A systematic review of virtual brainstorming from the perspective of creativity: affordances, framework, and outlook

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ABSTRACT
This study explores virtual reality (VR) as an emerging tool integrated into brainstorming activities to enhance creativity, and systematically reviews existing studies to provide an advanced literature review on this subject. Moreover, we propose a framework for enhancing creativity in virtual brainstorming (VB) based on the 4Ps (person, process, product, and press) of creativity, which provides guidance on leveraging VB to enhance creativity. Furthermore, eight affordances of VB are identified to enhance creativity: anonymity, appraisal, avatars, immersion, multiple communication, recording, simulated objects, and tracing. The potential perspectives of VB to enhance creativity based on this study’s framework are also explored, which deserves further investigation.

KEYWORDS
Virtual reality; virtual brainstorming; creativity method; 4Ps model of creativity; systematic review

1. Introduction
The creative process can be mediated by digital media and technologies (Jiménez-Narváez and Gardoni 2014; Li 2021; Núñez-Pacheco and Loke 2020), and technologies such as virtual reality (VR) have been increasing adopted for problem-solving and idea generation (Jin and Lee 2019; Yang and Lee 2020). These technologies have the potential to contribute towards better outcomes based on the changes in the creative process and its context (Jin and Lee 2019), by targeting commonly used idea generation methods, such as brainstorming. However, the connection between VR, brainstorming, and creativity is yet to be systematically examined.

To address this issue, we analyzed recent studies on the creative process and VR, and conducted a systematic literature review to classify and summarize these studies, based on the 4Ps (person, process, press, and product) model of creativity (Rhodes 1961). The 4Ps model of creativity was chosen because of its ability to guide researchers exploring creativity in any research field (Gruszka and Tang 2017). Accordingly, we propose a framework for virtual brainstorming (VB) to enhance creativity based on the 4Ps. VB serves to enrich the fundamental creative process associated with brainstorming, and this survey maps the process with VR as an emerging media form.

From the existing literature, we identified VB affordances that have the potential to enhance creativity. However, the relationship between VR, brainstorming, and creativity is complicated and undefined. Therefore, this
study not only aimed to explain these related terms, but also to help VR engineering and creativity practitioners understand the implicit relationships VR and brainstorming. The potential of VB to facilitate creativity in the current emerging VR era is also discussed. In the rest of this section, we discuss the evolving status of creativity and explain related terms related to brainstorming, and VR.

1.1. 4Ps of creativity

Creativity drives the advancements of human civilization and is closely related to individuals’ social, education, work, and daily lives (Sternberg 1999). Researchers have provided different answers to the question ‘what is creativity?’ by describing it as an aspect of intelligence (Freeman 1939), an unconscious process (Poincaré 2010), an element of problem-solving (Mansfield and Busse 1981), and an associative process (Spearman 1931). The concept of creativity can be traced back to two centuries ago, and it took 150 years of debate and research to differentiate it from the concepts of imagination, originality, genius, and talent (Sternberg 1999). Subsequently, studies on creativity thrived and have continued in recent decades. Although there are many definitions of creativity depending on the context and research domain, this study uses the below definition.

‘The word creativity is a noun naming the phenomenon in which a person communicates a new concept (which is the product). Mental activity (or mental process) is implicit in the definition, and of course, no one could conceive of a person living or operating in a vacuum, so the term press is also implicit.’ (Rhodes 1961, 305).

Person, process, and product interact with others surrounded by press, which means press could influence the person (Gu, Tang, and Jiang 2015; Specht 2017), process (Amabile 2011; Gong and Georgiev 2020), and product (Kim and Choi 2017). Furthermore, there has been significant research exploring methods that empower individuals to become more creative and/or generate more creative outputs, such as Georgiev, Sánchez Milara, and Ferreira (2017).

1.1.1. Person

The term ‘person’ ‘covers information about personality, intellect, temperament, physique, traits, habits, attitudes, self-concept, value systems, defense mechanisms, and behavior’ (Rhodes 1961, 307). On the one hand, various personalities and traits can make a person more creative in a process and generate more creative products than an individual without them (Bourgeois-Bougrine et al. 2018). For example, a decisive, demanding, and ambitious person is more active in ideation than a person without those traits (Puccio and Grivas 2009). On the other hand, some traits hinder creativity; for example, steadiness tends to maintain the status quo instead of breaking the existing rules and norms, resulting in lower creative performance in the process (Puccio and Grivas 2009). In addition, Zhang et al. investigated the influence of personal traits in sustainable organizational creativity, revealing that self-interested behaviour negatively affects creative performance. By contrast, personal trait regulatory focus has a positive effect on creativity (Zhang et al. 2019).

1.1.2. Process

The term ‘process’ applies to motivation, thinking, learning, and communication, regardless of the individual(s) and organization(s) (Rhodes 1961). There are four stages for constructing a new thought and idea: preparation, incubation, inspiration, and verification (Wallass 1926). These four stages are interconnected and overlap, and can be (re-)shuttled in any order or may even randomly recur until the outcome of creativity has been achieved effectively (Rhodes 1961). It is important to note that numerous researchers have discovered various processes for enhancing creativity. Brainstorming, however, is a commonly used idea generation technique (Carayannis 2020).
proposed by Osborn (Osborn 2012) to enhance creativity. The brainstorming process encourages individuals to produce a wide range of creative ideas without any critical evaluation in the initial stage, which is thought to prevent vague but potentially good ideas from being screened out at the very beginning.

1.1.3. Press
The term ‘press’ is described as the external sources and environment interacting with and influencing persons. When a person generates ideas, he or she needs to analyze the question, think about the possible solution, recall memory, and synthesize ideas. The process is relevant to his or her experiences, mentality, and value systems, which are influenced by internal and external sources (Rhodes 1961). Press can affect individuals’ behaviour and creativity (Arabyan and Vedelago 2017; Guegan et al. 2017). For example, the social-organizational work environment and the physical work environment positively affect creative performance (Dul, Ceylan, and Jaspers 2011). Other researchers have evaluated the physical environment (such as the internal organization of objects) that leads to high creative potential (McCoy and Evans 2002).

1.1.4. Product
The term ‘product’ means ‘an idea becomes embodied into the tangible form’ (Rhodes 1961, 309), which can be a sketch, a painting, or other physical objects (Rhodes 1961). Products can be seen as a result of creativity, and play a superior role in creativity: when a product is said to be creative, the related person, process, and press might be considered creative (Gruszka and Tang 2017). Therefore, researchers have explored various criteria to evaluate and measure products, including novelty, usefulness (Sternberg 1999), and originality (Simonton 1980). The consensual assessment technique, proposed by Amabile in 1982, has been frequently employed in product evaluation, with its prominent feature of judgment in real life (Amabile 2011). The technique involves two domain experts who independently evaluate the creativity level of each product, ranging from ‘not-at-all creative’ to ‘very creative’.

1.2. Virtual reality (VR)
VR refers to a wide range of computing technologies that allow humans to experience things in a virtual world through different senses (Burdea and Coiffet 2003; Gong and Georgiev 2020; Ryan 2015; Steuer 1992). VR enables users to experience a sense of feeling in a virtual environment (VE), usually referring to a computer-generated simulation of a real-world physical environment. A typical VR system consists of a computer-generated three-dimensional (3D) environment that allows users to immerse themselves in a virtual world and input systems that aid interaction with the virtual objects in the VE. Initially, VR was defined as a medium driven by technological hardware, such as computers, head-mounted displays, headphones, and motion-sensing gloves. However, researchers have queried defining VR as a medium (Burdea and Coiffet 2003), and some have suggested that the features of VR are not limited to its interactivity and immersive environment. Rather, it should include the imagination relevant to real-life problem-solving in various domains. It also refers to the mind’s capacity to perceive non-existent things (Burdea and Coiffet 2003). As a result, a universal concept has been accepted: ‘VR is a high-end user interface that involves real-time simulation and interaction through multiple sensorial channels, such as vision, sound, touch, smell, and taste’ (Burdea and Coiffet 2003, 39).

Research into VR technology has continuously expanded in various industries and applications, such as psychological and neurological rehabilitation (Alex, Wünsche, and Lottridge 2021; Georgiev et al. 2021; Georgieva and Georgiev 2019, 2020), education (Berni and Bortolotti 2020; Li 2021; Luusua, Ylipulli, and...
Pouke 2019), and entertainment (Kivelä et al. 2019). VR has undergone major improvements and has gradually become a new independent field of science and technology, and advances in display technology and computational power have made consumer VR possible. As a result, numerous researchers have attempted to discover creative methods by applying VR (Georgieva and Georgiev 2019, 2020; Hu, Georgiev, and Casakin 2020; Thornhill-Miller and Dupont 2016).

To unleash the potential of VR and address some uncertainties related to creativity, existing studies have integrated VR into brainstorming to enhance creativity. The disciplines of education, psychology, and engineering were early adopters of VR in creativity, and there are many benefits arising from incorporating VR into brainstorming, which have been identified (Gong et al. 2021). For example, choosing specific avatars to represent inventors among participants could encourage significant contribution and creative performance (Guegan et al. 2016). A few terms are discussed below to understand VR and related content better.

1.2.1. Virtual environment (VE)
VE refers to a computer-generated display that allows or compels the user(s) to have a sense of presence and interact with an environment, other than their actual one (Schroeder 2008). This definition can perhaps be easily understood by thinking of VE as a 3D environment generated by computers, enabling individuals represented by avatars to have a sense of presence and interact with others and/or the 3D environment. A VE can simulate physical and highly customized environments with 3D objects (Berni and Borgianni 2020; Huang, Hwang, and Chang 2020; Neroni, Oti, and Crilly 2021). This ability of VE could achieve priming, which refers to a phenomenon in which exposure to one stimulus influences an individual’s subsequent cognition or behaviours, without conscious guidance or intention (Bhagwatwar, Massey, and Dennis 2013; Guegan et al. 2016; Pouke et al. 2021).

1.2.2. Avatar
An avatar is a digital representation, such as a graphical instance or 3D body, controlled by individuals in the real world instead of a simple label or name. Avatars have the ability to perform actions and interact with others and/or the VE (Bell 2008). Many avatar factors can influence individuals’ behaviours and cognitions in a VE, such as the Proteus effect, presence, and social identification (Guegan et al. 2016; Sanchez-Vives and Slater 2005; Slater 2018).

1.2.3. Immersion
Immersion is reflected at a subjective level in the sense of presence, which is defined as the objective technical properties of the system (Slater 2003). As the system provides more displays and precise tracking to maintain fidelity, the user has a more ‘immersive’ feeling. An immersive VR system allows the immersed individual to perceive a given environment through natural sensorimotor contingencies (for example, turning 360° while seeing a continuous update of the visual field in correspondence with the gaze direction; seeing a virtual body substituting one’s own, and providing motor and tactile synchronous feedback) (Slater 2018; Slater and Sanchez-Vives 2016). However, it is important to note that, before the arrival of such highly immersive systems, the desktop VR could also serve a similar purpose with a lower immersion (Slater 2018).

1.3. Virtual brainstorming (VB)
VB is a widely discussed term in recent years. Although various dimensions have been studied, such as investigating the brainstorming in virtual collaborative environments, the definition of VB was not identified during the systematic review included in this study. Without a clear definition of VB, its meaning is
unclear. Does VB refer to the virtual teams that perform brainstorming? Or is it brainstorming performed in a virtual world? Therefore, in this study, VB is defined as a virtual environment that facilitates the brainstorming process (that is, primarily the brainstorming task(s)) and synchronizes the participants and 3D digital entities in VEs, in which avatars represent brainstorming participants who follow the adapted brainstorming rules to produce as many rudimentary ideas as possible, without systematic evaluations or critiques from others (the brainstorming rules refer to (Osborn 2012)). This means the literature review includes immersive VB and non-immersive VB, as long as it contains the three necessary elements: avatars (individuals represented), VEs (3D environments), and brainstorming. VB is included in electronic brainstorming but differs from electronic brainstorming. Electronic brainstorming refers to ‘the use of computer technology to facilitate the entry and automatic dissemination of ideas in real-time to all members of a group, each of whom may be stimulated to generate other ideas’ (Cooper, Galuppe, and Bastianutti 1990, 237).

1.4. Affordances

Affordance is a controversial term, as it emphasizes the relationship between the design and the user, instead of certain properties belonging to a design (Norman ). It is challenging to define and clarify the term ‘affordance’; nevertheless, Norman defined affordance as ‘the relationship between a physical object and a person (or for that matter, any interacting agent, whether animal or human or even machines and robots)’ (Norman 2013, 11). Moreover, ‘affordances are the possible interactions between people and the environment. Some affordances are perceivable, others are not’ (Norman 2013, 19). Other researchers defined the concept as ‘cues of the potential uses of an artifact by an agent in a given environment’ (Burlamaqui and Dong 2015, 305). This study narrows the scope of affordances to the interactions between individuals and the property or quality of VR that defines possible uses in brainstorming by individuals in such VEs for creativity enhancement.

2. Methods

In general, systematic reviews focus on a particular topic and provide theoretical knowledge for relevant research, discuss the current status of knowledge in a specific topic, represent research findings, and provide directions for future work (Moher et al. 2009, 2011). Following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher et al. 2009, 2011), the researchers first identified the study’s purpose, and accordingly performed searching and screening related work.

2.1. Research question and goal

The use of VB to aid creativity enhancement is still an emerging field of research; therefore, it is worth trying to understand how VB enhances creativity, and possible future research directions for VB-related studies. The most relevant works on employing VB for creativity enhancement follow. Several studies designed VEs that recruited participants to brainstorm within VEs and compared their outputs, which could guide researchers to design and develop more creative VEs and enhance participants’ creativity (Bhagwatwar, Massey, and Dennis 2013, 2018; Minas, Dennis, and Massey 2016). Moreover, other researchers integrated VR into an application to support brainstorming, which could avoid the negative effects of traditional brainstorming or electronic brainstorming, enhancing individuals’ creativity (Kut’ák et al. 2019; Petrykowski et al. 2018). Furthermore, researchers demonstrated that designing appropriate avatars in VB could contribute to creative outputs (Bonnardel and Pichot 2020; Guegan et al. 2016). Although researchers continue to explore
employing VR in brainstorming for creativity enhancement, they have so far focused on a specific, different aspect (e.g. avatars, applications, or VEs). Further systematic and comprehensive consideration is needed to help researchers who already have an overall understanding of VR adoption in brainstorming. Further understanding of VB affordances will help understand its properties and define its possible uses.

To the best of our knowledge, no prior study has conducted a systematic review to address the role of VB in enhancing creativity. This survey is the first to attempt a systematic review to collect relevant references and summarize VB affordances that enhance creativity. Therefore, this study synthesizes the most relevant prior research and addresses the following question: What are the affordances of VB for the enhancement of creativity?

This systematic review frames existing VB work under the 4Ps model of creativity model (Rhodes 1961). According to this model, VB is a new direction that could simulate the press, modify the process, and inspire a person to generate a creative product. This systematic review summarizes our understanding of VB for the enhancement of creativity. Accordingly, we proposed VB affordances to enhance creativity and discussed the potential directions for future research.

2.2. Search strategies and techniques

During the literature searching and screening stage, we constructed keywords related to VB affordances to enhance creativity. These keywords included searching for ‘virtual reality’ and ‘brainstorming’ in article titles and abstracts in academic research databases, including Scopus, Web of Science, EBSCO database, IEEE Xplore, and ACM Digital Library in October 2021. Total 390 papers were found during the material collection phase; that is 156 papers in Scopus, 113 articles in Web of Science, 89 papers in the EBSCO database, 16 papers in IEEE Xplore, and 16 papers in the ACM Digital Library. Overlapping articles (n = 152) were excluded, resulting in 238 unique articles being identified.

Next, we applied the following inclusion and exclusion criteria. Papers that met the following conditions were included: (1) The full text of the article should be available in English; (2) The article should be published in a journal, conference, or chapter of an e-book; (3) The article should provide evidence (e.g. user study) that a brainstorming task was conducted in VR; (4) The results discussed in the article should be related to creativity. In other words, papers that met one of the following conditions were excluded: (1) Articles were not written in English; (2) Articles in the form of abstract, tutorials, posters, or presentation; (3) Articles that did not use VR in the brainstorming task; (4) Articles with results are not related to creativity.

After reviewing the articles, 223 papers were excluded. Among these, some were not published in English (n = 5), others were published as a poster or abstract (n = 4), some did not use VR in a brainstorming task (n = 193), and other results were not related to creativity (n = 99). Some articles met more than one exclusion criterion. For example, a study’s result was not related to creativity, and VR was not used in brainstorming (Descotes et al. 2020). Eventually, 15 articles were identified for the systematic review, and agreed to by all the co-authors. The collection of articles was also extended by retrieving relevant citations from the original articles and searching for related papers via www.connectedpapers.com; subsequently, one paper was then added to the list. Thus, 16 articles were included in the systematic review, as illustrated in Figure 1.

3. Descriptive results summary of included studies

This research is relatively newfound; the literature search resulted in a list of 16 articles, with
the oldest one having been published in 2013 (Bhagwatwar, Massey, and Dennis 2013). The year that saw the highest number of published articles is 2020 (n = 6). *The Computers in Human Behavior Journal* and *The Hawaii International Conference on System Sciences* both provided the highest number of articles (n = 2) regarding publications and conferences. The number of papers, conferences, and journals was equally divided (n = 8).

VB for creativity enhancement has received attention from researchers as far afield as Czechia, France, the United States, Japan, and Germany. Researchers from France appear to be the most active in this field; their research is associated with other disciplines, such as psychology, information, communication, and design. The number of participants across the studies ranged from six to more than 100, as shown in the second column of Table 1. Most studies employed students as participants (n = 11).

In terms of procedure, researchers conducted the brainstorming task based on the Osborn or/and Paulus principle (n = 6) (Osborn 2012; Paulus, Kohn, and Arditti 2011); other researchers did not state the principle used (n = 10) or/and procedure (n = 4). Problems that need to be solved by brainstorming were found to be different based on participants’ backgrounds. For example, when participants were from an engineering background, their task was to ‘imagine a silent flying public transportation for the future’ (Buisine and Guegan 2020, 6). Participants from a business school course were tasked with increasing tourism and reducing pollution (Bhagwatwar, Massey, and Dennis 2018). Although the task topic was closely related to the participants’ academic major, they did not mention it more precisely, and the task selection process in several studies is unknown (e.g. Buisine and Guegan 2020). Moreover, when participants were mixed samples or their specific backgrounds were not mentioned, the tasks were more general, such as reducing traffic jams (Bonnardel and Pichot 2020), and the best place to go to or activity to do on a Friday night (Kut’áč et al. 2019).

### 3.1. Research theory

Many theories have been propounded to investigate the effects of VB for creativity enhancement. Our analysis found that more than 20 different theoretical lenses were used in the existing research, which often related to the researchers’ fields. Nerveless, theoretical frames related to cognitive behaviours were most frequent; it is necessary, however, to explain the most frequently used terms as follows.

#### 3.1.1. Proteus effect

The Proteus effect, introduced by Yee and Bailenson, explains that individuals’ behaviours and attitudes can be affected by their self-representation in a VE (Yee and Bailenson 2007). Based on the self-perception theory,
| Author                          | Subjects | Research Questions                                                                                                                                                                                                                                                                                                                                 | Metrics                                      |
|--------------------------------|----------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------|
| Bhagwatwar, Massey, and Dennis (2013) | n = 80 Mean = 19.1 62% male | Does individual exposure to visual creativity priming in the VE improve the idea generation performance of a virtual team collaborating on an idea generation task?                                                                                                                      | Team-level idea generation performance       |
| Forens, Bonnardel, and Barbier (2015) | n = 66 Mean = 19.4 SD = 1.6 62% male | Is written communication or oral communication the most appropriate in virtual environments?                                                                                          | Number of unique ideas Average statistical originality of unique ideas |
| Bonnardel, Forens, and Lefevre (2016) | n = 33 | What is the influence of static versus dynamic personas on collective creative design?                                                                                                                                                                                                                                                                      | Empathy Fluency and originality of the ideas Quality of collaboration Manipulation checks Subjective variables Creative performance |
| Guegan et al. (2016) | n = 54 Mean = 23.4 SD = 2.7 83% male | How can avatars be a medium for stimulating creativity?                                                                                                                                                                                                                                                | -                                            |
| Minas, Dennis, and Massey (2016) | n = 140 Mean = 19.8 SD = 1.78 54% male | Does the design of a 3D virtual environment be used to deliberately influence the scope of attention during electronic brainstorming (EBS) and thus increase team creativity?                                                                 | Idea generation performance                  |
| Guegan et al. (2017) | n = 72 Mean = 22.7 SD = 1.9 54% male | Does performance increase when SIC are present?                                                                                                                                  | Creative performance Social identification   |
| Bhagwatwar, Massey, and Dennis (2018) | n = 168 Mean = 19.8 58% male n = 80 Mean = 19.1 62% male | Does priming during task execution using 3D objects in the VE improve brainstorming performance?                                                                                                                              | Performance                                   |
| Petrykowski et al. (2018) | n = 17 | Do participants perform better for specific Design Thinking tasks within the virtual reality in comparison to today’s digital whiteboards, although these are supported by personal interactions like video conferencing? | Number of created ideas Time needed Amount of repeated information Creative potential Creative performance |
| Bourgeois-Bougrine et al. (2018) | n = 60 15% male | Do virtual environments unleash everyone’s creativity, whatever their creative potential profile? Which combination of creative resources favours fluency in a brainstorming task? Which type of creative resources facilitate the production of original ideas? | Usability of system features                |
| Kuták et al. (2019) | n = 32 AR = 18-33 59% male | Does the multi-modal virtual reality mind map have the potential to transform the ways in which people interact, communicate, and share information?                                                                                                                                                  | -                                            |
| Bourgeois-Bougrine et al. (2020) | n = 60 Mean = 22 SD = 2.1 59% male | Does Multi-User Virtual Environments improve everyone’s creativity? Which type of creative resources facilitate fluency in a brainstorming task and the production of original ideas?                                                                                                          | Creative performance Creative potential       |
| Bonnardel and Pichot (2020) | n = 102 AR = 17–29 | Does the use of a dynamic persona allow participants to generate more ideas? Does the use of a dynamic persona allow participants to produce more original ideas? Does using a dynamic persona lead to a higher quality of creativity?                                                                 | Creativity Reactive empathy Quality of collaboration |
| Author                  | Subjects | Research Questions                                                                 | Metrics                                 |
|------------------------|----------|-------------------------------------------------------------------------------------|-----------------------------------------|
| Buisine and Guegan (2020) | n = 72   | Do participants interacting with a dynamic persona display more empathy?             | Control measure                        |
|                        | Mean = 23.6 | Can the use of a dynamic persona lead to a higher quality of collaboration score? | Creative identity of avatars            |
|                        | SD = 2.99 |                                                                                     | Creativity                             |
|                        |          | Do creative avatars increase participants' creative performance?                     |                                        |
|                        |          | Can proteus effect on avatars be mediated by the perception of the creative identity of avatars? | Mental workload                        |
|                        |          | Can previous exposure to creative avatars increase creativity in a subsequent session? | Work environment satisfaction          |
|                        |          | Does displaying social identity cues on avatars increase performance?                | Collaboration effectiveness            |
|                        |          | Will social identity cues on avatars be mediated by social identification?           | Communication efficiency               |
|                        |          | Does previous exposure to social identity cues increase performance in a subsequent session? | Number of created ideas                |
| Morales, Yamamoto, and Tsujino (2020) | n = 6 | Does working inside an immersive environment improve the users’ collaboration, creative skills, and communication? | Total utterance duration, frequency, and balance of participation |
|                        |          |                                                                                     | Usage count of symbolic gestures       |
| Ide et al. (2020)       | n = 18   | Will the use of symbolic gestures through avatars for expressing the participants’ behaviour and sentiments in Virtual brainstorming be effective? | Questionnaires for participants’ subjective |
|                        | AR = 21–26 |                                                                                     | Load of information divergence        |
| Hwang et al. (2020)     | n = 8    | Is the simple experience of the environment and avatars being rendered in a non-photorealistic manner sufficient to affect participants’ idea generation? | Count of node                          |
|                        |          |                                                                                     | Count of link                          |
|                        |          |                                                                                     | Logic with self                        |
|                        |          |                                                                                     | Logic with partner                     |
|                        |          |                                                                                     | Rarity of node                         |
|                        |          |                                                                                     | Rarity of link                         |
|                        |          |                                                                                     | Creativity scores                      |

AR: age range; SD: standard deviation.
individuals can infer their behaviours, attitudes, and emotions from their own behaviours and/or behaviours occurring in some circumstances (Bem 1972). Studies have confirmed that the Proteus effect could affect participants’ behaviours and attitudes in a VE (Buisine and Guegan 2020; Guegan et al. 2016; Slater 2018; Yee and Bailenson 2007). For example, individuals with attractive avatars have resulted in intimate self-disclosure and interpersonal distance (Waddell and Ivory 2015; Yee and Bailenson 2007). Moreover, engineering students with inventor avatars have felt more creative and delivered a higher creative performance in the dimensions of fluency and originality (Guegan et al. 2016).

3.1.2. Presence
Presence is an individual’s sense of ‘being there’ in an environment. Although individuals are not physically present in a VE, they have feelings of ‘being there’ (Slater 2018), and this feeling is referred to as ‘presence’. The level of presence depends on the devices – when a device can provide higher sensorimotor contingencies, the sense of presence and the level of immersion is higher (Slater 2018; Slater and Sanchez-Vives 2016). As a result, participants’ behaviour in VR is similar to that in a real environment (RE) (Sanchez-Vives and Slater 2005). For example, Kut’âk et al. designed a virtual mind map to communicate, interact, and share information in ideation and recruited subjects to test the system. The participants expressed their opinions in an immersive environment, which enabled them to communicate with others in telepresence without distractions (Kut’âk et al. 2019), leading to significantly positive effects on creativity.

3.1.3. Social identity
Social identity is the identity that varies along with continuity, involving interpersonal and intergroup behaviour(s). This identity is regarded as the common characteristics shared by group members, distinguishing them from other groups (Guegan et al. 2017). Social identity leads to individual behaviours that rely on the group’s characteristics, rather than their individual characteristics (Hatch and Schultz 2004), which means the influential power of social identity could outweigh individual behaviours (Buisine and Guegan 2020; Guegan et al. 2017). A study employed participants from a university to participate in a brainstorming session using avatars wearing traditional university suits. The study drew on the relationship between creativity and social solid identity among students. The results indicated that social identity was higher in VR groups, which led to higher scores of creativity performances than groups without social identity (Guegan et al. 2017).

3.1.4. Priming
The priming theory was proposed by Ratcliff and McKoon and is designated for accounting for the phenomena usually attributed to the spreading activation process. The theory assumes that ‘a prime and target are combined at retrieval into a compound cue that is used to access memory’ (Ratcliff and McKoon 1988, 385). Moreover, priming is a phenomenon in which exposure to one’s stimulus influences cognition or behaviours without conscious guidance or intention (Bhagwatwar, Massey, and Dennis 2013; Guegan et al. 2016). Therefore, researchers designed VEs to boost the participants’ cognition during brainstorming, such as specific plants in VE, or the open room with no roof and walls. Such VEs could enhance creative performance based on the priming theory (Bhagwatwar, Massey, and Dennis 2013; Minas, Dennis, and Massey 2016).

3.2. Devices in the research
Five studies were applied VR devices, such as HTC Vive (Hwang et al. 2020; Ide et al. 2020; Kut’âk et al. 2019; Morales, Yamamoto, and Tsujino 2020; Petrykowski et al. 2018). One
article did not provide device information; however, the applied VR headsets were deduced from the figure shown in the article (Hwang et al. 2020). Only one article included more detailed information, stating that ‘an HMD (HTC Vive), a base station, a Leap Motion controller for hand gesture, and a computer’ were used (Morales, Yamamoto, and Tsujino 2020, 521). Most studies (n = 9) described participants as being set up in separate rooms or spaces and provided with a computer (Bhagwatwar, Massey, and Dennis 2013; Bonnardel, Forens, and Lefevre 2016; Bonnardel and Pichot 2020; Bourgeois-Bougrine et al. 2018, 2020; Buisine and Guegan 2020; Guegan et al. 2016, 2017; Minas, Dennis, and Massey 2016). In the remaining two articles, one mentioned that participants used headsets (Bhagwatwar, Massey, and Dennis 2018), and the other depicted participants as seated in separate spaces (Forens, Bonnardel, and Barbier 2015). Therefore, it was inferred that the participants had been supplied with computers without VR devices. This implies that VEs in most studies are without highly immersive hardware. An additional advantage of using VR devices to increase the immersion and presence of a task is that it reduces the restriction of sitting in front of a computer screen and using a mouse, keyboard, or joystick (Neroni, Oti, and Crilly 2021). Without these VR devices, the computer cannot have an adaptive sense to change the view of the immersive space to match the user’s head and hand postures. As a result, the sense of immersion could be reduced (Burdea and Coiffet 2003; Slater 2018).

### 3.3. Research questions and measures

Although the papers selected for this study reported their work under different domains, their research questions focused on the metrics that impact VB effectiveness, as shown in the third column in Table 1. Additionally, a commonality between their systems was identified: they had focused on helping individuals achieve effective interaction, communication, and collaboration during VB. For example, some authors focused on the relationship between creative potentials and VB by accounting for the generated ideas (Bourgeois-Bougrine et al. 2020). Guegan’s team explored the influence of avatars’ appearance in creative performance during brainstorming tasks (Guegan et al. 2016, 2017). Other researchers designed systems and conducted brainstorming sessions to evaluate their VR systems (Kut’ák et al. 2019; Petrykowski et al. 2018). Moreover, researchers working on communication methods examined the effectiveness of symbolic gestures through avatars in expressing participants’ behaviour and sentiments (Ide et al. 2020). A similar study examined collaboration, creative skills, and communication when creating manga (Morales, Yamamoto, and Tsujino 2020).

From a measurement perspective, all the studies measured creativity or other factors related to creativity (the last column in Table 1). More than half of them adopted combined creative performance and other factors to assess creativity and the relationship between creativity and those factors (n = 13). In terms of creativity, ten studies measured the performance by two raters (experts in the related field) from different dimensions, such as novelty, originality, and idea uniqueness (as cited from the original studies); three other studies only measured the creativity by having their authors count the total number of ideas generated (Bonnardel, Forens, and Lefevre 2016; Ide et al. 2020; Petrykowski et al. 2018). Other factors combined in measurements depended on their research aims, such as empathy and the quality of collaboration (Bonnardel, Forens, and Lefevre 2016). Generated ideas and creative performance indicate a directly proportional relationship to enhanced creativity (Guegan et al. 2016). By contrast, some researchers attempted to measure factors that might indirectly enhance creativity, including the usability of system features (Kut’ák et al. 2019).
work environment satisfaction (Morales, Yamamoto, and Tsujino 2020), the influence of the VE on participants’ creative processes and products, by examining divergence, information load, and more (Hwang et al. 2020).

4. Virtual brainstorming for creative enhancement, based on the 4Ps of creativity

This study identified researchers who focused on creativity enhancement via VB and analyzed why these existing theories could enhance creativity in the previous section. This section also summarizes how (the reasons) and what (specific factors) causes creativity enhancement in VB. Thus, a framework for using VB to enhance creativity, according to the 4Ps of creativity, is first proposed, explaining why VB can be used to enhance creativity. While researchers have conducted experiments to verify their hypotheses, depending on their research background; it is necessary to explore the main reasons from the perspective of creativity. Moreover, the reviewed papers were divided (the original studies’ features, objectives, and conclusions are fundamental for our classification) to explain the VB factors that can lead to the enhancement of creativity, and propose VB affordances, based on this proposed framework.

This section is divided into three categories: 1) a framework for using VB to enhance creativity, based on the 4Ps of creativity, 2) how VB can support the process of enhancing creativity, and 3) how VB can support the press to enhance creativity.

4.1. VB framework for enhancing creativity based on the 4Ps of creativity

The concepts of VB, creativity, and the 4Ps of creativity were elaborated in the introduction. We also explained the relationship between VB and the 4Ps of creativity simply and understandably in the following. The person is the fundamental component who interacts with the personal process (i.e. personal thinking process) and the product under the personal press (i.e. individuals’ surrounding environments that affect how people formulate their ideas and behaviours). Figure 2 (left-hand side) uses a small circle to depict the relationship between the four fundamental factors, personal press with a dark green background surrounding the person, personal process, and product, all of which interact with each other. Brainstorming is a group idea generation method (Osborn 2012) that involves several individuals interacting and communicating in a group for problem-solving; this means more than one person participate in brainstorming. Each group member also needs to interact with others and develops others’ products through a series of processes (VB, in our case) under the press (VE in this study) surrounding the group. The six factors (person, personal process, product, personal press, group process, and group press) are not independent; they affect and interact with other factors. This means that changes in a factor will lead to changes in other factors and creativity. VR is mainly adopted for brainstorming to modify the group press (VE) or group process (VB), thereby supporting and influencing the person in the group, who interacts with other factors, to be more creative or generate creative products (as shown in Figure 2).

4.2. VB supporting the process to enhance creativity

There were only five existing studies (between 2015–2020) covering the processes of VB that can facilitate creative ideas. Among them, two solely focus on communication issues (Forens, Bonnardel, and Barbier 2015; Ide et al. 2020), while the rest designed VR applications that support brainstorming tasks (Kuťák et al. 2019; Morales, Yamamoto, and Tsujino 2020; Petrykowski et al. 2018). These two research
approaches are described in the following subsections.

4.2.1. Communication supporting the process
Forens, Bonnardel, and Barbier (2015) conducted the first study emphasizing communication among participants in VEs during the brainstorming process. Their experiments compared two communication methods and analyzed their respective influences on creativity enhancement. The authors further examined the level of creativity in the VB process by counting the number of unique ideas that emerged from the VB and by computing the statistical originality of these unique ideas. Their work implied that verbal communication could assist VB group members to be more effective in terms of idea generation and originality of ideas, compared with written communication (Figure 3).

Another group of researchers attempted to address the lack of body expression in VB, and examine whether the advantages of gesture-based communication exist or not (Ide et al. 2020). Their user evaluation included three conditions, namely face-to-face in a physical environment, VB with symbolic gestures, and VB without such gestures. Regarding symbolic gestures, avatars can employ up to nine different gestures used to share opinions, which are usually employed in an idea generation stage. For instance, thumbs up indicates a supportive view of a particular idea. Similarly, the effectiveness of these three conditions was evaluated by the number of ideas generated. In general, participants in the VB condition with symbolic gestures produced the highest number of ideas. Remarkably, the gestural interaction among participants also created a positive and supportive environment for VB. That is, the effectiveness of VB was also affected by participants’ attitudes and behaviours in such conditions. Specifically, the participants enjoyed using gestural representation as an important channel for exchanging information and response. Nevertheless, participants also mentioned negative impacts, such as cognitive load and distraction, similar to other gesture-driven systems. Finally, their findings also suggest that an anonymous VE could provide a more relaxed atmosphere, encourage participants to express their opinions, and alleviate the burden of responsibility.

- Definition of Multiple Communication (as an affordance of VB for creativity enhancement): The above works shed light on the
multiple ways of communication in VB, with the key feature being multiple participants (or stakeholders) in the process. Illustrates the multiple communication in the VB under our proposed framework of the 4Ps of creativity. Simultaneously, people directly influence each other, and their ways of communication include visual (e.g. textual contents, symbolic gestures), as well as oral (e.g. speech), which could enhance creativity (Morales, Yamamoto, and Tsujino 2020; Petrykowski et al. 2018).

4.2.2. Applications supporting the process

The second research approach refers to design-oriented applications that support VB and streamline idea generations. Kut’áč et al. built an interactive multi-modal mind map in VR (Kut’áč et al. 2019); however, it is important to note that a traditional method has limitations, such as the difficulty views of sticky notes and the potential of such notes falling off the wall. By contrast, a virtual mind map explicitly offers an enriched brainstorming environment, such as voice recognition for

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**Figure 3.** Summary of reviewed articles of communication supporting process

**Figure 4.** Relationship between multiple communication of VB and the 4Ps of creativity. In the left-hand side circle, the grassy green arrows pointing to persons, indicate that multiple communication included in the group process affects persons. The right-hand side circle indicates the interaction between persons and others.
effective communications, content recordings, voting function, and exporting results. The user evaluation of the mind map indicates that VR provides an immersive environment and allows users to work on brainstorming tasks with higher levels of attention and focus. In addition, participants also highlighted that the VR environments transform the creative process into a game-like environment (Figure 5).

Another work examined the effect of user collaboration in VR based on the number of generated ideas, with the critical feature that a participant can see others’ gestures through avatars. Participants generally favoured the VEs and hence generated more ideas than their non-VR counterparts (Petrykowski et al. 2018). Participants also mentioned that the prototype lacked facial expression, the digital representation was less accurate or unrealistic, which was inconvenient and left them unsatisfied.

Another study was used a collaborative system to support artistic activities, such as creating manga (Morales, Yamamoto, and Tsujino 2020). In the system, two types of key creators, namely writers and illustrators, complete their individual works, such as storyline drafting and planning, and character design. Thereafter, participants go through collaborative channels that support the discussion of manga details and brainstorming tasks. Three conditions (face-to-face, Skype, and SyncMeet) were evaluated in this experimental setting. Participants using SyncMeet were situated in a virtual meeting room where avatars communicated and collaborated remotely with other avatars (i.e. creators). Avatars support co-presence through multiple sensors (e.g. Leap Motion controllers) that track participants’ positions, movements, and gestural inputs. Similar to the aforementioned works, such co-presence encourages nonverbal communication and the expressions of agreement and/or disagreement. Additionally, such virtual workspaces include various work-oriented functions, including virtual whiteboards for sketching and writing contexts, marker tools for inputting annotations by gestures, voice recording tools for recording conversations, and automatic screenshot tools.

**Figure 5. Summary of reviewed articles of applications supporting process**
for capturing contents discussed in the virtual space. The user evaluation showed that Sync-Meet was more effective than Skype, with the following benefits: 1) the immersive environment was playful and encouraged participants to concentrate on the task without distractions; 2) participants were more relaxed and acted more easily and freely; 3) VE facilitates information sharing, and hence there was a more responsive collaboration among participants; 4) participants were more satisfied sharing the visualization of sketch and story manuscript. Although VB showed advantages over Skype, participants mentioned that the lack of eye contact and facial expression could inhibit the communication richness experienced, compared with face-to-face scenarios. From the research mentioned above, the affordance of VB is summarized as follows.

- **Definition of Immersion (as an affordance of VB for creativity enhancement):** Immersion provides a realistic experience for people using VR devices by increasing the presence of the task and reducing restrictions such as sitting and using a mouse. As shown in Figure 6, immersion has been included in the process, and it directly affects multiple persons. It is important to note that any interaction between persons and the group ideation press could influence persons’ cognition and behaviours in the creative process (Kut’ák et al. 2019; Morales, Yamamoto, and Tsujino 2020).

- **Definition of Tracing (as an affordance of VB for creativity enhancement):** Tracing refers to the real-time tracking of a person’s head or hands to facilitate the group ideation process. Tracing is related to immersive VR devices, such as HMDs or CAVE systems (where it is possible to actually track the participants’ head, hand, or full-body movements). Moreover, tracing is used to track participants’ location to capture their movements during brainstorming without VR devices. The leftmost circle is grass-green coloured (Figure 7) to illustrate the affordance. Meanwhile, tracing addresses the interaction between persons and supports rich communication and expression in the ideation process among stakeholders (Kut’ák et al. 2019; Morales, Yamamoto, and Tsujino 2020; Petrykowski et al. 2018).

- **Definition of Recording (as an affordance of VB for creativity enhancement):** This serves as a continuous recording of the group’s products and provides a snapshot or footprint of the creative process. As indicated by the left circle in Figure 8, persons with such affordance can interact with previous products, denoted by curved lines with orange and yellow arrows pointing to persons and products. This way, the affordance supports product iterations and hence nurtures better fundamentals of high-quality products (Kut’ák et al. 2019; Morales, Yamamoto, and Tsujino 2020).

- **Definition of Appraisal (as an affordance of VB for creativity enhancement):** Appraisal provides an opportunity for persons to evaluate all products, which can be seen as an interaction between products and persons (i.e. the interaction exists between persons and products, as indicated by the curved lines with orange and yellow arrows pointing to persons and products, as shown in Figure 9). Appraisal serves as an indispensable step for achieving creativity and creative products (Petrykowski et al. 2018).

### 4.3. VB supporting the press to enhance creativity

Two main trends were observed during this study, where researchers designed avatars and VEs for brainstorming sessions, and the VR elements were subsequently evaluated with the creative product (ideas) to verify their hypotheses. Such VR elements could influence
persons’ cognition, behaviours, and communication, thereby affecting their level of creativity and their effectiveness at generating creative products. Their occurrence of the trends is as follows: the appearance of avatars (n = 5) and VEs (n = 6).

### 4.3.1. Avatars in the press

We identified five articles related to two main trends – comparing avatars and static personas and comparing the various appearance of avatars. On the one hand, researchers explored representations of avatars, namely dynamic and static personas, to explore their influence on creativity (Bonnardel, Forens, and Lefevre 2016; Bonnardel and Pichot 2020). On the other hand, research studies focused on avatars’ appearance that could impact the individuals’ cognition and behaviours and potentially facilitate more creative outcomes (Buisine and Guegan 2020; Guegan et al. 2016, 2017), as shown in Figure 10.

The first research effort in comparing static and dynamic personas in VEs, indicated that dynamic personas, represented by avatars, lead to significantly higher empathy toward individuals’ personas than their static counterparts (Bonnardel, Forens, and Lefevre 2016). Empathy is an important personality trait, especially in team-based environments, as it helps an individual understand the other’s needs and, hence, impacts individuals’ creativity and its quality. Another follow-up study with a larger sample (n = 102), conducted by Bonnardel and Pichot (2020), aligned with the results shown in the previous work. Remarkably, the quality of creativity is somehow interconnected with the empathy triggered by the virtual entities. The sub-criteria of collaboration and empathy showed the presence of statistical significance but the absence of novelty, feasibility, and relevance.

The second group of studies primarily assumed that the existence of the Proteus effects phenomenon, and hence the participants of the creative process, will shift behaviours in an alternative digital horizon. Guegan et al. hypothesized that the usage of relevant avatars could enhance creativity by transforming one’s self-perception according to the Proteus effects. They designed two types of avatars (a series of ‘inventor’ and ‘non-inventor’ avatars) based on Second Life from Linden Labs. Evaluation by engineering students showed that the inventor avatars (those wearing a lab coat or using scientists’ instruments) could encourage individuals to generate more unique ideas than the ‘non-
inventor’ control group. It was verified that creativity could be enhanced by using relevant avatars, and avatars that resemble scientists or engineers could stimulate creative thinking (Guegan et al. 2016).

Moreover, Guegan et al. conducted an additional experiment under four conditions, constructed by two avatar designs (with or without social identification) in two user situations of RE or VE. Their results implied that avatars with social identification (the same uniform or high visual similarity) could induce social identity cues and increase fluency; in turn, such favourable factors could stimulate a higher number of unique ideas. They uncovered the positive effects of creative avatars designed for VB, such as self-assessed fluency, which means that participants felt more creative and had an increased collaboration motivation (Guegan et al. 2017).

Furthermore, Buisine and Guegan evaluated the interaction between individuals (Proteus effect and social identification) and found that such identifications in avatars can significantly influence creativity. They concluded a study in the same VE using a crossed design of four
types of avatars (creative and noncreative, and with and without social identification). They found that creative avatars positively affected creativity, but only in the condition of without social identification. By contrast, the condition with social identification affected creative avatars instead of noncreative avatars. Surprisingly, the social identification resulted in decreased creativity, which contradicts their prior findings (Buisine and Guegan 2020).

Accordingly, we provide the affordance below.

- Definition of Avatars (as an affordance of VB for creativity enhancement): An avatar is a 3D graphical representation of a person interacting with persons and other individuals. Avatars can exert temporary influences on persons’ cognition and behaviours (Guegan et al. 2016) and hence influence their communication and interaction with other persons (Buisine and Guegan 2020) (Figure 11).

4.3.2. VEs in the press
There are three types of experiments regarding the use of VEs for creativity enhancement: comparing the influence of VEs and REs, different settings in VEs, and similar settings in mixed reality (MR) environments and VEs (Figure 12).

Two studies compared the influence of VE and RE for creativity enhancement (Bourgeois-Bougrine et al. 2018, 2020). The results indicated that groups in VE (similar to the RE) generated more products than their counterparts in RE because of the anonymity in the communication. However, VB did not uniformly enhance creativity for all participants regarding the individual’s traits. The high risk-taker, divergent thinkers, and mentally flexible participants were significantly more creative in the VE than those in the RE. In contrast, there was no difference in creativity for participants with a low score of risk-taking, divergent thinking, and mental flexibility in the VE and RE.

Some researchers have focused on adding objects to VE design, such as adding priming objects to enhance creativity. One study focused on setting up an open space (arched glass roof) versus a closed area in a VE, as shown in Figure 13 (A). The study evaluated priming objects: the concept of openness and its influence on creativity. The authors found that more novel, workable, and relevant ideas were generated in the open VE than in the
closed environment (Minas, Dennis, and Massey 2016).

Moreover, Bhagwatwar et al. examined creativity priming influences by comparing two VEs – an open-space VE and another space named the creativity primed environment, with visibility of certain natural elements, such as trees and flowers (Figure 13 (B) right-side). They suggested that individual cognition could be affected by the creativity primed environment, thereby enhancing individuals’ creativity (Bhagwatwar, Massey, and Dennis 2013). Subsequently, the authors compared the difference between the priming VEs (i.e., the VE with contextual priming using 3D objects, namely topic-specific VEs), which was related to their brainstorming tasks (reducing pollution and increasing tourism), shown in Figure 13 (C), another VE with priming objects related to creativity (similar to the

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**Figure 10. Summary of reviewed articles of avatars in the press**

| References | Subjects | Comparison | Procedure | Measures | Results |
|------------|----------|------------|-----------|----------|---------|
| Bomardel et al. (2016) | 33 participants | Group (G) 1. Non-persons. G 2. Static persons. G 3. Dynamic persons. | The classic brainstorming paradigm (Paulus et al., 2011). In the first, divergent thinking phase (25 minutes), participants were asked to generate as many ideas as they could, while in the second, convergent thinking phase (15 minutes), they had to select the best ideas and develop them. | Reduce traffic jams in the city in 40 mins | Second Life | Fluency | G 3 > G 1 > G 2 | Originality: G 3 > G 2 > G 1 | Quality of collaboration: G 3 > G 2 | Empathy: G 3 > G 2 | The creative dimension of avatars: G 3 > G 2 | Deindividuation: G 3 > G 2 | Presence: G 3 > G 2 | Self rated fluency: G 3 > G 1 | The fun factor: G 2 & 3 > G 1 | Fluency: G 3 > G 2 & 1 | Uniqueness: G 3 > G 2 & 1 |
| Guégan et al. (2016) | 54 final-year engineering students | G 1. Face-to-face brainstorming. G 2. Neutral avatars in VE. G 3. Creative avatars in VE. | Participants were then presented with Osborn’s (1953) brainstorming rules (focus on quantity, withhold criticism, welcome unusual ideas, combine and improve ideas) and asked to perform two successive 15-min brainstorming sessions. | Traveling on snow, sand or water in 15 mins | Group 1. In a room around a table. Group 2 & 3. In three isolated boxes gathered around a virtual table using their avatars. | Second life or face-to-face | Computers or tablets and keyboards | Text | Creativity dimension of avatars: G 3 > G 2 | Deindividuation: G 3 > G 2 | Presence: G 3 > G 2 | Self assessment: G 3 > G 1 | Fluency: G 3 > G 1 & 1 | Uniqueness: G 3 > G 2 & 1 |
| Guégan et al. (2017) | 72 final-year engineering students | G 2. Face-to-face with SIC avatars. G 3. VB without SIC avatars. G 4. VB with SIC avatars. | Participants were presented with Osborn’s (1953) brainstorming rules (focus on quantity, withhold criticism, welcome unusual ideas, combine and improve ideas). | New transportsations means in 15 mins | In face-to-face, the participants gathered around a table, tablets and keyboards. In VB, participants were in three isolated boxes gathered around a virtual table using their avatars. | Second life or face-to-face. | Computers or tablets and keyboards | Text | Fluency | Uniqueness | Social identification | G 3 > G 4 & 1 & 2 |
| Buuine and Guégan (2020) | 72 final-year engineering students | G 2. Creative avatars without SIC. G 3. Non-creative avatars with SIC. G 4. Non-creative avatars without SIC. | Participants were presented with Osborn’s (1953) brainstorming rules (focus on quantity, withhold criticism, welcome unusual ideas, combine and improve ideas). | Traveling on snow, sand or water in 15 mins | Participants were in three isolated boxes gathered around a virtual table using their avatars. | Second life | Computers or tablets and keyboards | Text | Presence | Perception of the creative identity of avatars | Social identification | Fluency | Uniqueness | G 3 > G 4 & 1 & 3 | G 2 & 4 > G 1 & 3 | G 2 & 4 > G 1 & 3 | G 2 & 4 > G 1 & 3 | G 2 & 4 > G 1 & 3 | G 2 & 4 > G 1 & 3 | G 2 & 4 > G 1 & 3 |
| Bomardel and Pichot (2020) | 102 participants | G 1. Static persons. G 2. Dynamic persons. | Participants were presented with the classic brainstorming paradigm (Osborn, 1963; Paulus et al., 2011), the task came in two phases: 1) a divergent thinking phase, in which participants were asked to generate as many ideas as they could (25 min); and 2) a convergent thinking phase, in which they had to select the best ideas and develop them (15 min). | Reduce traffic jams in the city in 40 mins | Participants were placed in separate rooms. | Second Life | Computers | Text | Fluency | Originality | Quality of creativity | Empathy | Quality of collaboration | G 2 > G 1 | G 2 > G 1 | G 2 > G 1 | G 2 > G 1 | G 2 > G 1 |
previous creativity primed environment), shown in Figure 13 (B) right-side, and the generic VE (i.e. the previous neutral priming VE), as shown in Figure 13 (B) left. Their results showed that both priming VEs could improve creative performance because priming could manipulate individuals’ nonconscious cognition and behaviour, thus increasing group performance. In particular, contextual priming using 3D objects is appropriate to implement priming in a VE, encouraging individuals’ design thinking, particularly during ideation (Bhagwatwar, Massey, and Dennis 2018). Meanwhile, other researchers have focused on how brainstorming in a VE is different in a MR environment. Hwang et al. examined the different effects of VR and MR on brainstorming. In both conditions, participants viewed the same menu with colourful blocks; in the MR environment, they saw the standard physical laboratory room and interacted with their real partners. In the VE, the participants entered a virtual laboratory room resembling the physical one, and their partners appeared in the avatars. In a follow-up experiment, the participants explained that their involvement in the VE was more creative and exciting than brainstorming in the MR environment. The score of their creativity was higher in the VR than in the MR. In brief, the effects of reality and anonymity can explain their findings. However, the participants also mentioned that the feeling of togetherness was absent owing to the lack of facial expression and natural reaction in VR (Hwang et al. 2020).

- Definition of Simulated objects (as an affordance of VB for creativity enhancement): Simulated objects situated in VR creates VEs that influence peoples’ cognition and behaviours through priming and eventually enhance creativity. It can be seen as a positive or negative interaction between the press and person depending on the simulated objects (Bhagwatwar, Massey, and Dennis 2013; Minas, Dennis, and Massey 2016), as shown in Figure 14.
- Definition of Anonymity (as an affordance of VB for creativity enhancement): Anonymity allows persons to communicate
| References | Subjects | Comparison | Procedure | Conditions | Platforms, Devices, Communications | Measures | Results |
|------------|----------|------------|-----------|------------|-----------------------------------|----------|---------|
| Bourgeois-Boeugrine et al.(2018) | 60 psychology undergraduate students | Group (G1). Virtual environment (VE) | Participants were given the same information and instructions about the task and rules of brainstorming. New solutions to improve the daily mobility in 10 mins. | Second Life | Computers, Text | Second Life | | |
| Bourgeois-Boeugrine et al.(2020) | 60 psychology undergraduate students | G. 2. Real environment (RE) | The participants were given the same information and instructions about the task and rules of brainstorming (Do not judge others' ideas, do not restrict yourself, wild ideas are welcome, do not hesitate to use others' ideas to improve them). Produce as many ideas as possible without worrying about quality. | | | | | |
| Minas et al. (2013) | 140 sophomores and juniors from an introductory business course | G. 1. Open VE | The participants were used Open Wonderland that offered a set of tools, including "sticky pads" similar to the GroupSystems Electronic Brainstorming (EBS). Each participant was assigned to one pad, and was instructed to use it to record ideas. Every 3 minutes, the participants were instructed by the experimenter over the voice tool in the VE to rotate to a new notepad and were further instructed to build off the ideas of the other team members written on the pad. | Increase tourism in 15 mins | Open Wonderland | | |
| Bhagavatwar et al. (2018) | 80 sophomores from various business school courses | G. 1. Creativity priming VE | Participants were instructed to generate as many ideas as possible, and build off the ideas of others in the team brainstorming. | Increase tourism in 15 mins | Open Wonderland | | |
| Bhagavatwar et al. (2018) | 168 sophomores and juniors from various business school courses | G. 1. Generic VE | Participants were instructed to generate as many ideas as possible, and build off the ideas of others in the team brainstorming. | Increase tourism in 15 mins | Open Wonderland | | |
| Hwang et al. (2020) | eight subjects | G. 1. Mixed reality condition | The participants were given the same information and instructions about the task and rules of brainstorming. Each pair was then randomly assigned to the MR or VR condition. Water and energy conservation was considered a criterion for the VE condition. | | | | |
| Hwang et al. (2020) | eight subjects | G. 2. Virtual reality condition | The participants were given the same information and instructions about the task and rules of brainstorming. Each pair was then randomly assigned to the MR or VR condition. Water and energy conservation was considered a criterion for the VE condition. | | | | |

**Figure 12.** Summary of reviewed articles of VEs in the press
without scruples and express their feelings freely during the group ideation process in a VE. Figure 15 depicts such an interaction between persons and encourages persons to communicate with the reduced barrier, thus positively driving the outcomes of creativity (Bhagwatwar, Massey, and Dennis 2018; Bourgeois-Bougrine et al. 2018, 2020; Ide et al. 2020).

5. Discussion

5.1. Identified affordances of VB

In the previous sections, we reviewed articles on factors of VB that enhance creativity. Referring to the key research question, we qualitatively explored the affordances of VB from a wide range of existing literature. Such affordances exist and cause interactions between individuals and numerous building blocks of brainstorming. All the reviewed papers focused on designing the two factors, press and process, based on the 4Ps of creativity. In addition, researchers analyzed the person and/or product after brainstorming sessions to verify the effectiveness of enhanced creativity. Through this, the review systematically generalized and identified the affordances of VB that enhance creativity. Finally, our key findings of the affordances of VB under our framework are summarized as follows:

1. Anonymity allows persons to communicate without scruples and express their feelings in the process, decreasing the social barriers in the process and increasing the number of products (Guegan et al. 2017; Hwang et al. 2020).

2. Appraisal is an interaction related to products and persons. Appraisal integrated into VB cannot be halted before all participants have made their contributions; this also ensures that the assessment points are contributed directly and are not influenced by others (Petrykowski et al. 2018). Although it is not directed at enhancing creativity, it enables individuals to identify the best products and improve the latest iteration, which means assisting persons in improving the quality of their creative products.

3. Avatars as a self-representation of persons provide interaction between persons, cognitions and behaviours, other persons, and group ideation press during the group ideation process. Avatars can be designed to induce the Proteus effect or social identification, influence persons’ cognition and behaviours, and enhance creativity. Moreover, an avatar–person correspondence is an interaction between individuals and avatars in a VB. The opportunity of selecting corresponding avatars could allow users to choose avatars that positively affect their emotions and

Figure 13. (A) Sketch of the screenshot of the open and closed spaces in VE. Modified from ‘Opening the mind: designing 3D virtual environments to enhance team creativity,’ by Minas, R. K., Dennis, A. R., & Massey, A. P., 2016, 49th Hawaii international conference on system sciences (HICSS), p.250, IEEE. (B) Sketch of the screenshot of the neutral and the creativity priming VE. Modified from ‘Creative virtual environments: Effect of supraliminal priming on team brainstorming,’ by Bhagwatwar, A., Massey, A., & Dennis, A. R., 2013, 46th Hawaii international conference on system sciences (HICSS), p.224, IEEE. (C) Sketch of the screenshot of topic-specific VE. Modified from ‘Contextual Priming and the Design of 3D Virtual Environments to Improve Group Ideation,’ by Bhagwatwar, A., Massey, A., & Dennis, A., 2018, Information Systems Research, 29(1), p.76-77.
help them become creative (Guegan et al. 2016).

(4) Immersion can be seen as an interaction between persons and the press. Using devices (e.g. HMD) in VB enables persons to be immersed in a more realistic VE, which could influence their cognition and behaviours in the group ideation process and assist them in concentrating on a task with fewer distractions and generating more products (e.g. ideas) (Kut’ák et al. 2019; Morales, Yamamoto, and Tsujino 2020).

(5) Multiple communication combines different communication methods, not only oral or written (Forens, Bonnardel, and Barbier 2015) but also visual and graphical (Ide et al. 2020). Communication is the key linkage between persons. When persons engage in VBs, they could choose any communication method to help them communicate and collaborate. Such communication means can motivate them to discuss with other individuals and eventually reach the creativity goal in a remote manner.

Figure 14. Relationship between simulated objects of VB and the 4Ps of creativity. The first circle (left-hand side) indicates simulated objects included in group press and affected persons. The second circle (right-hand side) with colourful arrows indicates the interactions between group press and persons.

Figure 15. Relationship between anonymity of VB and the 4Ps of creativity. The first circle (left-hand side) indicates anonymity included in group press and affects persons by light blue arrows. The second circle (right-hand side) with orange arrows indicates the interactions between persons.
(6) Recording automatically records the process and products, which helps persons interact with the previous products, and improve the previous products to create iterations of products afterward (i.e. increase the product quality). Furthermore, voice recognition could automatically transform speech to text, capture activities and ideas, record various contents, and support multiple communications to enhance creativity (Kut’ák et al. 2019; Morales, Yamamoto, and Tsujino 2020).

(7) Simulated objects could be virtual entities in the form of 3D vectors in VEs or simulated REs, which could help persons enhance their creativity. Simulated objects serve as both a relationship and interaction between simulated objects and individuals, which could induce the priming to shape individuals’ subconsciousness and further influence their behaviours. For example, 3D objects, such as windows, inspiring colours, and plants, increase positive emotions to prime individual cognition and encourage design thinking (Bhagwatwar, Massey, and Dennis 2013; Minas, Dennis, and Massey 2016). Moreover, it is easier to simulate the RE to influence persons, for example, by setting up an open space (e.g. arched glass roof) in which the interacting group members generate more novel, workable, and relevant ideas (Minas, Dennis, and Massey 2016).

(8) Tracing involves using the positions and movements of persons that strengthen the expressiveness of VB. It is an interaction between a person and other persons, as an alternative means of communication, and expression in the group ideation process. When a person participates in a VB, the tracing system could capture others’ locations and movements in real time. Such captured information supports the sense of co-presence and workspace awareness (Kut’ák et al. 2019; Morales, Yamamoto, and Tsujino 2020; Petrykowski et al. 2018).

5.2. Future research directions

Although the researchers have exerted significant effort into VB to enhance creativity, there is room for further exploration, as indicated by the proposed framework.

(1) Persons should be the main factor in VB in terms of interacting with other factors. The researchers have explored the positive effects of encouraging persons to be creative, such as the creative avatars in VE, to enhance a person’s creative performances (Guegan et al. 2016). However, these experiments were based on a single discipline; we suggest exploring the creative avatars based on different disciplines. With discipline-specialized avatars, the effectiveness of creative avatars suitable for students from various disciplines should be investigated. Moreover, many unidentified factors may affect a person’s creativity, such as habits. Furthermore, it is possible to cultivate a person’s way of thinking; for example, adding an intentionally bad-designed game (ill-structured one) to VB could be a method to induce persons’ interactions and cultivate critical thinking (Hall et al. 2020).

(2) Personal process includes a series of subprocesses that interconnect with numerous factors. The reviewed papers focused narrowly on the group ideation process instead of the personal process. Factors such as motivation could affect the personal process (Legaki et al. 2020). An individual can be motivated, for instance, through a priming game by delivering illustrations of the goals and achievements. These spark persons’ creative performance and eventually gain a bigger pool of ideas than their counterparts without the
priming game (Dennis, Minas, and Bhagwawar 2013).

(3) Personal press can shape a persons’ cognition and behaviour, which subsequently affects a person’s needs, sensations, perceptions, and creativity. Each generated product uniquely reflects the initiator’s self, sensory equipment, mentality, value system, and adjustment to daily life. In other words, the personal press is considered as a cumulative effect. However, the current experiments were limited to a short period (i.e. less than one hour). Thus, studies with extended experimental periods should be conducted.

(4) Products could be developed in VB. The researchers designed systems to evaluate the products that could be improved further by themselves and other participants (e.g. (Petrykowski et al. 2018)). Moreover, an avatar’s body size, such as its height, not only affects individuals’ behaviour and emotions (e.g. confidence) (Freeman et al. 2014) but also provides unique perspectives to interact with others and the virtual world (Nishida et al. 2019). Therefore, designing unusually sized avatars could be an opportunity to re-examine and observe the dimensions of products. It also enables the improvements of the product from an empathetic perspective. Another example is a dynamic sketch-based tool for brainstorming, which enables image co-creation. The tool could recognize images and provide artificial intelligence (AI)-recommended solutions in the brainstorming process. Their work opens the potential of new affordance among users, products, and AI to generate ideas through human-AI collaboration in VEs (Perlin, He, and Zhu 2018).

(5) Group process in the framework is the core of the idea generation process throughout the VB. On the one hand, researchers have explored and designed systems for modifying the group ideation process, such as recording and tracing, to positively enhance creativity (Petrykowski et al. 2018). On the other hand, researchers have explored the influence of communication methods in enhancing creativity (Forens, Bonnardel, and Barbier 2015; Ide et al. 2020). However, the lack of facial expressions remains a neglected factor that negatively impacts the user experience in VB. It is possible to integrate new technologies into VB (e.g. micro-expression recognition) (Li, Huang, and Zhao 2021), and recognizing micro-expressions on the user’s face and creating those on the avatars’ face, although masked by VR headsets, could enable avatars to be more natural yet expressive. Such micro-expressions allow avatars, on behalf of multiple users, to understand the communication effectively and hence facilitate remote collaboration. Moreover, we can consider the design of avatars from different perspectives, such as providing alternative user input modality to the user’s feedback loop, to actualize highly realistic avatars that open numerous opportunities for user’s communication and collaboration. For example, it has been verified that the integrated electroencephalography feedback system into VR could affect individuals’ attention, flow state, and creative performance (Mattila et al. 2020; Yang et al. 2019). Furthermore, it is possible to use eye-tracking data as an objective measure to collect gaze behaviour (Papavlasopoulou, Sharma, and Giannakos 2020) or to recognize the different intentions for better communication (Jang et al. 2014).

(6) Group press is the VE surrounding the group members during the ideation. Researchers continued to design the VEs and conduct experiments to find the creative VE that enhances creativity; however, all the VEs were situated in well-defined laboratory conditions or controlled setups in meeting rooms that emulate the real-
life environments. It is necessary to employ such experimental VEs in real-life environments, such as natural ones (e.g. forests (Fleury, Blanchard, and Richir 2021; Mattila et al. 2020)). Such environments could enable individuals to gain additional sensory feedback (visual, auditory, and even simulated smell and touch) to feel refreshed and amused and release stress (Serrano, Baños, and Botella 2016). As a result, they generate more creative outputs and hence become more creative. Group press suggests that if we simulate a natural environment for brainstorming, a VE-aided relationship between individuals and nature might be developed, enhancing individuals’ creativity. Moreover, a non-standard environment might influence individuals’ emotions (e.g. exciting, new-fangled). Researchers have indicated that the benefits of nonstandard environments could provide an unusual experience to stimulate cognitive flexibility in a creativity task (Ritter et al. 2012). However, there are also several concerns; for example, some people may experience cognitive distancing, the perception of being in a fictional environment that leads to lower responses in a VE (Hartmann and Fox 2020).

5.3. Consideration

Only a few researchers focused on this topic, and we attempted to explore the potential reasons for this. The discomfort resulting from using VR devices is one of the key reasons (Nie et al. 2019), and the potential risk of sickness when using VR might require specific permissions from Ethics committees. In addition, the lower visual display quality of HMDs is a distraction and leads to dissatisfaction; thus, completing brainstorming is physically demanding (Kut’ák et al. 2019). Moreover, it is a challenge to build a VE that allows several participants to interact (Muhanna 2015).

Although brainstorming is a classical method (Osborn 2012) conducted in VR, other methods use the features of VR better. For example, some recent studies evaluated idea generation in VR based on sketching, which does not require training, and VE provides context on where the sketched product will be located (Yang and Lee 2020; Yang et al. 2018).

5.4. Limitations

Our systematic review of the VB literature included only 16 studies identified from dedicated search criteria and backward and forward reference searches in selected articles. However, given the growing number of publications in this field, we cannot guarantee that all research has been covered in our review. Nonetheless, our systematic literature review still provides clear and comprehensive insights on the topic and will be of value to future researchers.

6. Conclusion and future work

This study provides insights into how VR integrated into the creative process (brainstorming) can enhance creativity based on the 4Ps of creativity. This systematic review explains how VR has been used to enhance creativity by synthesizing diverse and fragmented literature related to the topic. The fundamental conceptions related to creativity, brainstorming, and VR are explained, and the term VB is defined. The method and process used in collecting the reviewed articles were reported, and the research-related contents (such as samples, questions, and venue) were described. Next, the researchers explored evidence that VB can change the press and process elements of the 4Ps creativity model, thereby influencing a person’s creativity to produce creative products. This study also identified eight VB affordances and explained the interactions between VR and individuals during the creative process. Finally, VB affordances to enhance creativity
(anonymity, appraisal, avatars, immersion, multiple communication, recording, simulated objects, and tracing) were summarized, and potential future directions based on this framework were presented.

VB for creativity enhancement is a novel research, and its potential deserves to be explored further in the future. In particular, VB affordances were examined and categorized for the first time, which served as the interactions between individuals and other cues of VR to enhance creativity. Except for these mentioned affordances, several unexplored aspects based on our framework are also proposed, which might present future directions in VB to enhance creativity, such as capturing and recognizing facial expressions, feedback systems, games, integrating AI recognition systems, simulating a natural environment, simulating a nonstandard environment, and creating unusually sized avatars.

Disclosure statement
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Funding
This work was supported by Academy of Finland: [Grant Number 346208]; China Scholarship Council: [Grant Number 202107960006]; Opetushallitus (Finnish National Agency for Education): [Grant Number TM-20-11342]; European Union’s Horizon 2020 research and innovation programme: [Grant Number H2020 -856998].

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