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The Application and Value of Virtual Reality Technology in Brainstorming from a Creativity Perspective

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Abstract

Grounded in the 4P (press, process, person, product) Creativity Model framework, this study conducted a retrospective review of the application of virtual reality (VR) technology in brainstorming over the past decade. The findings revealed that VR could provide immersive situational experiences that fulfill the cognitive needs for exploratory thinking among brainstorming participants, thereby enhancing brainstorming effectiveness. Through a literature analysis, this study summarized the specific types of VR tools, research topics, and interactive devices utilized in 21 relevant papers on VR-enabled brainstorming, and discussed their strengths and limitations. The research indicated that VR technology could optimize the divergent thinking and creativity processes inherent in brainstorming. With technological progress, VR has evolved from initially serving merely as an environmental tool providing immersive sensations, to an important technological means capable of directly intervening in and modulating human cognition. Based on the underlying mechanism of VR technology application in brainstorming, this study envisioned promising directions for future research aimed at elucidating the greater potential of VR in facilitating brainstorming activities.

Keywords *: virtual Reality, Brainstorming, Creativity, Collaborative Learning, interactive.*

1.0 Introduction

Recent studies have demonstrated that utilizing digital technologies to facilitate the creative process could be an effective approach (Li, 2021; Stolaki & Economides, 2018). As an emerging digital tool, virtual reality (VR) has already been incorporated into various stages of the creative process (Yang & Lee, 2020). Brainstorming, which stimulates creativity through divergent thinking, is known to be a critical component of the creative process (Baruah & Green, 2023; Mohd, et al 2022.,). Given that brainstorming entails intensive and flexible creative thinking activities, the application of virtual reality technology in brainstorming contexts remains in its nascent stages (Gong et al., 2022). Consequently, the interrelations between virtual reality, brainstorming, and creativity warrant further systematic investigation.

To elucidate this issue, we carried out a systematic literature review of recent applications of VR technology in brainstorming, drawing on Rhodes' 4P Creativity Model (1961) encompassing product, person, process, and press/environment. First, we delineated

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correspondences between cognitive needs arising during brainstorming stages and the technical capabilities afforded by VR technologies. Next, we analyzed the advantages, limitations, developmental patterns, and values of specific VR applications in brainstorming contexts. Finally, we identified promising avenues for continued VR exploration across diverse brainstorming stages. Rhodes' 4P framework was selected as an analytical lens owing to its broad applicability for investigating creativity across research domains (Gruszka & Tang, 2017).

The literature review revealed an array of functional support capacities afforded by virtual reality technologies in brainstorming contexts, as well as their potential to enhance creativity; however, the precise mechanisms correlating these three elements remain opaque. Consequently, while explicating key conceptual matters, the present study is intended to analyze the inherent interconnections between virtual reality technologies and brainstorming through the lens of the four "P" framework. Additionally, we will discuss how virtual reality may serve to elicit richer creative resources throughout the brainstorming process. By constructing a lucid conceptual framework and engaging in logical reasoning, this study aspires to broaden scholarly understanding of how virtual reality-assisted brainstorming may foster heightened creativity, thereby laying the groundwork for follow-up empirical research.

1.1 Creativity

Creativity has been recognized as a vital source of human progress and personal growth (Maslow, 1962). Within academia, divergent perspectives exist regarding the conceptualization of creativity, including as an aspect of intelligence (Freeman, 1939), an unconscious process (Poincaré, 2010), a constituent element in problem-solving (Mansfield & Busse, 1981; Liang et al., 2022; Tu & Akhter, 2022; Xie, et al., 2022), and a process of associative thinking (Spearman, 1931). Synthesizing across definitions, creativity could be characterized as the capacity to externalize novel concepts in tangible form, a process which encompasses rich underlying psychological activities and manifestation through external media (Rhodes, 1961; Yu et al., 2022). The present study adopts Rhodes' (1961) 4P Creativity Model, which elucidates the enhancement of creativity across four key dimensions—Press (environment), Process, Person, and Product—with interactions among these dimensions giving rise to greater creative output (Cascini et al., 2022; Gruszka & Tang, 2017; Zhang, et al., 2022).

1.1.1 Press (Environment)

The construct of "Press" delineates the sway exerted by the external environment upon an individual's inner psychological state (Rhodes, 1961; Zhang et al., 2022). In the course of generating creative ideation, individuals undertake a sequence of psychological processes including problem analysis, solution conceptualization, experiential recollection, and idea integration. Such processes are shaped through a dual influence of one's lived experiences, psychological structures, values, and environmental cues (Mazza et al., 2022; Zhang, Akhter, & Al-Abyadh., 2022). Empirical research demonstrates that the external milieu could impact individual creativity through diverse mechanisms. For instance, enhancing organizational climate and refining the work environment have been shown to positively facilitate creative output at the individual level (Fan & Cai, 2022).

1.1.2 Process

The construct of "process" denotes the progression of cognitive and behavioral operations integral to creativity, encompassing aspects such as motivation, contemplation, learning, and communication (Rhodes, 1961). The generation of a wholly novel concept or idea commonly

undergoes four phases: preparation, incubation, illumination, and verification. These four stages may recur iteratively until culminating in a creative end product (Rhodes, 1961). Currently, researchers often deploy various process-driven techniques to catalyze creativity. Among these, brainstorming represents a prominent approach for engendering creative ideation, wherein participants are prompted to articulate thoughts freely without evaluation during initial stages, so as to avert the premature elimination of promising, high-potential notions (Hu et al., 2012).

1.1.3 Person

The concept of "person" refers to individual characteristics related to creativity, including personality, intelligence, temperament, habits, and so on (Rhodes, 1961). Certain personality traits could render individuals possessing those traits more creative and able to generate more creative outcomes compared to those lacking such traits (Zwir et al. 2022). Some individual characteristics may enhance one's creativity. For instance, individuals with strong curiosity and active thinking patterns are more likely to conceive of innovative ideas (Gross et al. 2020). When solving problems, decisive and perseverant personalities may enable more focused thinking, whereas excessively rule-abiding personalities could restrict the development of creativity. Introverted personalities may inhibit imagination, while open personalities are more conducive to cultivating creativity (Ismailovich, 2021).

1.1.4 Product

The "product" refers to the creative output itself as manifested in physical form (Rhodes, 1961). The innovation embodied in the output is indicative of creativity. For creative products to exert influence, they must undergo evaluation and adoption. The primary criteria for such evaluation are novelty, usefulness, and originality (Kim & Lim, 2020). The novelty of innovative products stems from their introduction of entirely new designs or functions that break established patterns and provide users with a completely novel experience. Usefulness entails the ability of the product to solve practical problems and satisfy user needs, rather than merely achieving superficial innovation. Originality necessitates that the product's design and functions are not simply copied or plagiarized from others, but rather represent the unique insights and crystallization of the original designer's creativity.

1.2 Virtual Reality

Virtual reality (VR) refers to a wide range of computing technologies that simulate virtual environments, allowing users to experience stimuli through various senses (Gong & George, 2020). Typical VR systems utilize computer-generated three-dimensional (3D) environments to enable user immersion and interaction within the virtual world. Beyond interactivity and immersive capabilities, the most overlooked functionality of virtual reality is its ability to enhance imagination, which could facilitate improved ideation and problem-solving (Burdea & Coiffet, 2003).

Research on educational applications of virtual reality is burgeoning, with investigations utilizing VR to promote more creative solutions (Kim et al., 2022; Radianti et al., 2020). To leverage the potential of VR for enhancing creativity and address theoretical gaps, emerging research has begun integrating virtual reality into brainstorming sessions to amplify creative output (Chen et al., 2020). Fields including education, psychology, and engineering have previously applied virtual reality to cultivate creativity, finding brainstorming in virtual environments has many advantages (Wang et al., 2022).

1.3 Brainstorming

Brainstorming is a widely utilized team creativity technique focused on divergent idea generation (Heslin, 2009). Originally proposed by Osborn in the 1940s (Paulus & Kenworthy, 2019), it requires participants to freely propose as many creative ideas as possible without judgment or criticism (Heslin, 2009). Typical brainstorming adheres to four core principles: 1) encouraging the generation of numerous ideas; 2) avoiding premature evaluation of ideas; 3) promoting unrealistic and unconventional ideas; and 4) building upon and improving others' ideas (Paulus & Kenworthy, 2019).

Research demonstrates that compared to individual ideation, brainstorming could elicit more creative ideas (Paulus & Kenworthy, 2019). Member diversity in backgrounds also facilitates idea generation (Cady & Valentine, 1999). However, limitations exist including production blocking, evaluation apprehension, and pressures to conform (Diehl & Stroebe, 1987). Potential solutions encompass taking turns, clarifying evaluation criteria, asynchronous online formats, etc. (Paulus & Kenworthy, 2019). With information technology advancements, network-based virtual environments provide broader communication platforms, overcoming time and space constraints of traditional brainstorming (Siegle, 2020). In particular, virtual reality could generate immersive situated contexts to promote diverse ideas and solutions (Hu et al., 2016).

3.0 Method

A systematic review conducts in-depth analysis on a specific research topic, providing theoretical support for current and future research activities in the field (Moher et al., 2009). Specifically, a systematic review summarizes relevant literature, delineates the state of knowledge on the research topic, discusses existing problems, and proposes recommendations for subsequent research directions (Moher et al., 2009). This study follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher et al., 2015) to formulate the systematic review research question as followed:

(1) As of July 2023, what types of tools has VR served as to support applications in brainstorming from 2013 until now?
(2) How have the advantages and limitations of virtual reality technology in brainstorming enhanced creativity?

3.1 Search Strategies and Techniques

During the literature search process, we constructed relevant keywords pertaining to the research topic, specifically searching academic databases using the terms "virtual reality" and "brainstorming" in titles. The search scope covered the Scopus and Web of Science databases, including literature published before July 2023. Preliminary search results showed 73 related articles in Scopus and 55 in Web of Science. After removing duplicates, we screened the results based on the following preset inclusion and exclusion criteria: Inclusion criteria were (1) full text is in English; (2) document type is journal article, while abstracts, tutorials, posters, presentations, etc. were excluded; (3) study provides empirical data demonstrating experiments utilizing virtual reality technology for brainstorming and the content is relevant to creativity research.

3.2 Descriptive Results Summary of Included Studies

After review, 106 articles were excluded. Specifically, 55 were duplicates, 2 were published without English, 2 were published as abstracts or notes, 6 were reviews without empirical

evidence, 19 did not use VR in brainstorming tasks, and 23 were irrelevant to creativity. Therefore, 21 articles were included in the systematic review. Figure 1 demonstrates the process of article screening and selection.

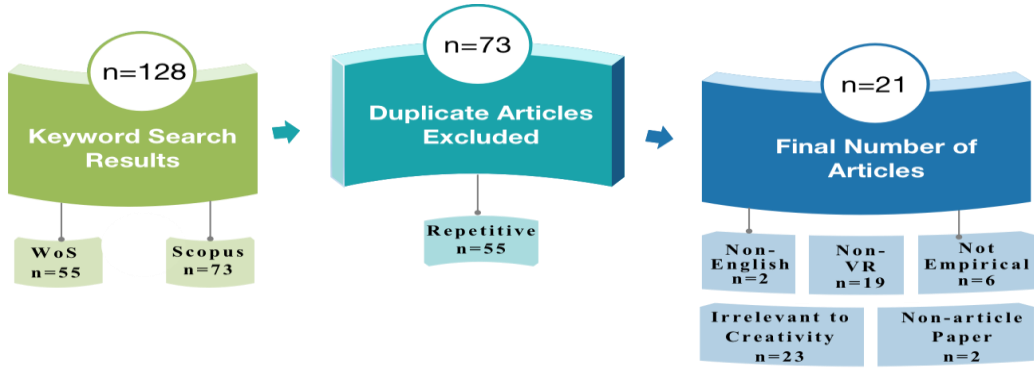

Figure 1: Schematic of the System Review Selection Process.

4.0 Descriptove Results Summary of Includes Studies

This research area is relatively new, with the earliest article published in 2013 (Bhagwatwar et al., 2013). 2020 (n = 6) and 2018 (4 articles) were the years with the highest number of published papers. The role of virtual reality in enhancing creativity has garnered attention from researchers in countries including France, the United States, Japan, and Germany. French researchers have been the most active in this field. Research topics are primarily concentrated in psychology (n=4), human-computer interaction (n=4), and innovation management (n=3). The number of participants in the studies ranged from 6 to over 100, with most participants being adults (n=19), particularly university students (n = 14).

4.1 VR Devices in the Research

Two studies utilized HTC VR devices (Ide et al. 2020; Kut'ák et al. 2019). Two others used Oculus VR devices (Petrykowski et al. 2018; Pituxcoosuvarn et al., 2021). One study did not provide device information, but graphics indicate a standalone VR headset was used, although the brand is unclear (Hwang et al. 2020). In most studies (n = 9), participants were situated in a single space interacting in 2D via one computer (Bhagwatwar et al., 2013; Bhagwatwar et al., 2018; Bonnardel et al., 2016; Bonnardel & Pichot 2020; Bourgeois-Bougrine et al. 2018, 2020; Buisine & Guegan 2020; Gelner et al., 2023; Guegan et al. 2016, 2017; Minas et al., 2016; Gonçalves & Campos, 2018; Forens et al., 2015; Morozov et al.,2014); Morales et al., 2020; Strohmann et al., 2017). We could therefore infer that highly immersive hardware was lacking in most virtual environments used.

4. 2 Advantages and Limations of VR in Brainstorming Application

At present, the application of virtual reality technology in idea stimulation has spawned many solutions aimed at enhancing creative thinking. From a problem-solving perspective, although these solutions vary, they point toward the same goals and developmental trajectories. Technologically, the various application examples share some key technical features and build upon these continuously. This study reviewed and analyzed 21 past studies on virtual reality in brainstorming (see Table 1), categorized them based on the 4P Creativity Mode, and explored the instrumental role of virtual reality technology in idea stimulation, influential factors, as well

as its advantages and limitations in brainstorming. In addition, this study analyzed application development trends and patterns of change, along with potential trajectories for integrating virtual reality with brainstorming.

4.2.1 Press

Communication Environment Tool. Virtual reality (VR) has been applied in brainstorming activities as a communication environment tool. Bourgeois-Bougrine et al. (2018) explored whether multi-user virtual environments could enhance the creativity of individuals with different creative potential profiles. In the experiment, 20 groups of 3 public transportation users each completed brainstorming tasks in real and virtual environments. Participants' creative potential was assessed using a creative potential profiling tool. At the team level, the virtual environment generated significantly more ideas and originality compared to the real environment. However, the creativity enhancement effect of the virtual environment was inconsistent across individuals. Participants with high risk-taking propensity performed better creatively in the virtual environment, while divergent thinking and mental flexibility had positive impacts on fluency in the virtual environment. This study emphasized that virtual environments may not unlock everyone's creative potential, with significant individual differences. In contrast, Hwang et al. (2020) conducted a preliminary experiment comparing virtual reality (VR) and mixed reality (MR) impacts on collaborative creativity, with participants brainstorming about saving water and energy. Researchers speculated that the level of environmental realism may influence creative thinking. Participants reported being unable to feel a sense of collaborating with real people in the virtual environment, which may explain the lack of logical connections between participants.

Gelner et al. (2023) similarly concluded that virtual environments are not always optimal. They surveyed 42 business school students who had experienced both face-to-face and virtual meetings in MBA courses. Results showed that in conceptualization stages mainly involving brainstorming, most students considered face-to-face meetings more effective. However, both modalities were comparable in research/preparation and report writing stages. Since the first project phase emphasized brainstorming, students found face-to-face meetings more effective for enabling better teambuilding and communication richness. But if projects contained minimal brainstorming, differences were insignificant. Face-to-face was also seen as more effective if projects concluded with presentations. Pituxcoosuvarn et al. (2021) compared virtual reality (VR) brainstorming and online whiteboard brainstorming impacts on student creative thinking. They found no significant differences in the quantity or quality of ideas generated within the same timeframe. As students were more familiar with online whiteboards, they considered VR less user-friendly, taking longer to attach sticky notes and write in VR. Thus, they preferred the online whiteboard. However, researchers believed VR brainstorming has the potential to elicit more high-quality ideas if students become more accustomed to VR.

4.2.2 Process

Avatar Tool. In virtual environments, participants could communicate and collaborate through different virtual avatars. Bonnardel et al. (2016) explored the impacts of dynamic avatars (played by researchers) versus static avatars (containing only text and images) on collective creative design. They had two professional groups (designers and human factors engineers) conduct creative tasks in Second Life, with one group using dynamic avatars and the other static avatars. Results showed the dynamic avatar group generated slightly more ideas and originality than the static group, with somewhat higher collaboration quality. Both

professional groups also outperformed a control group of just three non-expert participants in creativity. In a follow-up study, Bonnardel and Pichot (2020) assigned 102 students into two groups to undertake creative tasks in Second Life. The dynamic avatar group scored significantly higher in creative quality, empathy, and collaboration quality compared to the static avatar group. This approach could help designers deeply understand users and actively gather information. These two studies demonstrate some advantage of dynamic avatars in virtual environments for collective creative design, but more research is needed to substantiate effects since the method is quite novel. The application prospects in various virtual collaborations are promising if the challenge of generating high-quality dynamic avatars could be overcome.

On the other hand, Buisine and Guegan (2020) experimentally investigated the impacts of personal identity cues (e.g. inventor persona avatars) and social identity cues (e.g. school uniforms) of virtual avatars on brainstorming performance. Compared to plain avatars, creative personas increased fluency and originality, but adding social identity cues weakened this effect. Although social identity cues increased group identification, they unexpectedly decreased creative performance. Social identity cues may have negative effects if their meaning mismatches creativity, warranting further research on impacts of different types. Another experimental study also examined influences of different virtual avatar types on engineers' brainstorming (Guegan et al., 2016). Compared to plain avatars, creative personas with inventor features increased participant fluency and originality. This effect also persisted over time, remaining present in subsequent face-to-face brainstorming. Limitations of virtual avatar applications include unclear cognitive mechanisms producing the effects (e.g. self-perception) and the need to design and validate creative personas for different populations. Further research is thus needed to fully harness this effect, such as elucidating mechanisms and expanding to diverse groups.

4.2.3 Person

Priming Tool. Bhagwatwar et al. (2013) compared differences between various types of virtual reality environment priming techniques. They utilized 3D objects for situational priming, i.e. virtual reality environments with specific themes relevant to their brainstorming tasks (reducing pollution and increasing tourism). By embedding different visual priming elements in the virtual environments, results found appropriately designed virtual environments could enhance team brainstorming performance by stimulating broader associative thinking.

Bhagwatwar et al. (2018) further examined the impacts of using 3D objects for situational priming in virtual environments on team brainstorming performance and creativity. Researchers applied the "priming" theory in cognitive psychology, where words and images could activate participants' mental associations regarding a concept. In virtual environments, relevant 3D priming objects could be displayed during task performance for "contextual priming." Using an experimental approach, the study compared team brainstorming performance in virtual environments with and without priming objects. Results showed teams generated higher quality ideas with greater breadth and depth in virtual environments incorporating 3D priming objects. This demonstrates direct impacts of priming element designs in virtual environments on team performance. Activation of the target concepts and heightened task engagement are proposed underlying mechanisms of the influence. However, the study notes different types of priming object designs, and their mechanisms require further research, and VR environment effects diminish over time due to limited duration. Overreliance on priming tools may cause mental fixedness, restricting creative ideation.

Cognitive and Behavioral Research Tool. Utilizing VR to observe and analyze participants' cognitive and behavioral patterns during brainstorming. Forens et al., (2015) conducted a study on the impacts of different communication modes in brainstorming on group creativity, assigning 66 students into text communication and voice communication groups. Results showed the voice communication group generated more and more original ideas. Related discussions propose text communication could cause cognitive interference, while voice communication is more spontaneous and efficient. Appropriate communication modalities may enhance team creativity in virtual environments, but more research is needed to determine best practices. Gonçalves and Campos (2018) proposed a virtual reality interface design concept called "subtle place illusion" that employs VR to construct new user interface paradigms. They examined the effects of varying degrees of place illusion on creative writing in different virtual environments, noting moderate place illusion improves self-perceived creativity. Using creative fiction writing as the task, they designed three writing environments with no, subtle, and full virtual reality. Overall, the degree of virtual reality impacted creativity, with moderate subtle virtual reality superior to full immersion. This provides new perspectives for designing creativity-enhancing virtual environments.

Meanwhile, Bourgeois-Bougrine et al. (2020) showed individual traits also influence participant creativity in virtual environments. At the team level, virtual environments increased fluency and originality. But not all individuals benefited equally. Participants with high risk-taking propensity, divergent thinking, and mental flexibility performed better in virtual environments. Overall, compared to traditional lab settings, virtual reality provides higher fidelity and immersion for various cognitive and behavioral experiments, aiding researchers in thoroughly exploring and validating factors influencing human cognition and behavior such as emotions, personality, social influences, etc. (Guegan et al. 2017). However, current related studies have relatively small sample sizes, with generalizability of conclusions still needing further testing, and explanations of cognitive mechanisms in virtual environments remain insufficient. Future research in this area should conduct larger-scale experiments in virtual reality to improve quality and incorporate more diverse experimental variables in virtual settings to enable more compelling scientific investigations.

In another study, Morales, Yamamoto, and Tsujino (2020) proposed the concept of "subtle spatial illusion" and found through experiments that moderate spatial immersion in virtual environments could increase users' self-perceived creativity, holding importance for designing creativity-targeted virtual environments. Adopting a creative writing task, the study conducted a multi-angle quantitative and qualitative analysis of user creativity across different virtual environments, validating the optimal effects of subtle spatial illusions. Despite some limitations, this finding provides a novel perspective for promoting creatively designed virtual environments. Moreover, compared to physical environments, 3D virtual environments could be more readily customized, priming a concept through environment design to improve individual and team performance. One study designed two different virtual environments, one open and one enclosed, with the open environment aimed at eliciting "open-mindedness" to broaden participant attentional scope (Minas et al., 2016). Results showed teams generated more and more creative ideas in the open environment, demonstrating environment design improved team creativity. This study holds significance in showing cognitive priming through virtual environment design could enhance team performance, providing new directions for related research. Of course, VR brainstorming has some pros and cons, such as customizability benefits and lack of face-to-face communication. Optimization of aspects like interface design and member interaction could leverage VR advantages.

Gesture Interaction Tool. In virtual environments, natural gesture interactions could provide more intuitive and effective support for communication and understanding between users. Ide et al (2020) found introducing appropriate gesture interactions could markedly improve understanding and collaboration between participants in virtual environments. Given communication constraints in virtual environments, and many social VR platforms allow symbolic gesture options for expressing intents which are scarcely studied, researchers designed three brainstorming conditions: face-to-face, VR with gestures, VR without gestures. Groups of 3 participated in 10-minute brainstorms, with analysis of objective data like idea quantity, participation level, gesture frequency, and subjective questionnaire feedback. Although no significant idea quantity differences emerged, the gesture condition showed the highest average production. Subjective feedback indicated participants felt gestures better expressed intents and emotions. Networked Minds Social Presence questionnaire behavioral interdependence factors showed significant differences between "gesture" and "no gesture" conditions, suggesting gestures increased social presence. Overall, remote virtual communication reduces social presence, but thoughtfully designed symbolic gestures could mitigate this problem. Considering the small sample size and equipment limitations possibly influencing results, future research could employ more realistic environments and avatars, larger samples, diverse populations, and gesture designs. Explanations of the mechanisms were insufficient in this study. Future work could manipulate more mediating variables, incorporate physiological or neural metrics, and test variable relationships through statistical models to obtain more reliable causal conclusions. This research provided foundational evidence for understanding virtual gesture effects, but broader investigations are needed for comprehensive understanding. Future research could explore designing gestures aligning with human cognitive expectations and conventions and examine specific effects of different gestures on understanding and collaboration. While gesture interactions enable more natural and intuitive communication, technological implementation with greater accuracy and stability also poses challenges, necessitating cognitive load-conscious interaction design.

4.2.4 Product

Virtual Facilitator Tool. To assist and promote collaborative creativity like remote team brainstorming, some research has explored incorporating virtual facilitators in virtual environments. Strohmann et al. (2017) designed a web application called brAInstorm for computer-mediated electronic brainstorming. The system includes an intelligent facilitation agent (IMO) capable of various brainstorming facilitator functions like orchestrating stage procedures and providing stimuli. Researchers used artificial intelligence techniques like natural language processing and machine learning to enable IMO to recognize language, learn user preferences, and accordingly automate brainstorming processes. For instance, IMO could detect killer phrases and intervene, or provide new perspectives when discussions stall. Researchers extended GitHub's Hubot chatbot and integrated wit.ai's natural language platform to implement IMO's interactive capabilities. Evaluation plans involved experimentally validating IMO's effects and case studies applying it in design thinking projects. This virtual facilitator tool advantageously automates collaboration efficiency improvements and could reduce social anxiety and improve engagement compared to face-to-face communication, providing a new perspective for human-computer interaction research. However, its intelligence level and interaction forms still need optimization.

Collaborative Sharing Product Tool. Some researchers have leveraged VR technologies to develop multiplayer collaborative virtual whiteboard products where participants could interact

and operate the virtual whiteboard through their virtual embodied presence to collaboratively generate more creative ideas (Morozov et al., 2014; Petrykowski et al, 2018). Participants also noted lack of facial expressions, inaccurate or unrealistic digital representations were inconvenient and unsatisfying (Petrykowski et al., 2018). These cases demonstrate the potential of immersive virtual environments to further facilitate team member collaboration and information sharing compared to traditional remote collaboration, serving as new platforms for collaborative creativity activities like brainstorming. Another study created an interactive multi-user mind map product tool in a virtual environment, enabling team members to organically construct and organize ideas together in virtual space and discuss and vote on the mind map (Kut'ák et al., 2019). This virtual collaborative mind mapping overcomes physical sticky note conveniences and storage limitations, providing teams a more natural and immersive collaborative experience (Monahan et al., 2008).

Table 1: Summary of Reviewed Articles.

Categorical	Activity	Type of tool	Author	Research Content
Press	An appropriate environment stimulates creativity potential.	Communication Environment Tool	Bourgeois-Bougrine et al., (2018)	An investigation into the influence of multi-user virtual environments on individual creativity.
			Gelner et al., (2023)	A comparison of face-to-face offline and virtual environments regarding their impacts on team collaboration.
			Hwang et al., (2020)	Exploring collaborative creativity in virtual and mixed realities to generate innovative ideas for water and energy conservation.
			Pituxcoosuvarn et al., (2021)	A comparative study on how VR and web-based online whiteboarding brainstorming meetings affect students' creative thinking.
Process	Stimulate and foster enhanced creativity in the process	Avatar Tool	Bonnardel et al., (2016)	An examination of the differential impacts of dynamic versus static virtual characters on participants' performance in creative design tasks.
			Bonnardel and Pichot, (2020)	Dynamic and static virtual characters enabled participants to interact in real-time with avatars embodying archetypal future users, while providing relevant user information throughout the creative process.
			Buisine and Guegan, (2020)	An empirical investigation into how fluctuations in self-identity in virtual environments affect brainstorming creativity.
			Guegan et al., (2016)	An inquiry into how avatars as virtual representations of self could serve as mediums to catalyze creativity.
Person	Personality and characteristics influence creativity	Priming Tool	Bhagwatwar et al., (2013)	Utilizing "priming" techniques in VR environments to manipulate unconscious cognition and behavior in order to optimize team brainstorming performance.
			Bhagwatwar et al., (2018)	Leveraging 3D objects for priming in virtual reality environments to enhance performance in brainstorming creativity tasks.
		Cognitive and Behavioral Research Tool	Bourgeois-Bougrine et al., (2020)	Assessing the potential of multi-user virtual environments (MUVEs) to augment user creativity, with a focus on the role of personality traits like risk-taking propensity.
			Forens et al., (2015)	Evaluating how different communication modalities impact the creative performance of groups undertaking brainstorming activities in multi-user virtual environments (MUVEs).
			Guegan et al., (2017)	Leveraging a social identity approach to compare group performance in face-to-face and virtual brainstorming environments.

Categorical	Activity	Type of tool	Author	Research Content
			Minaset al., (2016)	Deploying environmental cues and priming techniques in virtual environments to modulate participants' cognitive processes.
			Moraleset al., (2020)	Facilitating effective discussion and collaboration around artistic concepts during remote storyboarding brainstorming sessions by creatives with diverse narrative abilities.
			Gonçalves and Campos, (2018)	A study investigating the influence of varying levels of place illusion in virtual environments on creative writing performance.
		Gesture Interaction Tool	Ide et al., (2020)	An analysis of the role and influence of symbolic gestures in VR communication.
Product	Generated product	Virtual moderator Tool	Strohmann et al., (2017)	Optimizing remote brainstorming collaboration through interaction design innovations in virtual facilitators.
		Collaborative Product Sharing Tool	Kut'ák et al., (2019)	Conceptualizing virtual reality mind guides to support collaborative activities like brainstorming.
			Morozov et al., (2014)	Exploring applications of VR technologies for facilitating creative collaborative activities.
			Petrykowski et al., (2018)	VR whiteboards designed to emulate real work environments for collaborative work and application of design thinking methodologies.

4.2.5 Key Takeaways from the 4P Analysis

This study systematically introduced the instrumental role of virtual reality technology in brainstorming and analyzed the advantages and limitations of virtual reality technology in brainstorming (Table 2). However, to promote technological developments in the design field, seeking information solely within current development contexts is far from sufficient. Therefore, this study analyzed the developmental trajectories and trends of virtual reality from a broader scope anchored in time, aiming to gain an in-depth understanding of the evolution and changes in integrating virtual reality with brainstorming.

Table 2: The Advantages and Disadvantages of VR Technology in Brainstorming.

Categorical	Type of tool	Advantages	Disadvantages
Press	Communication Environment Tool	Improve the efficiency and distance of information communication	Lack of logical connection between the participants
Process	Avatar Tool	Expand the participants' sensory and psychological experience	High quality and low cost dynamic avatar generation is a difficult problem
Person	Priming Tool	Provide novel heuristic methods to stimulate participants' innovative thinking	The duration of a VR environment is limited, and the effect will gradually decay
	Cognitive and Behavioral Research Tool	Enhance participants' creativity, spatial awareness and reflective ability	The technical precision is insufficient, and the drawing method is difficult to master
	Gesture Interaction Tool	Interaction is more intuitive and natural	Accuracy and stability may affect the user experience
Product	Virtual Moderator Tool	Compared to face-to-face communication could reduce social anxiety and increase engagement	The level of intelligence and the form of interaction still need to be optimized
	Collaborative Product Sharing Tool	Promote information sharing and enhance cooperation efficiency	Information collection and processing capacity is insufficient, lack of comprehensive resource base

4.3 Development and Changes of VR in Brainstorming

Virtual reality technology and brainstorming activities are showing an increasingly integrated trend. Specifically, the number of VR research and applications in brainstorming formed two distinct peaks in 2018 and 2020 (as shown in Figure 2). We speculate that the first peak around 2018 may be related to the rapid advancement of 3D computing and visualization technologies at that time. The promotion of these emerging technologies provided opportunities for the emergence of various new design tools and methods. The second peak is closely related to the widespread use of consumer VR devices around 2020 (when Oculus Quest 2 was released). In this new stage, research focuses more on VR as an emerging technology and human behavioral research tool, and how it affects and improves the brainstorming process, rather than just emphasizing the advantages of VR technology itself. From the 4P perspective, the development of VR applications in brainstorming is imbalanced. As can be seen from Figure 3, the topics of creativity generation and evaluation under "Person" have always been the main research focus of VR applications. The development of these two types of applications is almost synchronous with that of VR technology.

By analyzing virtual environment research in recent years, we find that although high-end VR devices like Oculus Quest 2 could provide users with high-definition display and immersive interaction experience, many studies still chose lower-performing hardware due to budget constraints. As a result, the virtual environments built in these studies still have shortcomings in visual effects, motion tracking, and haptic feedback, and could not provide users with a high level of immersion. Therefore, if researchers could obtain more resources to upgrade devices, they would be able to build more realistic and natural virtual environments to truly leverage the advantages of VR technology for research. We look forward to continued progress in virtual environment technologies in the future, so that more researchers could obtain high immersion at low cost without hardware constraints.

Figure 2: A Stacked Area Graph Depicting the Amount of VR Applications Distributed Across Various Tool Types from 2013 to 2023.

4.3 Technical Value of Vr Applications in Brainstorming

Figure 3 shows the value and expected integrality of practice-based VR in brainstorming, with the four main areas represented by red, green, yellow, and blue circles. The largest blue circle represents the application of VR technology to personnel (Person), while the red, green, and yellow circles represent the application of VR technology to process (Process), product (Product), and environment (Press), respectively. Through analysis of 21 studies, this research

concludes that virtual reality technology demonstrates certain value across these 4 domains. Thus, a Venn diagram could represent these four concentric circles. The rectangles within the circles represent the realized and potential value of VR applications. As a value summary, VR tool types are also shown in the center of the figure as a few small squares representing the number of applications listed in Table 1.

Currently, the value of VR technology in enhancing creativity in brainstorming is the most salient and intuitive, as it could provide participants with more inspiration sources. Reviewing the development over the past decade, we could see that the "Person" theme of individual personality research has received the most attention, while the other three types of themes have received relatively equal attention. There is great potential for growth in focusing on the theme of "Person" personality characteristics, as this value continues to increase with big data and AI technologies. The flexibility and diversity of VR enables richer and more varied research in this domain.

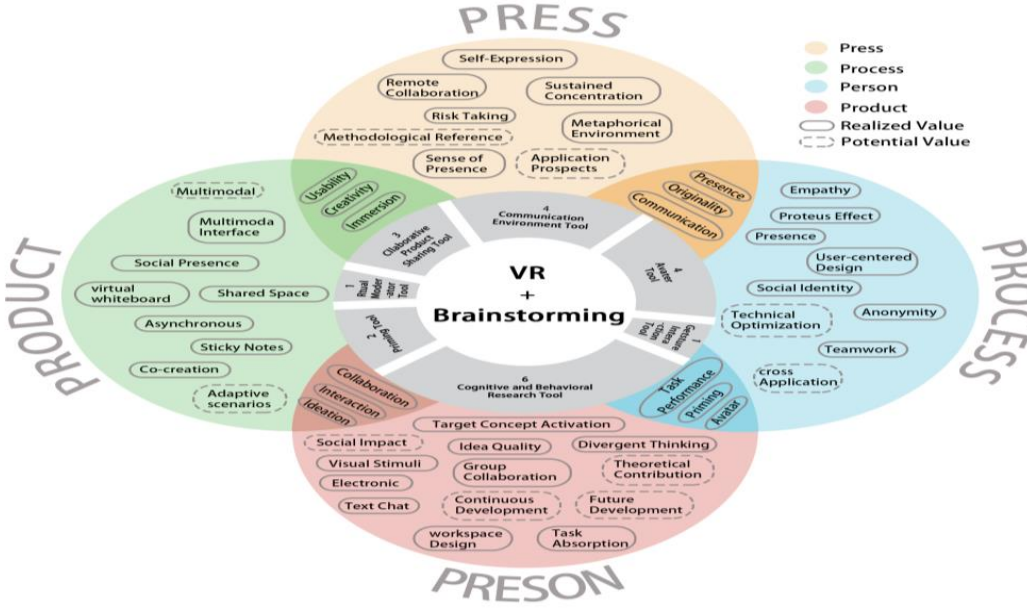

Figure 3: Technical Value of Vr Application in Conceptual Design.

5.0 Results

Through reviewing virtual reality technology applications in brainstorming, this study identified from a brainstorming perspective new trends in integrating and developing virtual reality technologies to enhance creative performance:

Cognitive Needs. Brainstorming involves highly complex thinking activities requiring strong associative abilities, imagination, and innovative thinking. Virtual reality could fulfill these cognitive needs through immersive environments. Specifically, virtual environments provide scenario experiences with high immersion, triggering participants' multisensory perceptions. This not only enriches the material input of brainstorming, but also broadens participants' thinking scope by inducing a state of flow, helping break fixed experiential patterns. Research shows appropriate levels of environmental immersion could enhance participant imagination and thought fluency. However, overreliance on virtual environments also has negative impacts.

Some studies find it is difficult to establish effective logical connections solely through virtual communication, with a lack of tension and collision between participants. Therefore, virtual immersion needs to be moderately combined with real communication, providing customized scenario experiences while incorporating focused logical discussions at key nodes, enabling thinking that is both openly fluid and rationally focused to fully leverage both advantages. Future work may develop hybrid interaction modes balancing the immersion of virtual environments and communication efficiency of real environments.

Optimizing Creativity. Virtual reality provides brainstorming with various new communication forms that could effectively optimize the creative process. First, virtual personas allow participants to exhibit diverse personalities through different virtual roles. Studies show such identity shifting could increase participant proactivity and openness. Second, applying virtual gestures makes communication more intuitive, enabling participants to quickly gesture ideas. Such new forms play a positive role in mitigating the lack of nonverbal communication in virtual environments. However, the reliability and usability of these technologies still needs improvement, with potential misrecognition or interaction difficulties increasing cognitive load in current applications. Next steps should continue optimizing these interaction technologies, lowering user thresholds while ensuring communication quality. Future research may develop natural gesture recognition and high-fidelity virtual character rendering technologies to dramatically enhance virtual communication effects.

Facilitating Collaborative Work. Virtual reality platforms support geographically and culturally dispersed brainstorming teams, possessing strong connective power. Team members could use various shared tools like virtual whiteboards and 3D mind maps in the virtual space for idea organization and communication. Compared to traditional meetings, this form is more inclusive, reducing social anxiety and making participants more willing to actively voice opinions. However, virtual collaboration also faces some quality loss such as visual detail degradation and echoing. In addition, fully virtual remote brainstorming encounters communication difficulties. Therefore, a balance should be sought between online virtual and offline face-to-face meetings to leverage their respective strengths. Occasional offline subgroup discussions could also be incorporated to build member relations. Future work may combine VR, AR and sensing technologies to create higher-fidelity hybrid interaction modes.

Process Management. Virtual reality could apply various intelligent tools to optimize brainstorming process management. For instance, virtual facilitators integrating speech recognition, natural language processing, and machine learning could automatically analyze speech and orchestrate discussions. Virtual facilitators could systematize stage transitions while providing new perspectives when discussions stall. In addition, through analyzing user data, virtual facilitators could provide personalized guidance. However, existing tools lack natural human-computer interaction. Next steps should continue enhancing interaction modes, developing multisensory communication and emotional computing capabilities to create intelligent, high-fidelity virtual facilitators.

6.0 Conclusion and Discussion

This study reviewed the related literature on the application of virtual reality (VR) technology in brainstorming over the past decade. Based on the 4P Creativity Mode, the 21 selected papers were categorized into four classes. Each study's VR application was examined and classified into different tool types. This paper analyzed the advantages and disadvantages of applying VR

technology to brainstorming, while considering development methods of VR applications and impacts of different creativity types. The number of VR research and applications in brainstorming reached peaks in 2018 and 2020, consistent with technological breakthroughs and industrialization of VR devices, highlighting the driving effect of technological innovation. The study also found VR technology characteristics' importance depends on users' cognitive demands. Additionally, this study discussed potential future development directions of VR technology in brainstorming, including aspects of cognitive demands, optimizing creativity, assisting collaboration, and process management. These trends could help participants better understand the role of VR in brainstorming and develop more efficient and meaningful VR applications.

This study has some limitations in fully covering all meaningful research literature. Although some data supported the arguments, limited quantitative research means results may have subjectivity. Specific numerical data helped identify trends and patterns but could not accurately reflect related literature quantities in each category. Future studies could improve objectivity by expanding sample sizes and adopting more rigorous quantitative methods.

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References

Baruah, J., & Green, K. (2023). Innovation in virtual teams: The critical role of anonymity across divergent and convergent thinking processes. The Journal of Creative Behavior. https://doi.org/10.1002/jocb.603

Bhagwatwar, A., A. Massey, & A. Dennis. 2018. "Contextual Priming and the Design of 3D Virtual Environments to Improve Group Ideation." Information Systems Research 29(1): 169–185. https://doi.org/10.1287/isre.2017.0721

Bhagwatwar, A., Massey, A., & Dennis, A. R. (2013, January). Creative virtual environments: Effect of supraliminal priming on team brainstorming. In 2013 46th Hawaii international conference on system sciences (pp. 215-224). IEEE. https://doi: 10.1109/HICSS.2013.152.

Bonnardel, N., & Pichot, N. (2020). Enhancing collaborative creativity with virtual dynamic personas. Applied ergonomics, 82, 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. doi:10. 1080/14606925.2016.1129145.

Bourgeois-Bougrine, S., P. Richard, J.-M. Burkhardt, B. Frantz, & T. Lubart. 2020. "The Expression of Users' Creative Potential in Virtual and Real Environments: An Exploratory Study." Creativity Research Journal 32(1): https://doi.org/10.1080/10400419.2020.1712162

Bourgeois-Bougrine, S., P. Richard, T. Lubart, J. M. Burkhardt, & B. Frantz. 2018. "Do Virtual Environments Unleash Everyone's Creative Potential?" In Proceedings of the 20th Congress of the International Ergonomics Association (IEA 2018) Volume VII: Ergonomics in Design, Design for All, Activity Theories for Work Analysis and Design, Affective Design 20 (pp. 1328-1339). Springer International Publishing. http://link.springer.com/10.1007/978-3-319-96071-5_134

Buisine, S., & J. Guegan. 2020. "Proteus vs. Social Identity Effffects on Virtual Brainstorming." Behaviour & Information Technology 39(5): 594–606. https://doi.org/10.1080/0144929X.2019.1605408

Cady, S. H., & Valentine, J. (1999). Team innovation and perceptions of consideration: What difference does diversity make?. Small group research, 30(6), 730-750. https://doi.org/10.1177/10464964990300060

Cascini, G., Nagai, Y., Georgiev, G. V., Zelaya, J., Becattini, N., Boujut, J. F., ... & Wodehouse, A. (2022). Perspectives on design creativity and innovation research: 10 years later. International Journal of Design Creativity and Innovation, 10(1), 1-30. https://doi.org/10.1080/21650349.2022.2021480

Diehl, M., & Stroebe, W. (1987). Productivity loss in brainstorming groups: Toward the solution of a riddle. Journal of personality and social psychology, 53(3), 497. https://doi.org/10.1037/0022-3514.53.3.497

Dul, J., Ceylan, C., & Jaspers, F. (2011). Knowledge workers' creativity and the role of the physical work environment. Human resource management, 50(6), 715-734. https://doi.org/10.1002/hrm.20454

Fan, M., & Cai, W. (2022). How does a creative learning environment foster student creativity? An examination on multiple explanatory mechanisms. Current Psychology, 41(7), 4667-4676. https://doi.org/10.1007/s12144-020-00974-z

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

Fü rst, G., Ghisletta, P., & Lubart, T. (2016). Toward an integrative model of creativity and personality: Theoretical suggestions and preliminary empirical testing. The Journal of Creative Behavior, 50(2), 87-108. https://doi.org/10.1002/jocb.71

Gelner, A., Eitel, M., Mikhail, M., Olbrich, L., Pierri, A., Borgato, A., & Landgraf, T. (2023). An exploration on the effectiveness of face-to-face and virtual meetings in educational projects dealing with impact innovation. CERN IdeaSquare Journal of Experimental Innovation, 7(1), 12-17. https://doi.org/10.23726/cij.2023.1415

Gonçalves, F., & Campos, P. (2018, September). Mild place illusion: A virtual reality factor to spark creativity in writing. In Proceedings of the 36th European Conference on Cognitive Ergonomics (pp. 1-8). https://doi.org/10.1145/3232078.3232085

Gong, Z., Lee, L. H., Soomro, S. A., Nanjappan, V., & Georgiev, G. V. (2022). A systematic review of virtual brainstorming from the perspective of creativity: affordances, framework, and outlook. Digital Creativity, 33(2), 96-127. https://doi.org/10.1080/14626268.2022.2064879

Gross, M. E., Zedelius, C. M., & Schooler, J. W. (2020). Cultivating an understanding of curiosity as a seed for creativity. Current Opinion in Behavioral Sciences, 35, 77-82. https://doi.org/10.1016/j.cobeha.2020.07.015

Gruszka, A., & Tang, M. (2017). The 4P's creativity model and its application in different fields. In Handbook of the management of creativity and innovation: Theory and practice (pp. 51-71).

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., F. Segonds, J. Barré, N. Maranzana, F. Mantelet, & S. Buisine. 2017. "Social Identity Cues to Improve Creativity and Identifification in Face-to-Face and Virtual Groups." Computers in Human Behavior 77: 140–147. https://doi.org/10.1016/j.chb.2017.08.043

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

Harris, A. (2016). Creativity, education and the arts. London, UK: Palgrave Macmillan. https://doi.org/10.1007/978-3-319-63661-0

Heslin, P. A. (2009). Better than brainstorming? Potential contextual boundary conditions to brainwriting for idea generation in organizations. Journal of Occupational and Organizational Psychology, 82(1), 129-145. https://doi.org/10.1348/096317908X285642

Hu, M., Shealy, T., Milovanovic, J., & Gero, J. (2022). Neurocognitive feedback: a prospective approach to sustain idea generation during design brainstorming. International Journal of Design Creativity and Innovation, 10(1), 31-50. https://doi.org/10.1080/21650349.2021.1976678

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

Hwang, A. H. C., Sun, Y., McKee, C., & Won, A. S. (2020, March). Real or surreal: A pilot study on creative idea generation in MR vs. VR: Anonymous. In 2020 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW) (pp. 676-677). IEEE. https://doi:10.1109/VRW50115.2020.00189.

Ide, M., Oshima, S., Mori, S., Yoshimi, M., Ichino, J., & Tano, S. (2020, December). Effects of avatar's symbolic gesture in virtual reality brainstorming. In Proceedings of the 32nd Australian Conference on Human-Computer Interaction (pp. 170-177). https://doi.org/10.1145/3441000.3441081

Ismailovich, S. A. (2021). Socio-Psychological Problems of Educating an Independent-Minded, Creative Person in the Educational Process. Central asian journal of literature, philosophy and culture, 2(12), 4-7. https://doi.org/10.47494/cajlpc.v2i12.264

Kim, H., So, H. J., & Park, J. Y. (2022). Examining the effect of socially engaged art education with virtual reality on creative problem solving. Educational Technology & Society, 25(2), 117-129. https://www.jstor.org/stable/48660128

Kim, M., & Lim, C. (2021). Developing a Scientific Creativity Test to Explore the Relationship between Elementary Students' Creative Process and Product-Focusing on Biology. Journal of Korean Elementary Science Education, 40(4), 520-544. https://doi.org/10.15267/keses.2021.40.4.520

Kuťák, D., Doležal, M., Kerous, B., Eichler, Z., Vašek, J., & Liarokapis, F. (2019). An interactive and multimodal virtual mind map for future workplace. Frontiers in ICT, 6, 14. https://doi.org/10.3389/fict.2019.00014

Li, Y., Mohd Nordin, N. R., Akhter, S., Kumar, T., & Shaheen, M. (2022). Does green entrepreneurial behavior enhance through entrepreneurship education, perceived-ability to use technology, and commitment to environment? Understanding the contribution of entrepreneurial motivation and university support. Economic Research-Ekonomska Istraživanja, 1-20.

Li, Z. (2021). Creativity and opportunity: How COVID-19 fosters digital dance education. Digital Creativity, 32(3), 188-207. https://doi.org/10.1080/14626268.2021.1967406

Liang, W., Akhter, S., & Kumar, T. (2022). Relationship Between Unhappy Musicians, Resistance Toward Innovation and Uncreative Music Products: Psychological Security as Moderator. Frontiers in Psychology, 13, 922404-922404.

Maslow, A. H. (1962). Toward a Psychology of Being. New York, Cincinnati.

Mazza, Alessandro, Olga Dal Monte, Selene Schintu, Samuele Colombo, Nicola Michielli, Pietro Sarasso, Peter Törlind, Marco Cantamessa, Francesca Montagna, & Raffaella Ricci. "Beyond alpha-band: The neural correlate of creative thinking." Neuropsychologia 179 (2023): 108446. https://doi.org/10.1016/j.neuropsychologia.2022.108446

Minas, R. K., A. R. Dennis, & A. P. Massey. 2016. Opening the Mind: Designing 3D Virtual Environments to Enhance Team Creativity. 2016 49th Hawaii International Conference on System Sciences (HICSS), 247–256. https://doi:10.1109/HICSS.2016.38

Moher, D., Shamseer, L., Clarke, M., Ghersi, D., Liberati, A., Petticrew, M., ... & Stewart, L. A. (2015). Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. Systematic reviews, 4(1), 1-9. https://doi.org/10.1186/2046-4053-4-1

Monahan, T., McArdle, G., & Bertolotto, M. (2008). Virtual reality for collaborative e-learning. Computers & Education, 50(4), 1339-1353. https://doi.org/10.1016/j.compedu.2006.12.008

Morales, M. C. T, Yamamoto, K., & Tsujino, Y. (2020). SyncMeet: Virtual Work Environment for Collaborative Manga Creation. In Design, User Experience, and Usability. Case Studies in Public and Personal Interactive Systems: 9th International Conference, DUXU 2020, Held as Part of the 22nd HCI International Conference, HCII 2020, Copenhagen, Denmark, July 19–24, 2020, Proceedings, Part III 22 (pp. 518-532). Springer International Publishing. https://doi.org/10.1007/978-3-030-49757-6_38

Morozov, M., Smorkalov, A., & Fominykh, M. (2014, July). Sticky Notes--A Tool for Supporting Collaborative Activities in a 3D Virtual World. In 2014 IEEE 14th International Conference on Advanced Learning Technologies (pp. 683-687). IEEE. https://doi: 10.1109/ICALT.2014.200.

Osborn, A. F. (1953). Applied imagination.

Paulus, P. B., & Nijstad, B. A. (Eds.). (2003). Group creativity: Innovation through collaboration. Oxford University Press.

Paulus, P. B., & Yang, H. C. (2000). Idea generation in groups: A basis for creativity in organizations. Organizational behavior and human decision processes, 82(1), 76-87. https://doi.org/10.1006/obhd.2000.2888

Petrykowski, M., Berger, P., Hennig, P., & Meinel, C. (2019). Digital collaboration with a whiteboard in virtual reality. In Proceedings of the Future Technologies Conference (FTC) 2018: Volume 1 (pp. 962-981). Springer International Publishing. https://doi:10.1007/978-3-030-02686-8_72.

Pituxcoosuvarn, M., Victoria, A. K., OGATA, H., & MURAKAMI, Y. (2021). Effects of Virtual Reality on Students' Creative Thinking during a Brainstorming Session. In 29th International Conference on Computers in Education Conference, ICCE 2021 (pp. 387-391).

Radianti, J., Majchrzak, T. A., Fromm, J., & Wohlgenannt, I. (2020). A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda. Computers & Education, 147, 103778. https://doi.org/10.1016/j.compedu.2019.103778.

Rhodes, M. (1961). An analysis of creativity. The Phi delta kappan, 42(7), 305-310. https://www.jstor.org/stable/20342603

Shah, J. J., Vargas-Hernandez, N., & Smith, S. M. (2003). Metrics for measuring ideation effectiveness. Design studies, 24(2), 111-134. https://doi.org/10.1016/S0142-694X(02)00034-0

Sternberg, R. J. (Ed.). (1999). Handbook of creativity. Cambridge University Press.

Stolaki, A., & Economides, A. A. (2018). The Creativity Challenge Game: An educational intervention for creativity enhancement with the integration of Information and Communication Technologies (ICTs). Computers & Education, 123, 195-211. https://doi.org/10.1016/j.compedu.2018.05.009

Strohmann, T., Siemon, D., & Robra-Bissantz, S. (2017). brAInstorm: Intelligent assistance in group idea generation. In Designing the Digital Transformation: 12th International Conference, DESRIST 2017, Karlsruhe, Germany, May 30–June 1, 2017, Proceedings 12 (pp. 457-461). Springer International Publishing. https://doi.org/10.1007/978-3-319-59144-5_31

Sucu, B., & Folmer, E. (2014). The blind driver challenge: steering using haptic cues. In Proceedings of the 16th international ACM SIGACCESS conference on Computers & accessibility (pp. 3-10). https://doi.org/10.1145/ 2661334. 2661357

Tu, J. J., & Akhter, S. (2022). Exploring the role of Entrepreneurial Education, Technology and Teachers' Creativity in excelling Sustainable Business Competencies. Economic Research-Ekonomska Istraživanja, 1-19.

Xie, D., Saeed, N., Akhter, S., & Kumar, T. (2022). A step towards a sustainable environment in top Asian countries: the role of higher education and technology innovation. Economic Research-Ekonomska Istraživanja, 1-24.

Yang, E. K., & Lee, J. H. (2020). Cognitive impact of virtual reality sketching on designers' concept generation. Digital Creativity, 31(2), 82-97. https://doi.org/10.1080/14626268.2020.1726964

Yu, G., Akhter, S., Kumar, T., Ortiz, G. G. R., & Saddhono, K. (2022). Innovative application of new media in visual communication design and resistance to innovation. Frontiers in Psychology, 13.

Zhang, D., Akhter, S., Kumar, T., & Nguyen, N. T. (2022). Lack of Emotional Experience, Resistance to Innovation, and Dissatisfied Musicians Influence on Music Unattractive Education. Frontiers in Psychology, 13.

Zhang, X., Akhter, S., Nassani, A. A., & Haffar, M. (2022). Impact of News Overload on Social Media News Curation: Mediating Role of News Avoidance. Frontiers in Psychology, 13, 865246-865246.

Zhang, Z., Akhter, S., & Al-Abyadh, M. A. (2022). Determinants of Unverified News Sharing on Social Media and Its Effects on Corporate Image. Frontiers in Psychology, 3583.

Zwir, I., Del-Val, C., Hintsanen, M., Cloninger, K. M., Romero-Zaliz, R., Mesa, A., ... & Cloninger, C. R. (2022). Evolution of genetic networks for human creativity. Molecular psychiatry, 27(1), 354-376. https://doi.org/10.1038/s41380-021-01097-y