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Immersive Virtual Environments' Impact on Individual and Collective Creativity

A Review of Recent Research

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Abstract: This paper explores the recent advances in research concerning the impact of immersive virtual environments affordances on the expression of users' creativity at individual and team levels. While the top virtual reality (VR) application areas are entertainment and gaming, simulation and training for professionals, research in the domain of the psychology of creativity and VR is advancing rapidly in Europe. Indeed, between 2014 and 2021, 72% of publications in this domain resulted from European research in diverse fields such as engineering, design, music composition, art-making, and so forth. These studies took advantage of advanced VR affordances, such as head and hand motion trackers to synchronize an avatar in real-time, live streaming of a video into a VR headset screen to create artwork, etc. Four main topics were explored: (a) new creativity techniques involving a virtual upgrade of traditionally used techniques, virtual sketching and prototyping, as well as sophisticated interactive virtual menus and motion tracking systems, (b) the right digital self-representation for enhancing creativity and the degree to which users identify with the "persona avatar" in the context of user-centered innovations, (c) the impact of physical and social virtual contextual cues on creative performance, and (d) the perception of virtual reality by creativity and innovation professionals. Our review confirms that VR supports greater creative performance at individual and collaborative levels as well as enjoyment and fun. However, as rich and varied as this literature has become, it presents major methodological limitations that should be addressed in future research.

Keywords: immersive virtual environments, users-centered creative design, virtual creativity techniques, persona avatars, self-perception

Although it has been claimed that "creativity is intelligence having fun" (Scialabba, 1984), for most people, opportunities for fun and creativity, especially in their workplace, appear rather limited. Initial work on features of physical work environments that foster creativity has recently led to an interest in the potential of virtual environments for the same purpose. Early research on virtual reality (VR) and creativity suggests that VR environments could be conducive to individual and collaborative creativity through fun co-creation experience, role-play, empathy, immersion, anonymity, flow, enjoyment, and so forth. (Gül & Maher, 2009; Kohler et al., 2011; Uribe Larach & Cabra, 2010, Ward & Sonneborn, 2011). Virtual reality, which is among the technologies that define the 21st century, can support creativity in three ways (Burkhardt & Lubart, 2010): (a) to help people develop skills related to creativity or creative thinking; (b) to support people's creative process and performance while engaging in a creative task; and (c) to engage people in new kinds of experiences.

The development of high-quality VR technology and the recently reduced cost of VR headsets have given rise to multiple applications. While the most popular VR application areas in Europe are entertainment and gaming, simulation and training for professional and industrial use, healthcare, real estate, and architecture (Bezegová et al., 2018, p. 26), research in the domain of the psychology of creativity and VR is gaining pace among European academics. Seven years ago, a systematic literature review was conducted using keywords search strings such as "virtual world" AND "creativity"; "virtual environment" AND "creativity"; and "virtual world" AND "innovation" (Alahuhta et al., 2014, p. 4). The authors found 47 relevant articles between 2000 and 2013. Their analysis identified 8 VR affordances based on their potential ability to enhance team creativity in virtual worlds: (a) avatars as graphic self-representations; (b) changing the frame of reference (i.e., enabling individuals to change their environment through avatars, roles, or surroundings); (c) co-presence (i.e. sense of presence with other avatars in the same place); (d) immersion (the impression that one is participating in a realistic experience); (e) multimodality (the ability to combine different media); (f) rich visual information (e.g., models, drawings, objects, and data); (g) simulation capabilities (tools allowing interacting teams to model new artifacts and create objects that are impossible in real life); and (h) supporting tools for creative work (integrated tools and features, such as AI and artificial agents, that support the creative task at hand).

Building on this research, this paper aims to explore recent advances in European academic research concerning the expression of users' creativity in multi-user virtual environments (MUVEs). MUVEs are digital spaces shared by multiple users where interaction with objects and users is performed through computer-generated representations of self, others, and the environment. These symbolic representations are crucial elements that can be classified as (Kadri et al., 2007): (a) virtual objects without symbolic meaning (e.g., arrow, sphere, line, triangle); (b) specific tools representing functions (e.g., scissors, eraser, paintbrush, hammer); (c) body parts (e.g., eyes, hands, fingers); (d) full-body representation (often called "avatar"). A wide variety of appearances can be generated from these symbolic representations, ranging from photorealistic or cartoonish renderings and first- or third-person perspectives to perceptions of external tools and illusory body ownership (see Seinfeld et al., 2020). User experience also depends on input/output devices and the sensory modalities they involve (e.g., headsets, motion tracking, 3D audio sounds, tactile and haptic feedback, and even scent and taste experiences).

The remainder of the paper is structured as follows. First, the method used to identify and select published research by European teams on creativity and MUVES since 2014 is reported. Then we present the results of our qualitative analysis, organized into four categories: (1) new advances in research aiming to adapt or support existing creativity techniques within MUVEs; some latest results on (2) avatars, and (3) immersion in virtual environments as specific VR features that may affect creative performance; and, finally, (4) research on the perception and acceptability of VR and MUVES by professional creativity facilitators. Conclusions and forward-looking perspectives are proposed at the end.

Method

Literature Selection

We conducted a literature review to identify the recent advances in this field between 2014 and 2021. Using several combinations of keywords such as "creativity," "creative," "creativeness," and "innovation" with "virtual world." "virtual environment," "virtual space," and "Avatar," the search process concerned:

(1) the major databases such as PsycINFO, ERIC, Google Scholar, JSTOR, Web of Science, etc.,
(2) key journals in virtual environments and creativity such as *Journal of Virtual Worlds Research*, *Computers in Human Behaviors, Psychology of Aesthetics, Creativity, and the Arts*, *The Journal of Creative Behavior*, *Thinking Skills and Creativity*, *Creativity Research Journal*, etc., and
(3) direct request to authors for a copy of a chapter or conference paper whenever needed.

A total of 153 articles, book chapters, and conference papers were collected. After reading the abstracts, we included publications that addressed virtual reality, augmented or mixed reality uses within the creativity domain (e.g., studies that explore users' creativity within more or less virtual immersive setting) and excluded articles that explored (1) the development of technical skills using virtual simulation in area such as manufacturing, medical or engineering domain (e.g., Lomanowska & Guitton, 2014), and (2) online or digital creativity without any immersive experience (e.g., Biasutti, 2015). As a result, 46 relevant publications were selected, out of which 33 (72%) were published by European teams (including articles, book chapters, and conferences proceedings). This represents a substantial increase compared to the last literature review (Alahuhta et al., 2014), where 49% of the articles were published by European teams (or at least the first author was a European). Of the remaining 13 eligible publications (Bilyatdinova et al., 2016; Chang et al., 2020; Davis & Boellstorff, 2016; Hong et al., 2016; Hong, El Antably, et al., 2019; Hong, Park, et al., 2019; Hu et al., 2016; Lau & Lee, 2015; Leonard et al., 2015; Tang et al., 2018; Ward, 2015;

Yang et al., 2018, 2019), 3 were conducted by US teams and 11 by Asian or mixed teams (China, Korea, Taiwan, Hong Kong, Russia, Israel, Egypt, Australia). These papers were excluded for the next part of the analysis due to the paper's focus on European research.

Within the 33 selected European research, various degrees of immersive systems were represented, ranging from VR headsets or CAVE (a cube-shaped immersive VR room where outside projectors are directed to three walls, floor, and ceiling of the room) to ordinary computer screens.

Qualitative Analysis

The content of the 33 studies was categorized into four topics and covered three methodological aspects. This categorization was both data-driven and informed by the authors previous research work in the domain of creativity and virtual reality. The four main topics encompass (a) the use of virtual creativity techniques, (b) avatar embodiment, (c) virtual environments effects, or (d) virtual reality perception by creativity and innovation professionals. Moreover, each article was analyzed through three methodological lenses: (a) virtual reality design and material (VR headsets, avatars, virtual spaces design, haptic and motion devices, etc.); (b) the nature and duration of the creative tasks (collaborative vs. individual; divergent vs. convergent tasks, brainstorming, sketching, etc.); and (c) the participants' number and type (students in psychology, design, engineering, etc. vs. professionals from diverse domains of expertise).

Adapting Existing Creativity Techniques in MUVEs

Creativity and innovation professionals use diverse creativity techniques and strategies to come up with creative design solutions or products that are original and, at the same time, satisfy constraints pertaining to the design problem at hand (Bonnardel, 2012; Bonnardel & Pichot, 2020; Bourgeois-Bougrine et al., 2017). VR offers a cost-effective means of implementing and optimizing nearly all conventional individual and collaborative creativity enhancement techniques while also offering potent new possibilities and combinations not available by other means (Thornhill-Miller & Dupont, 2016).

Our review (see Table 1) shows that 11 studies took advantage of VR affordances to explore new creativity techniques involving (a) a virtual upgrade of classic techniques such as the persona method (Bonnardel et al., 2016; Bonnardel & Pichot, 2020; Li et al., 2018), (b) virtual sketching and prototyping software (Obeid & Demirkan, 2020; Vistisen et al., 2019), and (c) sophisticated VR installations and interfaces (Forens et al., 2015; Fröhlich et al., 2018; Gerry, 2017; Men & Bryan-Kinns, 2018, 2019; Men et al., 2019). These techniques were tested during individual or collaborative creative tasks in domains such as design, music composition, and art-making. The participants were students as well as professionals.

A Dynamic Adaptation of the "Persona Method" to Support User-Centred Creative Design

The classic "persona" method aims to provide designers with end-user models (or archetypes) derived from field data. Personas are generally given a name and associated with a photo and a textual description revealing their needs, values, aspirations, and/or frustrations (Pruitt & Grudin, 2003). They are intended to allow designers to get a better understanding of users' intentions, stimulate empathy, and favor creativity (Brangier et al., 2011). Nevertheless, this method can be seen as reducing the involvement of designers in gathering user data (Goh et al., 2017). To overcome this limitation, Bonnardel and colleagues (Bonnardel & Pichot, 2020; Bonnardel et al, 2016) introduced "dynamic" personas allowing a more active role for the designer in needs analysis through conversation with the persona.

The dynamic persona is modeled by an avatar in a virtual environment. At this stage of development, dynamic personas are played by the experimenter, in accordance with the "Wizard of Oz" technique, but autonomous conversational agents could possibly be developed in the future (Callejas et al., 2014). The designers and/or the other stakeholders are also represented by avatars in the virtual environment, which allows them to choose their visual appearance and can ensure them, if they wish, anonymity in order to reduce evaluation apprehension and production blocking (Bourgeois-Bougrine et al., 2018; Brown et al., 1998). Regardless of their status (e.g., professionals or students), participants can interact with each other and exchange with the dynamic persona in order to gather information related to these archetypal users. Therefore, the designers and the other stakeholders become more active in searching for information elements related to future users.

In addition, in these studies, participants were asked to use a written communication mode (through a chat) to limit the negative effects of turn-taking. Studies aiming to compare the uses of dynamic and static personas (Bonnardel & Pichot, 2020; Bonnardel et al, 2016) showed that using a dynamic persona led to more active involvement of the participants through a questioning process to access information about future users and usages. It also seems to lead to a deeper understanding of future users and their intentions and emotions. This interpretation is consistent with the higher level of empathy that was observed when

Table 1. Studies on the impact of creativity techniques on participants' creative performance and user experience (2014–2021)

Authors	Country	Participants	Tasks	Creativity techniques	VR design & material
Bonnardel et al. (2016)	France	4 professionals: 2 designers and 2 ergonomists (persona) & 11 psychology students (no persona)	Collaborative brainstorming: 25 min (divergent phase) +15 min (convergent phase). Groups of 2 or 3	Virtual dynamic personas vs. static personas	Isolated boxes equipped with computers/Virtual meeting room/ Avatars/No VR headset.
Bonnardel & Pichot (2020)	France	102 psychology students	Collaborative brainstorming: 25 min (divergent phase) +15 min (convergent phase). Groups of 2	Virtual dynamic personas vs. static personas	Isolated boxes equipped with computers/Virtual meeting room/ Avatars/No VR headset.
Li et al. (2018)	France	10 students from a school of engineers.	Co-designing task: 20 min. Five pairs of collaborators: One is a Persona & Another is a designer.	Multi-view system & virtual dynamic Personas	Two projectors and two shutter glasses used in the multi-view system. Co-presence in physical environment/Headset & No avatar/ each collaborator has an experimental scene with special functions.
Vistisen et al. (2019)	Denmark	6 second-year students at a Design master program	Immersive sketching: Designing a virtual underwater exhibition about historical shipwrecks – Duration: not specified	Masterpiece VR/Tilt Brush/ Storyboard VR	Not specified.
Men & Bryan-Kinns (2018, 2019); Men et al. (2019)	UK	32 users (Men & Bryan-Kinns, 2018), 42 users (Men & Bryan-Kinns, 2019) & 52 users (Men et al., 2019) from the authors' school (Media and Arts Technology Centre)	Collaborative music composition in pairs: 4 sessions of 5 min (Men & Bryan-Kinns, 2018); 3 sessions of 8 min (Men & Bryan-Kinns, 2019); 4 sessions of 7 min/session (Men et al., 2019)	LeMO: Music interface + avatars + virtual space that includes a grey stage with a grid pattern	HTC Vive headsets (Each with a Leap Motion Controller mounted); the position and rotation of headsets are tracked by two tracking cameras set around the scene, and hand gestures are tracked by the Leap Motion Controller. Two PCs are used to run LeMo. Avatar: head and both hands synchronized with users' real movements in real-time, including position and rotation of head and gestures.
Obeid & Demirkan (2020) (Master thesis 2019)	Turkey	42 first-year undergraduate basic design students	Creation of a 3D geometrical composition. Duration: not specified	Gravity Sketch: Oculus vs. iPad	Oculus Rift DK2 to create virtual objects and move freely around them. The participants were able to walk around their design and draw on any part of it.
Forens et al. (2015)	France	66 psychology students	Collaborative brainstorming: 25 min. Groups of 3	Written vs. oral communication in VR: instant messaging system vs. audio chat system	Isolated boxes equipped with computers/Virtual meeting room/ Avatars/No VR headset.

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Table 1. (Continued)

Authors	Country	Participants	Tasks	Creativity techniques	VR design & material
Fröhlich et al. (2018)	Germany	9 experts computer graphics, game design, and didactics	Terraforming task: create at least one hill or mountain, one water body, and one lowland area adding virtual objects: trees, flowers, castles, lighting moods. 30–50 min.	VR-sandbox system: VR environment that contains a landscape, which the user designs via interacting with real sand	Virtual reality head-mounted display/triple kinetic depth sensing, hand tracking, VR menu items represented as bubbles. In VR, users see the virtual representation of the tracked sandbox and sand surface and form a terrain with their bare hands. Furthermore, they can interact with a virtual menu using their hands.
Gerry (2017)	Denmark	32 subjects from the Copenhagen community	Create a painting in VR by following a painter's actual movements (e.g., mimicking how the painter refills the brush with color mixed on the palette, and dips the brush into water, etc. Duration: not specified	Perspective sharing: superimposition of one experiential reality on top of another. Users see a video from a painter's point of view in tandem with a tracked rendering of their own hand	Leap Motion integration with the Oculus DK2 virtual reality headset. Co-presence of a participant and an artist (with 2 wide-angle Go-Pro HERO 4 cameras mounted onto a bicycle helmet/Binaural point-of-view audio was recorded using Roland CS-10EM binaural microphone). The artist recording was live-streamed into the other participant's Oculus screen played through KolorEyes on an Oculus DK2.

participants were provided with a dynamic persona than with a static one. The positive effect of the use of the dynamic persona was also observed in the quality of collaboration in the groups, which is consistent with greater involvement of the participants (e.g., either a designer and an ergonomist or two students together). The act of communicating with a third interlocutor in the form of a dynamic persona seems to stimulate the participants to exchange and collaborate more. This dynamic interaction may also favor the construction of a common frame of reference around the design problem, which is essential in collective creative activities (Valkenburg & Dorst, 1998). Therefore, using a dynamic persona in a virtual environment appears as an efficient way to enrich designers' mental representations about future users and to favor collaborative creative design activities.

Other Creativity Techniques Recently Tested in MUVEs

Other creativity techniques have been tested, such as virtual sketching and prototyping software (Obeid & Demirkan, 2020; Vistisen et al., 2019) and sophisticated VR installations and interfaces for music composition, terraforming, and art-making (Fröhlich et al., 2018; Gerry, 2017; Men & Bryan-Kinns, 2018, 2019; Men et al., 2019). The aim of these studies was to assess the feasibility of the techniques and users' experiences and perceptions. However, no measurement of the participants' creative performance was made. These studies involved VR headsets, interactive virtual menus, and motion tracking systems. For instance, Men and colleagues (Men & Bryan-Kinns, 2018, 2019; Men et al., 2019) explored how shared virtual environments should be designed to support creative, collaborative music-making. They designed and refined iteratively a virtual music interface that allows users to generate, remove, position, and edit music in pairs in a virtual space that includes a grey stage with a grid pattern. Gerry (2017) explored a new way to teach creativity through perspective sharing. This involves the superimposition of an artist painter's point of view that is live-streamed into the user's VR headset in tandem with a tracked rendering of the user's own hand. Finally, in one study (Fröhlich et al., 2018), the use of VR in combination with a sandbox was tested. The users were instructed to create a landscape using the sand and VR menu items represented as bubbles, which users could interact with using their hands. The VR bubbles offered different functions effects, for example, decorating the sand surface with virtual objects or teleportation. The context of working with sand as in childhood days and the VR functions and effects were all perceived as playful by the participants.

User's Embodiment by an Avatar: A VR Specific Feature Supporting Creative Processes

Avatars as User's and Character's Representations in MUVEs

Avatars are virtual characters that are increasingly present in popular culture, appearing in video games, social networks, and digital applications in general. By providing us with a fresh new appearance, they may impact the very perception of our own identity. Indeed, avatars are known to influence behavior through their individual identity cues ("Proteus effect") and through their shared identity cues ("Social identity effect"; Buisine et al., 2017; Guegan et al., 2019). The Proteus effect (i.e., the idea that a participant's perception of an avatar's appearance as "creative" might influence behavior in that direction), could be explained by; (a) self-perception: according to this theory, participants would be particularly sensitive to social cues associated with their new identity that they infer from their avatar; and (b) priming: the avatar might activate in memory, concepts that are associated with its appearance (Yee & Bailenson, 2007).

Beyond self-perception and personal identity, avatars may also be a convenient medium to emphasize social identity in a virtual environment. Social identity is defined as common features that are shared by the group members and distinguish them from other relevant groups (Tajfel & Turner, 1979). In this way, a positive evaluation of one's in-group may contribute to a positive evaluation of the self, leading people to work as a group and for the group to enhance performance (i.e., social laboring; Haslam, 2004).

Ten publications addressed the impact on the creativity of embodying an avatar, including six original studies (Table 2), three book chapters summarizing previous authors' publications (Buisine et al., 2017; de Sousa, 2015; Guegan et al., 2019), and one a review (Clark, 2020). The main research questions were:

Research Question 1 (RQ 1): What is the right digital self-representation for enhancing creativity?

Research Question 2 (RQ 2): What is the right representation to support engineers' creativity?

Research Question 3 (RQ 3): What is the impact of embodying a virtual user persona versus an inventor avatar?

Research Question 4 (RQ 4): How does the degree to which users identify with their avatar moderate their actual ability to generate creative ideas?

Table 2. Studies on the impact of avatars on creativity (2014–2021). All studies involved the measurement of creative performance

Authors	Country	Participants	Tasks	VR design & material
Guegan et al. (2016)	France	114 & 54 (Studies 1 & 2) final year students from a higher engineering institute	Collaborative brainstorming: 15 min × 2 sessions – Groups of 3	Inventor vs. non-inventor avatars/Virtual meeting room/Isolated boxes equipped with computers/No VR headset.
Buisine et al. (2016)	France	12 highly qualified employees from a large company's innovation department	Collaborative brainstorming: 10 min × 6 sessions – Groups of 6	Virtual static train station for the familiarization phase & virtual metro tour across Paris for ideation/Inventors' avatars vs. Personas' avatars (6 archetypal users of public transportation)/isolated boxes equipped with computers/No VR headset.
Guegan, Segonds, et al. (2017)	France	72 final-year engineering students from a French school of engineering known for the strong social identity (SIC) of its students	Collaborative brainstorming: 15 min – Groups of 3	Avatars with SIC (virtual coat school's insignia)/Isolated boxes equipped with computers/No VR headset.
Buisine & Guegan (2020)	France	72 final-year engineering students	Collaborative brainstorming: 15 min – Groups of 3	Avatars: Inventor vs. non-inventor X with or without SIC (virtual coat with school's insignia)/Virtual meeting room/isolated boxes equipped with computers/No VR headset.
de Rooij et al. (2017)	The Netherlands	61 students (Department of Communication and Cognition of Tilburg University)	Divergent thinking task: 3 min (things shaped like circles or triangle)	Three different avatars (made using body-scanning and auto-rigging software): Creative (artist stereotype), Non-creative (office worker stereotype), and Control (avatar wearing the clothes the participant is actually wearing)/Virtual room: a minimally designed living room of medium size, with three couches, three plants, a door, and a window with a city street view/Head-mounted display.
Marinussen & de Rooij (2019)	The Netherlands	57 students (Department of Communication and Cognition of Tilburg University)	Divergent thinking task: instances task, in a custom-made virtual environment (geometric shape, like a sphere or a cube). That is, they were instructed to generate as many instances of that shape as they could within 1 min (e.g., a planet when encountering the sphere)	Participants composed on laptop an avatar using Autodesk's Character Generator/The avatar was exported by the researcher in a virtual environment presented with a head mounted display, the HTC Vive/Participants used their avatars to navigate and be guided through a virtual maze until they came across a geometric shape (a sphere or a cube).

Note. To avoid redundancy the following four publications summarizing authors' previous work are not reported in Table 2: Buisine et al. (2017), de Sousa (2015), Guegan et al. (2019), and Clark (2020).

These studies (Table 2) involved mostly students in engineering and communication and cognition programs who performed collaborative brainstorming for 10–15 min in groups of three participants or divergent thinking tasks for 5 min performed individually). One study involved highly qualified employees from a large company's innovation department (Buisine et al., 2016). The participants in collaborative brainstorming sessions worked in groups of three in a virtual meeting room; they were isolated in individual experimental rooms equipped with computers, were represented by avatars, and did not wear a VR headset (Buisine & Guegan, 2020; Buisine et al. 2016; Guegan et al., 2016, Guegan, Nelson, et al., 2017; Guegan, Segonds, et al., 2017). Two studies used VR head mounted displays (de Rooij et al., 2017; Marinussen & de Rooij, 2019).

Avatars Exhibiting Identity Cues Increase Self-Perception of Creative Skills and Performance

In a series of experiments, avatars were used to modify self-perception in order to improve one's collaborative brainstorming creative performance (Buisine & Guegan, 2020; Buisine et al., 2016; Guegan et al., 2016; Guegan, Segonds, et al., 2017). To do so, the first step was to identify what kind of avatars would likely increase the perception of one's creative skills. In these experiments being conducted with engineering students, the authors studied the cognitive representation of creativity in this population, which led them to identify the concept of the Inventor as a common relevant creative figure for engineers. Accordingly, the authors designed and validated avatars featuring characteristics of inventors (e.g., looking like Einstein, wearing a laboratory coat or using scientists' instruments). They expected that users of these avatars, observing their digital appearance ("I embody an inventor"), would make implicit inferences about their creative skills ("I am creative") and improve their creative performance ("I have a lot of ideas/good ideas"). Consistently, their results showed that engineering students using inventor avatars during a virtual brainstorming session performed significantly higher in fluency and originality in comparison to students using neutral avatars and students in a face-to-face electronic brainstorming situation (Guegan et al., 2016). Moreover, this benefit endured over time because participants allocated to the inventor condition continued to perform higher in subsequent face-to-face brainstorming. Subjective data also showed that brainstorming in a virtual environment (either with a neutral or a creative avatar) was rated more fun than using an electronic brainstorming system.

Interestingly, two studies which investigated experimentally whether the degree to which users identify with their avatar moderates their actual ability to generate creative ideas suggest that self-similarity might be an even more effective way to support creative ideation than priming creative stereotypes (de Rooij et al., 2017; Marinussen & de Rooij, 2019).

Framing Creative Design Towards User's Needs by Providing Avatars Derived From Persona Characters

In further work, Buisine and colleagues (2016) examined whether avatars could be used to help engineers develop user-centered innovations motivated by customer needs instead of technological value. To investigate this question, they designed a case study with a major company in the transportation industry. A group of highly qualified employees from the innovation department was given inventor avatars like in the previous experiment, and another group was assigned avatars representing users of public transportation ("persona avatars," for example, a mother with a newborn, a child, an elderly person, a train manager). Both groups were immersed in a transportation situation (a metro tour across a virtual Paris) and had to find applications for smart windows in public transportation. As expected, the content of ideas was influenced in a manner congruent with avatars' appearance: the inventor condition led to a technically-centered ideation profile, oriented toward technological solutions, whereas the persona condition led to more user-centered, needs-oriented ideas. Consistently, inventors' production tended to be better evaluated according to industrial criteria, and those produced by personas tended to be evaluated as better by transportation users. These results suggest that avatar-mediated brainstorming could be a powerful tool enabling innovation teams to align ideation to their strategy (e.g., technology-centered or user-centered).

Avatars Exhibiting Shared Social Identity Cues Facilitate Group Identification and Creative Performance

In a subsequent experiment, Buisine and Guegan (2020) introduced VR social identity cues (SIC) on avatars' clothes (Figure 1), as it could be implemented in various professional contexts (e.g., clothes in the colors and logo of a company, sport team jerseys). On the basis of the Social Identity Model of Deindividuation Effects (Reicher et al., 1995; Spears & Lea, 1992, 1994), the authors assumed that virtual cues would positively affect group performance (see Tanis & Postmes, 2008). By perceiving themselves as members of a group rather than co-workers who are "gathered together," individuals should be more likely to engage in online collaborative work. The results confirmed this assumption

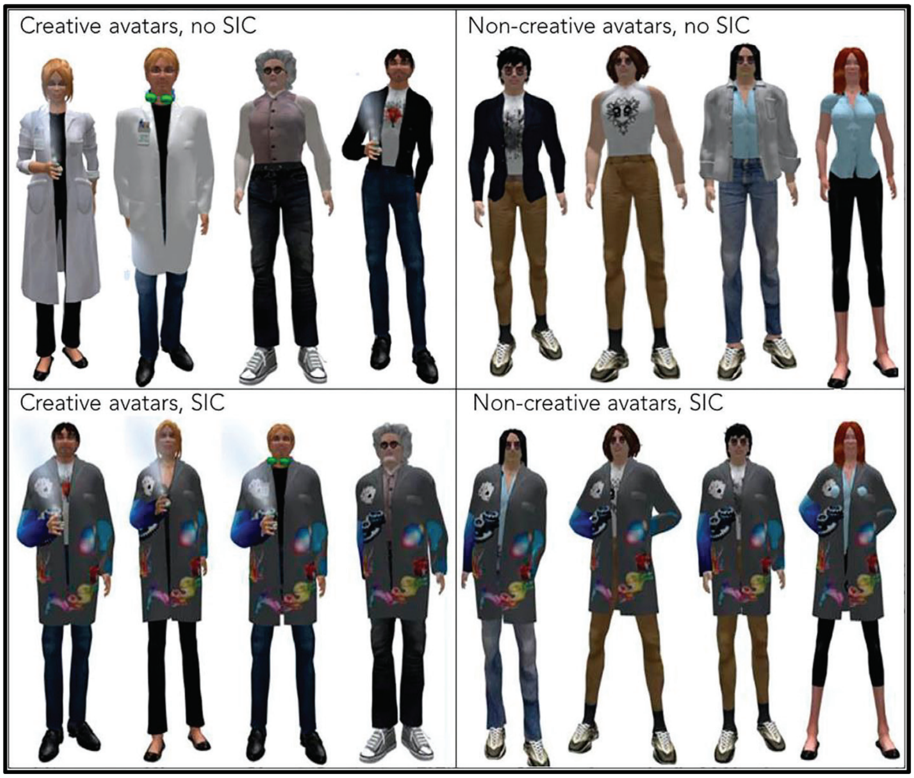

Figure 1. The collection of avatars differing in individual identity cues (creative vs. non-creative) and social identity cues (SIC vs. No SIC). Reprinted with permission from Buisine and Guegan (2020). © S. Buisine & J. Guegan.

by showing that social identity cues on avatars' clothes increased both group identification and creative performance.

Immersion in Virtual Environment: A Second VR Specific Feature

Impact of the Environment Content on Creativity in MUVEs

One of the most defining affordances of VR is the illusion of presence in virtual environments (VE). Early empirical studies have investigated the impact of VE features on creativity, for example, the feeling of sharing the same place and working within a cohesive group (Uribe Larach & Cabra, 2010), the inspiring, intrinsically motivating, and fun co-creation experience impacting the time spent in VE and the number of words in brainstorming sessions (Kohler et al., 2011), or the creative look of VE increasing performance on an ideation task in terms of number of ideas (fluency), originality (uniqueness), relevance and workability of ideas (which can be interpreted as a priming mechanism; Bhagwatwar et al., 2013). These results show a clear, positive impact of the visual creative environment on creative performance both quantitatively and qualitatively.

Nine recent publications brought support and provided some explanations regarding psychological processes involved in the effect of VE on creativity, including two book chapters summarizing previous authors' publications (Alahuhta et al., 2016; Eustáquio & de Sousa, 2019) and one conference proceeding (Bourgeois-Bougrine et al., 2018). Respectively four and then two empirical studies (Table 3) addressed the impact of physical and social virtual contextual cues on creative performance (Physical: Fleury et al., 2020; Guegan, Nelson, et al., 2017; Guegan et al., 2020; Nelson & Guegan, 2019; Social: Bourgeois-Bougrine et al., 2020; Frommet al., 2020).

The VE tested in these studies were: an artist studio, a meeting room, a lush green forest surrounded by mountains, an underwater environment featuring a coral reef, a virtual interior of an empty train car, a virtual library environment, a virtual replica of the headmistress's office, a replica of children schoolyard, and a dreamlike environment. All the studies involved the measurement of creative performance either in collaborative brainstorming (Bourgeois-Bougrine et al., 2020; Fromm et al. 2020) or in divergent thinking tasks (Fleury et al., 2020; Guegan, Nelson, et al., 2017; Guegan et al., 2020; Nelson & Guegan, 2019). One study used both convergent and divergent thinking tasks (Fleury et al., 2020). The participants were all higher education students except in one study, which explored the impact of VE on children's creativity

Table 3. Studies on the impact of virtual environments on creativity (2014–2021). All studies involved the measurement of creative performance

Authors	Country	Participants	Tasks	VR design & material
Guegan, Nelson, et al. (2017)	France	160 & 135 undergraduate students in psychology (survey & experimentation)	Divergent thinking task in VR: Torrance's cardboard boxes task. 10 min	Virtual creativity-conducive environment (CCE: artist studio) and virtual control environment (meeting room)/the view locked in first-person perspective: the participants moved using the keyboard and could explore in detail their environment using the mouse to control gaze direction in 360°/No avatar/No headset
Nelson & Guegan (2019)	France	50 & 100 undergraduate students psychology (Study 1 & 2)	Study 1 – divergent thinking task: Torrance's cardboard boxes task. 10 min in VR. Study 2 – "alien creatures" task. 10 min after being immersed for 5 min in VR	Study 1 – Two VE: a lush green forest surrounded by mountains & an underwater environment featuring a coral reef. Study 2 – three aquatic virtual environments integrating features characteristic of an alien planet/Computer & Oculus Rift DK2. Participants were unable to move in the virtual environment but were able to explore it at 360° by moving their heads. No Avatars.
Bourgeois-Bougrine et al. (2020)	France	60 undergraduate students psychology	Collaborative brainstorming in VR – 10 min – Groups of 3	Virtual meeting room/Avatars isolated boxes equipped with computers/No VR headset.
Fleury et al. (2020)	France	32 students or interns involved in the field of virtual reality	Divergent and convergent tasks in VR: Alternate Uses Test (AUT – 5 min) and the Remote Association Test (RAT)	Virtual interior of an empty train car-no visible landscape through the train's windows (as if they were in a tunnel). When the train was moving, the lights from inside the tunnel could be seen moving by/ HTC Vive headset/No Avatars.
Fromm et al. (2020)	Germany	18 students from the Applied Cognitive and Media Sciences study program	Collaborative brainstorming in VR – 12 min – Groups of 3	Virtual library environment with a crackling fire, a meowing cat, a table, sofas/Oculus Go to run. Social network application vTime XR. Participants took part from their homes.
Guegan et al. (2020)	France	96 school-aged children	Divergent thinking task in VR: Torrance's cardboard boxes task. 10 min	A replica of the headmistress's office, a replica of their schoolyard, and a dreamlike environment/No VR headset/No Avatars. The view locked in first-person perspective.

Note. To avoid redundancy, the following three publications summarising authors' pervious work are not reported in the Table 3: Alahuhta et al. (2016), Eustáquio and de Sousa (2019), and Bourgeois-Bougrine et al. (2018).

(Guegan et al., 2020). VR headset was used in three studies, whereas four studies used desktop computers.

Effects of Contextual Cues Contained in the Displayed Virtual Environment on Creative Performance

In terms of the physical contextual cues, studies explored two ways in which the virtual environment could foster creativity (Guegan, Nelson, et al., 2017; Guegan, et al., 2020; Nelson & Guegan, 2019): (a) by providing contextual cues congruent with the type of creative production expected (considered as examples of possible responses); and (b) by providing other kinds of contextual cues, which may influence creativity indirectly (increasing the accessibility of relevant knowledge). The results suggest that (a) originality and elaboration scores were higher in the virtual creativity-conductive condition (an artist studio) compared to the real meeting room or virtual meeting room

Table 4. Studies on the perception of creativity professionals (2014–2021)

Authors	Country	Participants	Tasks	VR design & material
Thornhill-Miller & Dupont (2016)	France	20 French-speaking professionals with experience working as creativity and innovation facilitators and consultants	No	No headset & no computer – Link to discover VR online
Leovaridis & Bahana (2017)	Romania	3 entrepreneurs in three different areas of creative industries (architecture, journalism, advertising)	No	No headset & No computer
Buisine & Guegan (2019)	France	19 professional creativity facilitators independent or internal consultants (from various companies)	No	No headset/3 computers to explore VR environments and avatars

(Guegan, Nelson, et al., 2017); and (b) the contents of the environment influenced the nature of the creative output by priming specific concepts (Guegan et al., 2020; Nelson & Guegan, 2019). In Fleury et al.'s (2020) paper, the question about the impact of contextual cues on creativity is more subtle. The objective of the study was to understand the effect of the perception of movement on divergent creativity by specifically isolating the visual perceptual component of movement through the use of virtual reality, allowing to create impressions of movement in the virtual environment, using the example of a train. Results showed that, empirically, scores for all creativity criteria (originality, fluency, flexibility, elaboration) were higher when the virtual environment was moving than when it was in a static position.

Group Creative Process and Social Context in MUVEs

With regard to virtual social context, two publications (Bourgeois-Bougrine et al., 2020; Fromm et al., 2020) addressed negative group effects during brainstorming sessions in virtual environments. Based on the participants' post-experimental interviews, Fromm and his colleagues (2020) reported a 44% occurrence of production blocking, which is the tendency to produce fewer ideas when group members must take turns expressing their ideas. Other negative group effects rarely occurred (17% for evaluation apprehension, 11% for social comparison, 11% for cognitive inertia, and 0% for social loafing). According to the participants, production blocking was most strongly influenced by VR affordances and constraints, whereas the other effects were more influenced by personality traits or group size.

Finally, a study provided evidence in favor of a combined perspective on the impact of VE on creativity (Bourgeois-Bougrine et al., 2020). Two kinds of effects were observed. First, there was a general effect of virtual reality environments: at the team level, fluency and originality were significantly improved in VE compared to the control situation (e.g., the real environment). Second, there was a modulatory effect based on an individual differences approach, in which the presence of specific personal factors such as risk-taking propensity, divergent thinking, and mental flexibility abilities enhanced the effect of the virtual work environment. The authors hypothesized that in situations of physical isolation, and anonymity of the participants, the virtual environment offered a "freedom-inducing" atmosphere that disinhibited cognitively participants. This kind of study has practical implications for predicting creative performance in virtual settings and optimizing it by taking into consideration the nature of the individuals engaged in creative work within virtual (or non-virtual) environments.

Perception and Acceptability of VR and MUVEs Amongst Professional Creativity Facilitators

Recent studies have investigated how professional creativity facilitators perceive VR technologies and the extent to which they might support their dissemination (Table 4). For example, a study conducted among a group of French-speaking professionals with experience working as creativity and innovation facilitators and consultants (Thornhill-Miller & Dupont 2016) showed little awareness of, and/or openness to, all the creativity-enhancing possibilities that VR-related technologies have to offer. When asked what type of avatar they would optimally select for themselves as facilitators of a creative problem-solving session, responses were also mostly conventional, with only two of them suggesting non-human avatars (e.g., robots or Martians). Within the group that explicitly identified their avatars, most of the participants (75%) chose an avatar of a known or familiar type, for example, enhanced versions of themselves or fictional or real characters of a creative nature, like Leonardo da Vinci.

These results are in line with a more recent study (Buisine & Guegan, 2019) that allowed independent or internal consultants (from various companies) specialized in group facilitation for collaborative creativity sessions to experience teamwork in a virtual environment (avatar manipulation, navigation in the environment, interaction with team members, idea generation and discussion through instant messaging). They were instructed to visit the four target virtual places, explore them, discuss the pros and cons of each environment and imagine what kind of creative session they could conduct there with what kind of customer. The results show that their perception of the potential benefits of virtual environments decreased after the test. They mentioned many limitations of the technology with regard to the usual facilitation process. Moreover, their expert perception of the creative process sometimes appeared contradictory to scientific results obtained in the domain.

However, more positive insight was observed in research conducted by Leovaridis and Bahana (2017). The purpose was to identify the internal and external factors that determined the use of VR as an innovative technology by entrepreneurs belonging to three creative domains: advertising, architecture, and journalism. The results suggest that the "entrepreneurs are approaching the field of virtual reality in order to be prepared for demand when this technology will be required by a wider audience, on a large scale, even if, for the moment, they are the ones influencing the demand through their belonging to the creative industries, having an important role in forming the public opinion" (p. 170).

Conclusion and Perspectives

The conducted review confirms that MUVEs hold the potential to support greater creative performance at individual and collaborative levels as well as enjoyment and fun. European teams have been addressing creativity in VR in diverse domains such as engineering, design, music composition, art-making, etc. Experimental designs have involved the testing of new creative techniques as well as sophisticated VR installations. Most studies assessed creative performance, and some focused on user experience. None of the studies using VR headsets mentioned the eventual dropouts for the sample due to VR-induced symptoms.

In contrast to the previous review (Alahuhta et al., 2014), our paper addressed both individual and team creativity. Moreover, in comparison to the 2014 review, studies in our review used richer multimodal communication and interaction affordances. Indeed, in addition to the usual VR communication channels (e.g., auditory, textual, visual, and graphic), more elaborated media was used, such as (1) head and hand motion trackers to synchronize the avatar and users' real movements in real time, (2) live streaming of a video of a painter into a participant's Oculus screen, in order to create a painting in VR by following the painter's actual movements, (3) virtual sketching, storyboard and prototyping tools, multi-view system, and so forth.

However, as rich and varied as this literature has become, exploring at individual or/and collective levels the relationship between creative performance and virtual environments, also reveals major methodological limitations: (a) population and sample size issues (small samples or ones composed mostly of students); (b) the use of mainly divergent thinking tasks or brainstorming as the only context to measure creativity; (c) the use of rudimentary virtual material (environment and avatar) incapable of dynamic interactions; (d) a static image of an environment; and (e) very limited VR exposure time (10–15 min in general). In our review, the effect sizes reported in the studies can vary according to the dependent variable chosen, as there are many indicators of creative performance (i.e., fluidity, originality, quality, elaboration index, etc.). Moreover, some of the studies presented in this paper evaluated creativity directly ($n = 13$) and others indirectly ($n = 14$ here the dependent variables are theoretically related to creativity). A meta-analysis on the Proteus effect was recently published (Ratan et al., 2020), which reports a small-but-approaching-medium effect size (d = 0.52 based on 37 studies, N = 3,101). Given the diversity of the studies included in our review, in terms of experimental situations and conditions, the dependent variables, and potential moderators, the conclusions drawn about their influence on creative performance should therefore be taken with caution.

It is also worth noting that research exploring the relations between user representations, user behavior, and performance is also still scarce (for a review, see Seinfeld et al., 2020). For instance, there is a need for more ecological simulation of "real place/world or situations" to study creativity in VR. Additionally, usability problems, as well as the occurrence of VR induced symptoms, effects, and after-effects in some situations (e.g., cybersickness and physical ergonomics; see Cobb et al., 1999; Nichols, 1999; Saredakis et al., 2020) has been repeatedly documented and could be potential barriers to VR's efficiency and adoption. Although none of the present reviewed studies in which participants are exposed to VR used standard measures of the after-effect, anecdotal evidence of such potential effects was provided in at least two of these. Vistisen et al. (2019, p.154) reported that "two of the six students experienced major cybersickness [. . .] that hindered their work progress." In the study by Gerry (2017), one participant reported being confused during the perspective-taking task with the VR Headset, which he attributes possibly to the fact he was on the autistic spectrum. Both studies used head-mounted display and motion-based interactions – which is associated with a potentially higher level of immersion. Most other studies are based on the desktop VR configuration with little or no visual motion, which might explain the absence of aftereffects. However, the lack of systematic information on this issue limits the ability to draw any conclusions on their actual prevalence. Additionally, usability problems were reported by the participants in a few studies, mostly in relation to gestures, orientation within a 3D environment, or interaction design (Buisine et al., 2017; Fröhlich et al., 2018; Li et al., 2018; Vistisen et al., 2019). Experiencing these problems was subsequently associated with decreasing interest, satisfaction, and/or performance. Equally important, studies of creativity in VR should address ethical concerns that have been recently pointed out, like the induction of unwanted cognitive, emotional or behavioral changes, the exposure to psychologically harmful experiences, social isolation, or the acquisition of personal data by third parties (see e.g., Slater et al., 2020).

As Thornhill-Miller and Dupont (2016) noted a few years ago, it would seem that the full range of potential contributions that VR has to make to creativity – including those topics further developed by the more recent research reviewed in this article – continue to be underused and underappreciated. Expanding and reformulating the four ways Lubart (2005) argued human-computer interactions, more generally, could assist and promote creativity, they suggest that there are at least five ways that VR can be used to enhance problem-solving and creativity: (a) by altering aspects of the self or self-perception, (b) by enhancing interactions and optimizing collaboration, (c) by optimizing environmental influences or conditions, (d) by facilitating guidance of the process or gamifying aspects of it, and (e) by offering a medium for integrating other creativity-enhancing technologies, like brain stimulation and neurofeedback. Future research can and should continue to be pursued in all of these directions.

References

Alahuhta, P., Nordbäck, E., Sivunen, A., & Surakka, T. (2014). Fostering team creativity in virtual worlds. *Journal for Virtual Worlds Research, 7*(3), 1–24. https://doi.org/10.4101/jvwr.v7i3.7062

Alahuhta, P., Sivunen, A., & Surakka, T. (2016). Virtual worlds supporting collaborative creativity. In Y. Sivan (Ed.), *Handbook on 3D3C Platforms: Progress in IS* (pp. 103–121). Springer. https://doi.org/10.1007/978-3-319-22041-3_4

Bezegová, E., Ledgard, M. A., Molemaker, R. J., Oberč, B. P., & Vigkos, A. (2018). *Virtual reality and its potential for Europe*. Ecorys. https://ec.europa.eu/futurium/en/system/files/ged/vr_ecosystem_eu_report_0.pdf

Bhagwatwar, A., Massey, A., & Dennis, A. R. (2013). Creative virtual environments: Effect of supraliminal priming on team brainstorming. In IEEE (Ed.), *2013 46th Hawaii International Conference on System Sciences* (pp. 215–224). IEEE. https://doi.org/10.1109/HICSS.2013.152

Biasutti, M. (2015). Creativity in virtual spaces: Communication modes employed during collaborative online music composition. *Thinking Skills and Creativity, 17*, 117–129. https://doi.org/10.1016/j.tsc.2015.06.002

Bilyatdinova, A., Karsakov, A., Bezgodov, A., & Dukhanov, A. (2016). Virtual environment for creative and collaborative learning. In S. Kunifuji, G. Papadopoulos, A. Skulimowski, & J. Kacprzyk (Eds.), *Knowledge, information and creativity support systems. Advances in intelligent systems and computing* (Vol. 416, pp. 371–381). Springer. https://doi.org/10.1007/978-3-319-27478-2_26

Bonnardel, N. (2012). Designing future products: What difficulties do designers encounter and how can their creative process be supported? *Work: A Journal of Prevention, Assessment & Rehabilitation, 41*(Suppl 1), 5296–5303. https://doi.org/10.3233/WOR-2012-0020-5296

Bonnardel, N., & Pichot, N. (2020). Enhancing collaborative creativity with virtual dynamic personas. *Applied Ergonomics, 82*, Article 102949. https://doi.org/10.1016/j.apergo.2019.102949

Bonnardel, N., Forens, M., & Lefevre, M. (2016). Enhancing collective creative design: An exploratory study on the influence of static and dynamic personas in a virtual environment. *The Design Journal, 19*(2), 221–235. https://doi.org/10.1080/14606925.2016.1129145

Bourgeois-Bougrine, S., Richard, P., Lubart, T., Burkhardt, J. M., & Frantz, B. (2018). Do virtual environments unleash everyone's creative potential? In S. Bagnara, R. Tartaglia, S. Albolino, T. Alexander, & Y. Fujita (Eds.), *Proceedings of the 20th Congress of the International Ergonomics Association (IEA 2018). Advances in Intelligent Systems and Computing* (Vol. 824, pp. 1–2). Springer. https://doi.org/10.1007/978-3-319-96071-5_134

Bourgeois-Bougrine, S., Buisine, S., Vandendriessche, C., Glaveanu, V., & Lubart, T. (2017). Engineering students' use of creativity and development tools in conceptual product design: What, when and how? *Thinking Skills and Creativity, 24*, 104–117. https://doi.org/10.1016/j.tsc.2017.02.016

Bourgeois-Bougrine, S., Richard, P., Burkhardt, J. M., Frantz, B., & Lubart, T. (2020). The expression of users' creative potential in virtual and real environments: An exploratory study. *Creativity Research Journal, 32*(1), 55–65. https://doi.org/10.1080/10400419.2020.1712162

Brangier, E., Bornet, C., Bastien, J. M. C., Michel, G., & Vivian, R. (2011). Mesure de la capacité des personas à générer des idées dans la conception de projets WEB [Measurement of the ability of personas to generate ideas in the design of WEB projects]. *Le Travail Humain, 75*(2), 121–145.

Brown, V., Tumeo, M., Larey, T. S., & Paulus, P. B. (1998). Modeling cognitive interactions during group brainstorming. *Small Group Research, 29*(4), 495–526. https://doi.org/10.1177/1046496498294005

Buisine, S., & Guegan, J. (2019). Creativity in virtual teams: Bridging the gap between professional wisdom and scientific insights. *Creativity Studies, 12*(2), 198–210. https://doi.org/10.3846/cs.2019.576

Buisine, S., & Guegan, J. (2020). Proteus vs. social identity effects on virtual brainstorming. *Behaviour & Information Technology, 39*(5), 594–606. https://doi.org/10.1080/0144929X.2019.1605408

Buisine, S., Guegan, J., & Vernier, F. (2017). Technological innovation in group creativity. In F. Darbellay, Z. Moody, & T. Lubart (Eds.), *Creativity, design thinking and interdisciplinarity. Creativity in the twenty first century* (pp. 185–201). Springer. https://doi.org/10.1007/978-981-10-7524-7_12

Buisine, S., Guegan, J., Barré, J., Segonds, F., & Aoussat, A. (2016). Using avatars to tailor ideation process to innovation strategy. *Cognition, Technology & Work, 18*(3), 583–594. https://doi.org/10.1007/s10111-016-0378-y

Burkhardt, J. M., & Lubart, T. (2010). Creativity in the age of emerging technology: Some issues and perspectives in 2010. *Creativity and Innovation Management, 19*(2), 160–166. https://doi.org/10.1111/j.1467-8691.2010.00559.x

Callejas, Z., Ravenet, B., Ochs, M., & Pelachaud, C. (2014). A computational model of social attitudes for a virtual recruiter. In A. Lomuscio, P. Scerri, A. Bazzan, & M. Huhns (Eds.), *Proceedings of the International Conference on Autonomous Agents and Multi-agent Systems* (pp. 93–100). International Foundation for Autonomous Agents and Multiagent Systems.

Chang, Y. S., Chou, C. H., Chuang, M. J., Li, W. H., & Tsai, I. F. (2020). Effects of virtual reality on creative design performance and creative experiential learning. *Interactive Learning Environments*, 1–16. https://doi.org/10.1080/10494820.2020.1821717

Clark, O. J. (2020, October 28). *How to kill a Greek God – A review, critique, and meta-analysis of 14 years of Proteus effect research*. https://doi.org/10.31234/osf.io/9rbcs

Cobb, S. V., Nichols, S., Ramsey, A., & Wilson, J. R. (1999). Virtual reality-induced symptoms and effects (VRISE). *Presence: Teleoperators & Virtual Environments, 8*(2), 169–186. https://doi.org/10.1162/105474699566152

Davis, D. Z., & Boellstorff, T. (2016). Compulsive creativity: Virtual worlds, disability, and digital capital. *International Journal of Communication, 10*, 2096–2118.

de Rooij, A., van der Land, S., & van Erp, S. (2017). The creative Proteus Effect: How self-similarity, embodiment, and priming of creative stereotypes with avatars influences creative ideation. In ACM (Ed.), *Proceedings of the 2017 ACM SIGCHI Conference on Creativity and Cognition (C&C '17)* (pp. 232–236). Association for Computing Machinery. https://doi.org/10.1145/3059454.3078856

de Sousa, C. C. (2015). Meta_Body: Virtual corporeality as a shared creative process. In D. Doyle (Ed.), *New opportunities for artistic practice in virtual worlds* (pp. 187–214). IGI Global. https://doi.org/10.4018/978-1-4666-8384-6.ch009

Eustáquio, L., & de Sousa, C. C. (2019). Creative collaborative virtual environments. In M. Khosrow-Pour (Ed.), *Advanced methodologies and technologies in artificial intelligence, computer simulation, and human-computer interaction* (pp. 461–473). IGI Global. https://doi.org/10.4018/978-1-5225-7368-5.ch034

Fleury, S., Agnès, A., Vanukuru, R., Goumillout, E., Delcombel, N., & Richir, S. (2020). Studying the effects of visual movement on creativity. *Thinking Skills and Creativity, 36*, 1–5. https://doi.org/10.1016/j.tsc.2020.100661

Forens, M., Bonnardel, N., & Barbier, M. L. (2015). How communication modalities can impact group creativity in multi-user virtual environments. In ACM (Ed.), *ECCE '15: Proceedings of the European Conference on Cognitive Ergonomics 2015* (pp. 1–4). ACM. https://doi.org/10.1145/2788412.2788439

Fröhlich, T., Alexandrovsky, D., Stabbert, T., Döring, T., & Malaka, R. (2018). VRBox: A virtual reality augmented sandbox for immersive playfulness, creativity and exploration. In CHI (Ed.), *CHI PLAY '18 The Annual Symposium on Computer-Human Interaction in Play* (pp. 153–162). CHI. https://doi.org/10.1145/3242671.3242697

Fromm, J., Mirbabaie, M., & Stieglitz, S. (2020, March). The effects of virtual reality affordances and constraints on negative group effects during brainstorming sessions. In DBLP (Ed.), *15th International Conference on Wirtschaftsinformatik, Potsdam, Germany* (pp. 1172–1187). DBLP.

Gerry, L. J. (2017). Paint with me: Stimulating creativity and empathy while painting with a painter in virtual reality. *IEEE Transactions on Visualization and Computer Graphics, 23*(4), 1418–1426. https://doi.org/10.1109/TVCG.2017.2657239

Goh, C. H., Kulathuramaiyer, N., & Zaman, T. (2017). Riding waves of change: A review of Personas research landscape based on the Three Waves of HCI. In *Proceedings of the International Conference on Social Implications of Computers in Developing Countries* (pp. 605–616). Springer. https://doi.org/10.1007/978-3-319-59111-7_49

Guegan, J., Buisine, S., Mantelet, F., Maranzana, N., & Segonds, F. (2016). Avatar-mediated creativity: When embodying inventors makes engineers more creative. *Computers in Human Behavior, 61*, 165–175. https://doi.org/10.1016/j.chb.2016.03.024

Guegan, J., Brechet, C., & Nelson, J. (2020). Dreamlike and playful virtual environments to inspire children's divergent thinking. *Journal of Media Psychology: Theories, Methods, and Applications*. *33*(1), 28–38. https://doi.org/10.1027/1864-1105/a000279

Guegan, J., Lubart, T., & Collange, J. (2019). (Social) identity and creativity in virtual settings: Review of processes and research agenda. In I. Lebuda & V. Glăveanu (Eds.), *The Palgrave handbook of social creativity research: Palgrave studies in creativity and culture* (pp. 191–207). Palgrave Macmillan. https://doi.org/10.1007/978-3-319-95498-1_13

Guegan, J., Nelson, J., & Lubart, T. (2017). The relationship between contextual cues in virtual environments and creative processes. *Cyberpsychology, Behavior, and Social Networking, 20*(3), 202–206. https://doi.org/10.1089/cyber.2016.0503

Guegan, J., Segonds, F., Barré, J., Maranzana, N., Mantelet, F., & Buisine, S. (2017). Social identity cues to improve creativity and identification in face-to-face and virtual groups. *Computers in Human Behavior, 77*, 140–147. https://doi.org/10.1016/j.chb.2017.08.043

Gül, L. F., & Maher, M. L. (2009). Co-creating external design representations: Comparing face-to-face sketching to designing in virtual environments. *CoDesign International Journal of CoCreation in Design and the Arts, 5*(2), 117–138. https://doi.org/10.1080/15710880902921422

Haslam, S. A. (2004). *Psychology in organizations: The social identity approach*. Sage.

Hong, S. W., El Antably, A., & Kalay, Y. E. (2019). Architectural design creativity in multi-user virtual environment: A comparative analysis between remote collaboration media. *Environment and Planning B: Urban Analytics and City Science, 46*(5), 826–844. https://doi.org/10.1177/2399808317733267

Hong, S. W., Jeong, Y., Kalay, Y. E., Jung, S., & Lee, J. (2016). Enablers and barriers of the multi-user virtual environment for exploratory creativity in architectural design collaboration. *CoDesign, 12*(3), 151–170. https://doi.org/10.1080/15710882.2015.1081239

Hong, S. W., Park, J., & Cho, M. (2019). Virtual vs. actual body: applicability of anthropomorphic avatars to enhance exploratory creativity in architectural design education. *Architectural Science Review, 62*(6), 520–527. https://doi.org/10.1080/00038628.2019.1669526

Hu, R., Wu, Y. Y., & Shieh, C. J. (2016). Effects of virtual reality integrated creative thinking instruction on students' creative thinking abilities. *Eurasia journal of mathematics, science and technology education, 12*(3), 477–486. https://doi.org/10.12973/eurasia.2016.1226a

Kadri, A., Lecuyer, A., Burkhardt, J., & Richir, S. (2007). The visual appearance of user's avatar can influence the manipulation of both real devices and virtual objects. In IEEE (Ed.), *Proceedings of the 3DUI 2007 Symposium on 3D User Interfaces*. IEEE Computer Society. https://doi.org/10.1109/3DUI.2007.340767

Kohler, T., Fueller, J., Stieger, D., & Matzler, K. (2011). Avatar-based innovation: Consequences of the virtual co-creation experience. *Computers in Human Behavior, 27*(1), 160–168. https://doi.org/10.1016/j.chb.2010.07.019

Lau, K. W., & Lee, P. Y. (2015). The use of virtual reality for creating unusual environmental stimulation to motivate students to explore creative ideas. *Interactive Learning Environments, 23*(1), 3–18. https://doi.org/10.1080/10494820.2012.745426

Leonard, A. E., Dsouza, N., Babu, S. V., Daily, S. B., Jörg, S., Waddell, C., Parmar, D., Gundersen, K., Gestring, J., & Boggs, K. (2015). Embodying and programming a constellation of multimodal literacy practices: Computational thinking, creative movement, biology, & virtual environment interactions. *Journal of Language and Literacy Education, 11*(2), 64–93.

Leovaridis, C., & Bahana, M. (2017). Aspects regarding virtual reality as innovation in creative industries. *Revista Romana de Sociologie, 28*(3–4), 157–172.

Li, B., Segonds, F., Mateev, C., Lou, R., & Merienne, F. (2018). Design in context of use: An experiment with a multi-view and multi-representation system for collaborative design. *Computers in Industry, 103*, 28–37. https://doi.org/10.1016/j.compind.2018.09.006

Lomanowska, A. M., & Guitton, M. J. (2014). My avatar is pregnant! Representation of pregnancy, birth, and maternity in a virtual world. *Computers in Human Behavior, 31*, 322–331. https://doi.org/10.1016/j.chb.2013.10.058

Lubart, T. (2005). How can computers be partners in the creative process: Classification and commentary on the Special Issue. *International Journal of Human-Computer Studies, 63*(4–5), 365–369. https://doi.org/10.101/j.ijhcs.2005.04.002

Marinussen, M., & de Rooij, A. (2019). Being yourself to be creative: how self-similar avatars can support the generation of original ideas in virtual environments. In ACM (Ed.), *Proceedings of the 2019 on Creativity and Cognition* (pp. 285–293). ACM.

Men, L., & Bryan-Kinns, N. (2018). LeMo: Supporting collaborative music making in virtual reality. In IEEE (Ed.), *2018 IEEE 4th VR workshop on Sonic Interactions for Virtual Environments (SIVE)* (pp. 1–6). IEEE. https://doi.org/10.1109/SIVE.2018.8577094

Men, L., & Bryan-Kinns, N. (2019). LeMo: Exploring virtual space for collaborative creativity. In ACM (Ed.), *Proceedings of the 2019 on creativity and cognition, C&C '19* (pp. 71–82). ACM. https://doi.org/10.1145/3325480.3325495

Men, L., Bryan-Kinns, N., & Bryce, L. (2019). Designing spaces to support collaborative creativity in shared virtual environments. *PeerJ Computer Science, 5*, Article e229. https://doi.org/10.7717/peerj-cs.229

Nelson, J., & Guegan, J. (2019). "I'd like to be under the sea": Contextual cues in virtual environments influence the orientation of idea generation. *Computers in Human Behavior, 90*, 93–102. https://doi.org/10.1016/j.chb.2018.08.001

Nichols, S. (1999). Physical ergonomics of virtual environment use. *Applied Ergonomics, 30*(1), 79–90. https://doi.org/10.1016/S0003-6870(98)00045-3

Obeid, S., & Demirkan, H. (2020). The influence of virtual reality on design process creativity in basic design studios. *Interactive Learning Environments*. Advance online publication. https://doi.org/10.1080/10494820.2020.1858116

Pruitt, J., & Grudin, J. (2003, June). Personas: Practice and theory. In ACM (Ed.), *Proceedings of the 2003 Conference on Designing for user experiences* (pp. 1–15). ACM.

Ratan, R., Beyea, D., Li, B. J., & Graciano, L. (2020). Avatar characteristics induce users' behavioral conformity with small-to-medium effect sizes: A meta-analysis of the Proteus effect. *Media Psychology, 23*(5), 651–675. https://doi.org/10.1080/15213269.2019.1623698

Reicher, S. D., Spears, R., & Postmes, T. (1995). A social identity model of deindividuation phenomenon. *European Review of Social Psychology, 6*, 161–198. https://doi.org/10.1080/14792779443000049

Saredakis, D., Szpak, A., Birckhead, B., Keage, H. A., Rizzo, A., & Loetscher, T. (2020). Factors associated with virtual reality sickness in head-mounted displays: A systematic review and meta-analysis. *Frontiers in Human Neuroscience, 14*, Article 96. https://doi.org/10.3389/fnhum.2020.00096

Scialabba, G. (1984). Mindplay. *Harvard Magazine, 86*(4), 16–19.

Seinfeld, S., Feuchtner, T., Maselli, A., & Müller, J. (2020). User representations in human-computer interaction. *Human–Computer Interaction, 36*(5–6), 400–438. https://doi.org/10.1080/07370024.2020.1724790

Slater, M., Gonzalez-Liencres, C., Haggard, P., Vinkers, C., Gregory-Clarke, R., Jelley, S., Watson, Z., Breen, G., Schwarz, R., Steptoe, W., Szostak, D., Halan, S., Fox, D., & Silver, J. (2020). The ethics of realism in virtual and augmented reality. *Frontiers in Virtual Reality, 1*, Article 1. https://doi.org/10.3389/frvir.2020.00001

Spears, R., & Lea, M. (1992). Social influence and the influence of the "social" in computer-mediated communication. In M. Lea (Ed.), *Contexts of computer-mediated communication* (pp. 30–65). HarvesterWheatsheaf.

Spears, R., & Lea, M. (1994). Panacea or panopticon? The hidden power in computer-mediated communication. *Communication Research, 21*(4), 427–459. https://doi.org/10.1177/009365094021004001

Tajfel, H., & Turner, J. C. (1979). An integrative theory of intergroup conflict. In W. G. Austin & S. Worchel (Eds.), *The social psychology of intergroup relation* (pp. 33–47). Brooks/Cole.

Tang, Y. M., Au, K. M., & Leung, Y. (2018). Comprehending products with mixed reality: Geometric relationships and creativity. *International Journal of Engineering Business Management, 10*, 1–12. https://doi.org/10.1177/1847979018809599

Tanis, M., & Postmes, T. (2008). Cues to identity in online dyads: Effects of interpersonal versus intragroup perceptions on performance. *Group Dynamics: Theory, Research, and Practice, 12*(2), 96–111. https://doi.org/10.1037/1089-2699.12.2.96

Thornhill-Miller, B., & Dupont, J. M. (2016). Virtual reality and the enhancement of creativity and innovation: Under recognized potential among converging technologies? *Journal of Cognitive Education and Psychology, 15*(1), 102–121. https://doi.org/10.1891/1945-8959.15.1.102

Uribe Larach, D., & Cabra, J. F. (2010). Creative problem solving in second life: An action research study. *Creativity and Innovation Management, 19*(2), 167–179. https://doi.org/10.1111/j.1467-8691.2010.00550.x

Valkenburg, R., & Dorst, K. (1998). The reflective practice of design teams. *Design Studies, 19*(3), 249–271. https://doi.org/10.1016/S0142-694X(98)00011-8

Vistisen, P., Luciani, D. T., & Ekströmer, P. (2019). Sketching immersive information spaces: Lessons learned from experiments in "sketching for and through virtual reality". In N. Steinø & M. Kraus (Eds.), *7th eCAADe Regional International Symposium: Virtually Real* (pp. 25–36). Aalborg University.

Ward, T. B. (2015). Content, collaboration, and creativity in virtual worlds. In G. P. Green & J. C. Kaufman (Eds.), *Video games and creativity* (pp. 119–136). Academic Press. https://doi.org/10.1016/B978-0-12-801462-2.00006-0

Ward, T. B., & Sonneborn, M. S. (2011). Creative expression in virtual worlds: Imitation, imagination, and individualized collaboration. *Psychology of Popular Media Culture, 1*(S), 32–47. https://doi.org/10.1037/2160-4134.1.S.32

Yang, X., Lin, L., Cheng, P. Y., Yang, X., & Ren, Y. (2019). Which EEG feedback works better for creativity performance in immersive virtual reality: The reminder or encouraging feedback? *Computers in Human Behavior, 99*, 345–351. https://doi.org/10.1016/j.chb.2019.06.002

Yang, X., Lin, L., Cheng, P. Y., Yang, X., Ren, Y., & Huang, Y. M. (2018). Examining creativity through a virtual reality support system. *Educational Technology Research and Development, 66*(5), 1231–1254. https://doi.org/10.1007/s11423-018-9604-z

Yee, N., & Bailenson, J. (2007). The Proteus effect: The effect of transformed self-representation on behavior. *Human Communication Research, 33*, 271–290. https://doi.org/10.1111/j.1468-2958.2007.00299

Yee, N., & Bailenson, J. (2009). The difference between being and seeing: the relative contribution of self-perception and priming to behavioral changes via digital self-representation. *Media Psychology*, 12(2), 195-209. https://doi.org/10.1080/15213260902849943

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