with activity processing, and managing the knowledge created. Regarding digital devices, this review highlights the value of web services to support the different modes of collaboration. Any future system will need to operate web services to connect the diversity of devices adapted to the specific collaboration mode. At present, these features are abstract, high-level recommendations, but they should be applied in system architecture.

V. Conclusion

Overall, the existing systems designed to support the creative process do not cover the full complexity of creativity, even when the technology seems to permit it. According to the present review, very few systems cover any other phases than ideation. Existing systems support relatively few methods and techniques. Moreover, collaboration is supported in either co-located or remote configurations but rarely in both. To sum up, no system permits co-located and remote collaboration during the entire creative process by applying a variety of methods (other than brainstorming) and by using a variety of devices adapted to the collaboration context. An effort should be made to expand the functionality of Creative Support Systems (CSS) to more creativity methods and collaboration modes. This review suggests that future work in the field should focus on the problem analysis and idea evaluation phases of the creative process. Of course, the creation of future CSS should not start from scratch but will be inspired by existing systems. There is a need to design even more coherent, intelligent systems that integrate a range of aspects of creativity, such as organization, monitoring and capitalization, method support and collaboration.

Further research must be done on the inconsistent terminology created by the expansion of the use of digital tools to assist human tasks, including creativity. This would allow us to better understand the differences in the digital system presented in this review and their functionalities. Another research avenue would be the creation of an overall CSS architecture that responds to the challenges posed by piloting and apply creativity workshop.

References

Alvarez, J.C., Su, H.-J., 2012. VRMDS: an intuitive virtual environment for supporting the conceptual design of mechanisms. Virtual Real. 16, 57–68. doi:10.1007/s10055-009-0144-z

Ardaiz-Villanueva, O., Nicuesa-Chacón, X., Brene-Artazcoz, O., Sanz de Acedo Lizarraga, M.L., Sanz de Acedo Baquedano, M.T., 2011. Evaluation of computer tools for idea generation and team

formation in project-based learning. Comput. Educ. 56, 700–711. doi:10.1016/j.compedu.2010.10.012
Aznar, G., 2005. Idées: 100 techniques de créativité pour les produire et les gerer. Editions d'Organisations, Paris.
Bao, P., Gerber, E., Gergle, D., Hoffman, D., 2010. Momentum: getting and staying on topic during a brainstorm, in: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'10). ACM, pp. 1233–1236.
Bellandi, V., Ceravolo, P., Damiani, E., Frati, F., Maggesi, J., 2012. Towards a collaborative innovation catalyst, in: 2012 Eighth International Conference on Signal-Image Technology Internet-Based Systems (SITIS 2012). IEEE, pp. 637–643. doi:10.1109/SITIS.2012.96
Bhagwatwar, A., Massey, A., Dennis, A.R., 2013. Creative virtual environments: effect of supraliminal priming on team brainstorming, in: Proceedings of 46th Hawaii International Conference on System Sciences (HICSS). IEEE, pp. 215–224. doi:10.1109/HICSS.2013.152
BIBA – Bremer Institut für Produktion und Logistik GmbH, n.d. Laboranova. http://www.laboranova.com/ (accessed 5.22.14).
Boden, M.A., 2009. Computer models of creativity. AI Mag. 30, 23–34.
Boly, V., 2008. Ingenierie de l'innovation: organisation et méthodologies des entreprises innovantes, Hermes Science Publications, Cachan, France.
Bonnardel, N., Zenasni, F., 2010. The impact of technology on creativity in design: an enhancement? Creat. Innov. Manag. 19, 180–191. doi:10.1111/j.1467-8691.2010.00560.x
Brade, M., Heseler, J., Groh, R., 2011. An interface for visual information-gathering during web browsing sessions: BrainDump – a versatile visual workspace for memorizing and organizing information, in: ACHI 2011, The Fourth International Conference on Advances in Computer-Human Interactions. pp. 112–119.
Brocco, M., Forster, F., Frieß, M.R., 2011. 360° open creativity support. J UCS 17, 1673–1689.
Browning, T.R., Fricke, E., Negele, H., 2006. Key concepts in modeling product development processes. Syst. Eng. 9, 104–128. doi:10.1002/sys.20047
Buisine, S., Besacier, G., Aoussat, A., Vernier, F., 2012. How do interactive tabletop systems influence collaboration? Comput. Hum. Behav. 28, 49–59. doi:10.1016/j.chb.2011.08.010
Chakrabarti, A., Sarkar, P., Leelavathamma, B., Nataraju, B.S., 2005. A functional representation for aiding biomimetic and artificial inspiration of new ideas. Artif. Intell. Eng. Des. Anal. Manuf. 19, 113–132.
Clayphan, A., Collins, A., Ackad, C., Kummerfeld, B., Kay, J., 2011. Firestorm: a brainstorming application for collaborative group work at tabletops. ACM, pp. 162–171.
CogniStreamer, n.d. CogniStreamer® – open innovation and collaboration platform http://www.cognistreamer.com/ (accessed 5.21.14).
Damanpour, F., Aravind, D., 2012. Organizational structure and innovation revisited: from organic to ambidextrous structure, in: M.D. Mumford (Ed.), Handbook of Organizational Creativity. Academic Press, San Diego, pp. 483–513.
Da Silva, F.Q.B., Costa, C., Franca, A.C.C., Prikladinicki, R., 2010. Challenges and solutions in distributed software development project management: a systematic literature review, in: 5th IEEE International Conference on Global Software Engineering (ICGSE). IEEE, pp. 87–96. doi:10.1109/ICGSE.2010.18
Deloitte, 2011. Mobile Technology – Keep Pace in a Changing Consumer Environment.
Equipe de Recherche sur les Processus Innovatifs (ERPI), n.d. 48h Innovation Maker | 48h pour faire émerger des idées! http://www.48h-innovation-maker.com/?language=en (accessed 11.5.15).
Forster, F., Frieß, M.R., Brocco, M., Groh, G., 2010. On the impact of chat communication on computer-supported idea generation processes, in: Proceedings of the First International Conference on Computational Creativity (ICCC X), Lisbon, Portugal (January 2010), pp. 165–174.
Friess, M.R., Kleinhans, M., Klügel, F., Groh, G., 2012. A tabletop application environment for generic creativity techniques. Int. J. Comput. Inf. Syst. Ind. Manag. Appl. 4, 55–65.

Gabriel, A., Monticolo, D., Mauricio, C., Bourgault, M., 2014. Process modelling for a creative problem solving support system. Presented at the International Conference on Innovative Design and Manufacturing, IEEE, Montréal, QC, Canada, pp. 181–186. doi:10.1109/IDAM.2014.6912691

Gardoni, M., Blanco, E., Rüger, S., 2005. MICA-Graph: a tool for managing text and sketches during design processes. J. Intell. Manuf. 16, 395–405.

Gero, J.S., Kannengiesser, U., 2004. The situated function–behaviour–structure framework. Des. Stud. 25, 373–391. doi:10.1016/j.destud.2003.10.010

Geyer, F., Budzinski, J., Reiterer, H., 2012. IdeaVis: a hybrid workspace and interactive visualization for paper-based collaborative sketching sessions, in: Proceedings of the 7th Nordic Conference on Human-Computer Interaction: Making Sense Through Design. ACM, pp. 331–340.

Geyer, F., Pfeil, U., Höchtl, A., Budzinski, J., Reiterer, H., 2011. Designing reality-based interfaces for creative group work, in: Proceedings of the 8th ACM Conference on Creativity and Cognition. ACM, pp. 165–174.

Glăveanu, V.P., 2010. Paradigms in the study of creativity: introducing the perspective of cultural psychology. New Ideas Psychol. 28, 79–93. doi:10.1016/j.newideapsych.2009.07.007

Grant, M.J., Booth, A., 2009. A typology of reviews: an analysis of 14 review types and associated methodologies. Health Inf. Libr. J. 26, 91–108. doi:10.1111/j.1471-1842.2009.00848.x

Gutwein, S., 2013. Computer support for collaborative creativity (Technical report). University of Munich, Munich.

Hailpern, J., Hinterbichler, E., Leppert, C., Cook, D., Bailey, B.P., 2007. TEAM STORM: demonstrating an interaction model for working with multiple ideas during creative group work, in: Proceedings of the 6th ACM SIGCHI Conference on Creativity & Cognition. ACM, pp. 193–202.

Hartmann, B., Morris, M.R., Benko, H., Wilson, A.D., 2010. Pictionaire: supporting collaborative design work by integrating physical and digital artifacts, in: Proceedings of the 2010 ACM Conference on Computer Supported Cooperative Work. ACM, pp. 421–424.

Herrmann, T., Nolte, A., 2010. The integration of collaborative process modeling and electronic brainstorming in co-located meetings. Presented at the Collaboration Researchers International Working Group (CRIWG) conference.

Hilliges, O., Terrenghi, L., Boring, S., Kim, D., Richter, H., Butz, A., 2007. Designing for collaborative creative problem solving, in: Proceedings of the 6th ACM SIGCHI Conference on Creativity & Cognition. ACM, pp. 137–146.

Howard, T.J., Culley, S.J., Dekoninck, E., 2008. Describing the creative design process by the integration of engineering design and cognitive psychology literature. Des. Stud. 29, 160–180. doi:10.1016/j.destud.2008.01.001

Huang, C.-C., Li, T.-Y., Wang, H.-C., Chang, C.-Y., 2007. A collaborative support tool for creativity learning: Idea storming cube, in: Seventh IEEE International Conference on Advanced Learning Technologies, 2007. pp. 31–35.

Hüsig, S., Kohn, S., 2009. Computer aided innovation – State of the art from a new product development perspective. Comput. Ind. 60, 551–562. doi:10.1016/j.compind.2009.05.011

Jones, A., Kendira, A., Lenne, D., Gidel, T., Moulin, C., 2011. The TATIN-PIC project: A multi-modal collaborative work environment for preliminary design, in: Proceedings of the 2011 15th International Conference on Computer Supported Cooperative Work in Design, CSCWD 2011. IEEE Computer Society, pp. 154–161. doi:10.1109/CSCWD.2011.5960069

Jones, A., Kendira, A., Gidel, T., Moulin, C., Lenne, D., Barthès, J. P., & Guerra, A., 2012. Evaluating Collaboration in Table-centric Interactive Spaces, in: AVI workshop on Designing Collaborative Interactive Spaces, DCIS 2012, pp. 1-10.

Jones, S., Poulsen, A., Maiden, N., Zachos, K., 2011. User roles in asynchronous distributed collaborative idea generation, in: Proceedings of the 8th ACM Conference on Creativity and Cognition. ACM, pp. 349–350.

Kitchenham, B., Charters, S., 2007. Guidelines for performing systematic literature reviews in software engineering (EBSE Technical Report No. EBSE-2007-01). Software Engineering Group, School of Computer Science and Mathematic, Keele University, Keele, UK.

KPMG Innovation Factory, 2014. PIT Idea Management Software. http://www.innovationfactory.eu/pit/

Liu, X., Li, Y., Pan, P., Li, W., 2011. Research on computer-aided creative design platform based on creativity model. Expert Syst. Appl. 38, 9973–9990. doi:10.1016/j.eswa.2011.02.032

Lopes, J.S., Alvarez-Napagao, S., Vazquez-Salceda, J., 2009. USE: a concept-based recommendation system to support creative search, in: 2009 IEEE/WIC/ACM International Conference on Web Intelligence and Intelligent Agent Technology – Workshops, WI-IAT Workshops 2009, September 15, 2009 – September 18, 2009, pp. 17–21. doi:10.1109/WI-IAT.2009.220

López-Ortega, O., 2013. Computer-assisted creativity: Emulation of cognitive processes on a multi-agent system. Expert Syst. Appl. 40, 3459–3470. doi:10.1016/j.eswa.2012.12.054

Lubart, T., 2003. Psychologie de la créativité. Armand Colin, Paris.

Lubart, T., 2005. How can computers be partners in the creative process: classification and commentary on the special issue. Int. J. Hum.-Comput. Stud. 63, 365–369. doi:10.1016/j.ijhcs.2005.04.002

MacLellan, C.J., Langley, P., Shah, J., Dinar, M., 2013. A computational aid for problem formulation in early conceptual design. J. Comput. Inf. Sci. Eng. 13, 031005.

Mangano, N., van der Hoek, A., 2012. The design and evaluation of a tool to support software designers at the whiteboard. Autom. Softw. Eng. 19, 381–421. doi:10.1007/s10515-012-0104-9

Martin, B., Hanington, B., Hanington, B.M., 2012. Universal Methods of Design: 100 Ways to Research Complex Problems, Develop Innovative Ideas, and Design Effective Solutions. Rockport Publishers, Beverly, MA.

Massaro, M., Bardy, R., Pitts, M., 2012. Supporting creativity through knowledge integration during the creative processes. A management control system perspective. Electron. J. Knowl. Manag. 10, 258–267.

McCaffrey, T., Spector, L., 2011. Innovation is built on the obscure: innovation-enhancing software for uncovering the obscure, in: Proceedings of the 8th ACM Conference on Creativity and Cognition. ACM, pp. 371–372.

Michalko, M., 2006. Thinkertoys, 2nd ed. Ten Speed Press, Berkeley, CA.

Mohan, M., Shah, J.J., Narsale, S., Khorshidi, M., 2012. Capturing ideation paths for discovery of design exploration strategies in conceptual engineering design, in: J.S. Gero (Ed.), Design Cognition and Computing ’12, Springer, New York, pp. 589–604.

Mumford, M.D., 2011. Handbook of Organizational Creativity. Academic Press, San Diego, CA.

Nemiro, J., 2004. Creativity in Virtual Teams: Key Components for Success. Pfeiffer, New York.

Ogot, M., Okudan, G.E., 2007. Systematic creativity methods in engineering education: a learning styles perspective. Int. J. Eng. Educ. 22, 566–576.

Osborn, A.F., 1963. Applied Imagination: Principles and Procedures of Creative Problem-Solving. Scribner, New York.

PatentInspiration, n.d. PatentInspiration – Search and analyze patents. http://www.patentinspiration.com/

Puccio, G.J., Cabra, J.F., 2012. Idea generation and idea evaluation: cognitive skills and deliberate practices, in: M.D. Mumford (Ed.), Handbook of Organizational Creativity. Academic Press, San Diego, pp. 189–215.

Ray, D.K., Romano, N.C., Jr., 2013. Creative problem solving in GSS groups: do creative styles matter? Group Decis. Negot. 22, 1129–1157. doi:10.1007/s10726-012-9309-3

Salerno, M.S., Gomes, L.A. de V., da Silva, D.O., Bagno, R.B., Freitas, S.L.T.U., 2015. Innovation processes: which process for which project? Technovation 35, 59–70. doi:10.1016/j.technovation.2014.07.012

Sawyer, K., 2012. Explaining Creativity: The Science of Human Innovation., 2nd ed. Oxford University Press, New York.

Schmitt, L., Buisine, S., Chaboissier, J., Aoussat, A., Vernier, F., 2012. Dynamic tabletop interfaces for increasing creativity. Comput. Hum. Behav. 28, 1892–1901. doi:10.1016/j.chb.2012.05.007

Seidel, S., 2011. Toward a theory of managing creativity-intensive processes: a creative industries study. Inf. Syst. E-Bus. Manag. 9, 407–446. doi:10.1007/s10257-009-0123-7
Setchi, R., Bouchard, C., 2010. In search of design inspiration: A semantic-based approach. J. Comput. Inf. Sci. Eng. 10. doi:10.1115/1.3482061
Shneiderman, B., 2007. Creativity support tools – accelerating discovery and innovation. Commun. ACM 50, 20–32.
Stratton, R., Mann, D., 2003. Systematic innovation and the underlying principles behind TRIZ and TOC. J. Mater. Process. Technol. 139, 120–126. doi:10.1016/S0924-0136(03)00192-4
Streitz, N.A., Geissler, J., Holmer, T., Konomi, S., Müller-Tomfelde, C., Reischl, W., Rexroth, P., Seitz, P., Steinmetz, R., 1999. i-LAND: an interactive landscape for creativity and innovation, in: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. ACM, pp. 120–127.
Sugimoto, M., Hosoi, K., Hashizume, H., 2004. Caretta: a system for supporting face-to-face collaboration by integrating personal and shared spaces, in: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. ACM, pp. 41–48.
Sundholm, H., Artman, H., Ramberg, R., 2004. Backdoor creativity: collaborative creativity in technology supported teams, in: F. Darses, R. Dieng, C. Simone, and M. Zacklad (Eds.), Cooperative Systems Design: Scenario-Based Design of Collaborative Systems. IOS Press, Amsterdam, pp. 99–114.
Tan, M., Tripathi, N., Zuiker, S.J., Soon, S.H., 2010. Building an online collaborative platform to advance creativity, in: 4th IEEE International Conference on Digital Ecosystems and Technologies (DEST), 2010. pp. 421–426.
ThinkTank, n.d. ThinkTank Structured Collaboration Software. http://www.groupsystems.com/
Tidd, J., Bessant, J., 2009. Managing Innovation: Integrating Technological, Market and Organizational Change, 4th ed. John Wiley & Sons, Chichester, UK.
Van Dijk, J., Vos, G.W., 2011. Traces in creative spaces, in: Proceedings of the 8th ACM Conference on Creativity and Cognition. ACM, pp. 91–94.
VanGundy, A.B., 2008. 101 Activities for Teaching Creativity and Problem Solving. John Wiley & Sons, San Francisco, CA.
Vattam, S., Wiltgen, B., Helms, M., Goel, A.K., Yen, J., 2011. DANE: fostering creativity in and through biologically inspired design, in: T. Taura and Y. Nakai (Eds.), Design Creativity 2010. Springer, New York, pp. 115–122.
Voigt, M., Bergener, K., Becker, J., 2013. Comprehensive support for creativity-intensive processes: an explanatory information system design theory. Bus. Inf. Syst. Eng. 5, 227–242. doi:10.1007/s12599-013-0272-6
Voigt, M., Niehaves, B., Becker, J., 2012. Towards a unified design theory for creativity support systems, in: D. Hutchison et al. (Eds.), Lecture Notes in Computer Science. Springer, Berlin, pp. 152–173. doi:10.1007/978-3-642-29863-9_13
Von Stamm, B., 2008. Managing Innovation, Design and Creativity. John Wiley & Sons, Chichester, UK.
Wang, H., Ohsawa, Y., 2013. Idea discovery: a scenario-based systematic approach for decision making in market innovation. Expert Syst. Appl. 40, 429–38. doi:10.1016/j.eswa.2012.07.044
Wang, H.-C., Cosley, D., Fussell, S.R., 2010. Idea Expander: Supporting group brainstorming with conversationally triggered visual thinking stimuli, in: Proceedings of the 2010 ACM Conference on Computer Supported Cooperative Work. ACM, pp. 103–106.
Warr, A., O'Neill, E., 2005. Understanding design as a social creative process, in: Proceedings of the 5th Conference on Creativity & Cognition. ACM, pp. 118–127.
Warr, A., O'Neill, E., 2007. Tool support for creativity using externalizations, in: Proceedings of the 6th ACM SIGCHI Conference on Creativity & Cognition. ACM, pp. 127–136.
WeListen Business Solutions, n.d. InnovationCast: What It Is. http://innovationcast.com/en/what_it_is
Westerski, A., 2011. Gi2MO: Interoperability, linking and filtering in idea management systems, in: Proceedings of the 8th Extended Semantic Web Conference. Springer, pp. 1-5.

Westerski, A., 2013. Semantic technologies in idea management systems: a model for interoperability, linking and filtering. Universidad Politécnica de Madrid, Escuela Técnica Superior de Ingenieros de Telecomunicación.

Westerski, A., Iglesias, C.A., Rico, F.T., 2010. A model for integration and interlinking of idea management systems, in: S. Sánchez-Alonso and I.N. Athanasiadis (Eds.), Metadata and Semantic Research. Springer, Berlin, pp. 183–194.

Wiggins, G.A., 2006. Searching for computational creativity. New Gener. Comput. 24, 209–222. doi:10.1007/BF03037332

Yilmaz, S., Christian, J.L., Daly, S.R., Seifert, C.M., Gonzalez, R., 2011. Collaborative idea generation using design heuristics, in: Proceedings of the 18th International Conference on Engineering Design (ICED11), Vol. 10. pp. 91–101.

Yuan, M., 2008. An Automatic Classification Approach to Idea Organization in Group Support Systems. PhD dissertation, University of Arizona.

Yuan, S.-T., Chen, Y.-C., 2008. Semantic ideation learning for agent-based e-brainstorming. IEEE Trans. Knowl. Data Eng. 20, 261–275. doi:10.1109/TKDE.2007.190687

Zanni-Merk, C., Cavallucci, D., Rousselot, F., 2009. An ontological basis for computer aided innovation. Comput. Ind. 60, 563–574.

Zanni-Merk, C., Cavallucci, D., Rousselot, F., 2011. Use of formal ontologies as a foundation for inventive design studies. Comput. Ind. 62, 323–336. doi:10.1016/j.compind.2010.09.007

Zeng, L., Proctor, R.W., Salvendy, G., 2011. Can traditional divergent thinking tests be trusted in measuring and predicting real-world creativity? Creat. Res. J. 23, 24–37. doi:10.1080/10400419.2011.545713