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Review Article

The Impact of Embodied and Enacted Metaphors on Cognition and Emotions in Technology-Mediated Experiences: A Scoping Review

Giulia Magni,[1,2] **Silvia Francesca Maria Pizzoli**,[1,3] **Elisa Scerrati**,[1,2] **and Claudia Repetto**[1]

[1]*Department of Psychology, Università Cattolica del Sacro Cuore, Milan, Italy*
[2]*Humane Technology Laboratory, Università Cattolica del Sacro Cuore, Milan, Italy*
[3]*Department of Psychology and Health Sciences, LAHTI–Laboratory for Advanced Human–Technology Interaction, Pegaso University, Naples, Italy*

Correspondence should be addressed to Giulia Magni; giulia.magni@unicatt.it

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Metaphors are a fundamental tool for shaping human understanding and interaction with the world. Indeed, they play a crucial role in cognitive and emotional processes, enabling individuals to comprehend one domain of experience in terms of another. Grounded in the Conceptual Metaphor Theory, this scoping review emphasizes the significant role of the body in metaphorical cognition and examines how technology may enhance cognitive and emotional abilities through metaphorical embodiment and enactment. Additionally, the review proposes the theoretical frameworks of active inference and Bayesian brain to provide a deeper understanding of how embodied metaphors shape cognitive and emotional experiences by integrating past experiences with current sensory inputs to make predictions about the future. Searches were conducted in the PubMed, PsycINFO, Scopus, and Web of Science databases to extract relevant articles. Out of the 2648 articles retrieved, a total of 19 studies met the inclusion criteria, comprising 15 studies concerning the effect of metaphors on different cognitive abilities (i.e., learning, creative cognition, and perception) and 4 studies regarding emotions (i.e., emotional regulation, arousal, and psychophysiological correlates). Data from these studies were systematically extracted, tabulated, and subjected to a narrative synthesis. Overall, findings suggest that the embodiment and enactment of metaphors, facilitated by immersive technologies, significantly influence cognitive processes and emotional experiences. This enhancement is observed across diverse demographic groups, indicating broad applicability. Despite promising implications, the review identifies a need for further research, especially among clinical populations and in exploring metaphors not traditionally framed within the Conceptual Metaphor Theory.

Keywords: active inference; cognition; embodied cognition; emotion; enacted metaphor; immersive technologies; metaphor; virtual reality

1. Introduction

A metaphor is a figure of speech that enables individuals to comprehend one domain of experience in terms of another [1]. According to Lakoff and Johnson [1], metaphors are not mere linguistic constructs but an inherent part of our thought processes, serving as indispensable tools in conveying complex and abstract concepts through structured mappings that link them to more concrete and familiar notions in everyday language. According to Cuccio [2], embodied metaphorical cognition views the body as the source domain of metaphorical mappings, therefore playing a crucial role in cognitive processes. Indeed, according to some accounts (e.g., [3]), the representations of the body itself are crucial for impacting cognition and structuring the conceptual system. A conceptual distinction between the body schema and the body image should take into account Gallagher's [4, 5] view. Indeed, the body's dual role—both as an object of intentional consciousness and as a motor system that enables movement—must be acknowledged in cognitive and perceptual processes, as well as its integral function in shaping perceptions, movements, and interactions within the world. Specifically, the body schema is a system of sensorimotor processes that constantly regulate posture and movements, allowing us to navigate and perceive the world, without the need for reflective awareness or perceptual monitoring, and it refers to the motor abilities that are foundational to action and perception. In contrast, the body image is the result of our perception and mental image of our own body. One of the body schema's functions concerns cross-modal communication, that is, the ability to transform visual inputs into motor competence, which suggests the presence of a mechanism of activation of perception and emotion-related areas of the brain, also referred to as embodied simulation. The embodied simulation is activated not only by direct observation of others but also by cognitive tasks such as mental imagery and language comprehension [6]. Cuccio [2] argues that the body schema and the body image interact in an embodied simulation. On the one hand, the former is the primary and basic source of an associative mapping from sensorimotor abilities to perception, which is enacted and cannot be passively received. On the other hand, in metaphors from the body image, the source of the metaphor is the body as an object of representation and knowledge.

In light of these insights into embodied cognition, it is essential to consider the foundational framework provided by the Conceptual Metaphor Theory (CMT) proposed by Lakoff and Johnson [1], which posits that metaphors are a cognitive tool that people use to understand abstract concepts by mapping them onto more concrete, familiar notions. This framework suggests that metaphors meaningfully reflect how bodily experiences guide mental processes, with research indicating significant metaphorical effects on attention, memory, social perception, attitudes, and judgments. For instance, it has been observed how holding a warm cup can make people perceive others as warmer in personality, while thinking about a "rough day" leads to perceiving physical surfaces rougher [7]. This implies that metaphors meaningfully reflect how bodily experiences project their schematic or inferential structures to guide mental processes [8, 9]. Indeed, drawing on an embodied cognition perspective, metaphor comprehension is considered to rely on sensorimotor simulation [10–12]. Wilson and Gibbs [13] highlight how real and imagined body movements prime metaphor comprehension, emphasizing the role of embodied metaphors in structuring abstract domains. This supports the notion that metaphors, by invoking bodily experiences, significantly influence cognition and emotions [13, 14]. On this note, Lakoff and Johnson [1] argue that conceptual and perceptual processes share many of the same physiological and neurophysiological subprocesses: Within an embodied mind, the same neural system engaged in perception (lower level activities) plays a central role in conceptualization (higher level cognitive abilities). Research suggests that both weak and strong forms of embodiment may significantly have an impact. Indeed, the weak embodiment perspective acknowledges the role of sensorimotor experiences in shaping cognition while also suggesting that cognitive processes can also operate independently [15]. Conversely, the strong versions of embodied cognition, where the sensorimotor experiences and cognitive processes are conceived as more directly linked, may have a more impactful explanatory power but encounter many theoretical and practical challenges [16]. Therefore, the strength of embodiment is an important aspect to take into consideration when exploring how individuals engage with abstract concepts.

Building on these insights into embodied cognition and metaphor comprehension, the role of advanced technologies, particularly extended reality (XR), becomes increasingly significant in exploring and understanding the link between these phenomena. XR technologies facilitate more immersive and interactive experiences by combining physical and digital environments, such as virtual reality (VR) and augmented reality (AR). Specifically, VR refers to fully immersive digital environments that engage users through the use of headsets and controllers, while AR integrates digital elements with the physical world by adding digital layers to the real-world environment. Indeed, embodied technologies, such as VR, can help understand how the brain operates: Through the creation of an embodied simulation of the body in the world, actions, concepts, and emotions are represented and predicted [17, 18]. Therefore, similarly to the brain, XR maintains a model of the body and the space around it in order to predict the consequences of one's actions, thoughts, and emotions [19, 20]. Thanks to the embodied properties of these media, individuals can be immersed in simulated environments, where physical actions and perceptions can be closely aligned with virtual experiences. This allows researchers to manipulate and examine the intricate dynamics of metaphorical thinking in real time [14]. Moreover, XR's capacity to simulate different scenarios and its ability to strongly induce emotional reactions in the users can help dissect the mechanisms through which bodily sensations and actions shape cognitive and emotional processes, offering a deeper understanding of the embodied nature of metaphorical thought [10, 21]. Thus, embodied technologies are described both as a methodological toolkit and a way to deepen the theoretical understanding of metaphors as fundamental elements of human cognition.

1.1. Rationale and Objectives. Grounded in the CMT, this scoping review embarks on a systematic exploration of how embodied and enacted metaphors, facilitated by technology, shape cognitive and emotional abilities. Specifically, embodied metaphors refer to metaphors grounded in the bodily experiences and sensorimotor systems to understand abstract concepts, such as "grasping an idea." Enacted metaphors, instead, involve physically performing actions that represent these concepts, like breaking through virtual walls to symbolize overcoming obstacles. Emphasizing the body's integral role, as posited by embodied metaphorical cognition [2], we delve into how technological modalities serve as conduits for metaphorical engagement, enhancing cognitive abilities such as memory, problem solving, and creative thinking, as well as emotional regulation and arousal.

This scoping review will provide a comprehensive overview of the diverse ways in which embodied and enacted metaphors, using various technological modalities that foster a sense of immersion, presence, and agency in VR, affect cognition and emotions. Specifically, immersion refers to the VR system's ability to deliver a vivid and surrounding virtual environment [22], presence is the subjective experience of being in one place even when physically situated in another [23], and agency addresses the user's capacity to act within the virtual environment and see the effects of their actions [24].

The following research question determined the aim of the review:

How does the embodiment and enacting of metaphors through technology-mediated experiences impact cognition and emotions?

Specifically, the paper seeks to investigate how the use of various technological tools such as VR, desktop interfaces, and videogames impacts the fruition of metaphors and influences cognitive (e.g., memory, problem solving, decision-making, attentional focus, creative thinking, linguistic abilities, and mental imagery) and affective abilities (e.g., emotional regulation, mood states, and emotional expression). Moreover, it aims to explore these effects across diverse demographic groups, including both clinical and healthy populations, spanning various age ranges.

Therefore, the specific research questions are as follows:

i. Which metaphors are implemented through technological media to investigate the impact on cognitive and emotional areas?

ii. How do the embodiment and enactment of metaphors influence cognitive processes?

iii. How do the embodiment and enactment of metaphors influence emotional experiences and expressions?

As the literature suggests [9, 25–27], the main hypothesis is that the embodiment and enactment of metaphors through technology-mediated experiences have significant implications for cognition and emotions. Considering the immersive nature of new technologies, it is anticipated that such embodiment and enactment of metaphors may enhance individuals' sense of agency and engagement, amplifying their impact on cognition and emotions.

2. Methods

2.1. Protocol and Registration. To the best of our knowledge, there have been no other attempts at using a scoping review approach to investigate the relationship between embodied and enacted metaphors on cognition and emotion. Thus, the present scoping review is aimed at collecting and consolidating existing knowledge on the topic as well as exploring the implications and significance of the findings from earlier studies. Specifically, this framework allows the synthesis of the literature and facilitates the exploration, mapping, and understanding of the current available literature [28]. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRISMA-ScR; [29]) was used as the reporting guideline for the final review outcomes. The protocol of the present scoping review has been registered in the Open Science Framework (osf.io/r84ym; [30]).

2.2. Search Strategy. Data were gathered on October 21, 2024, through a computerized search across four prominent databases: PubMed, Scopus, Web of Science, and PsycINFO. Each database was searched independently using a specific search string comprising various terms and truncations to specify the population and outcomes of interest (see supporting information (available here)). The following string was used to filter titles, abstracts, and keywords of the articles:

metaphor∗ AND cognit∗ OR memory OR language∗ OR linguistic OR reason∗ OR learn∗ OR attenti∗ OR executive function∗ OR emotion∗ AND technolog∗ OR immersive reality OR extended reality OR virtual reality OR augmented reality OR mixed reality OR desktop OR videogam∗.

Supplementary search methods, including the ascendancy and descendancy approaches, were employed to broaden the relevant articles pool by considering articles that were referenced or that cited the key studies identified during the initial search. Additionally, preprint articles relevant to the review were searched on PsyArXiv.

Results from each database search were imported into Rayyan [31] to detect duplicates.

2.3. Study Selection. A total of 3170 studies was initially retrieved from the searches on PubMed, PsycINFO, Web of Science, and Scopus databases. Following the removal of duplicates, 2749 articles remained, which underwent screening for relevance based on titles, abstracts, and keywords. Subsequently, the full-text versions of the remaining 36 articles were reviewed, resulting in the inclusion of 19 articles in the present review. Specifically, two authors (G.M. and S.F.M.P.) independently screened first the titles and abstracts and then the full texts against the eligibility criteria and, if necessary, resolved conflicts through discussion with a third author.

In particular, studies meeting the following criteria were included:

1. Written in English.

2. Containing experimental data; hence, publications of other types such as meta-analyses, systematic reviews, editorials, reviews, and perspectives were excluded.

3. Conducted on human subjects; consequently, studies that did not include human participants were not included.

4. Assessed specific outcomes pertaining to cognition or emotion using a quantitative approach, thereby excluding studies employing qualitative data.

5. Included the concept of metaphor that aligns with the CMT framework.

Articles were excluded if they failed to meet the inclusion criteria. Specifically, the most common reasons for exclusion included being of other publication types (e.g., editorials, reviews, and book chapters), lacking quantitative outcomes related to cognitive and affective processes, and not assessing metaphors as defined in this review. Further details of the study selection process are provided in the PRISMA flowchart (Figure 1).

2.4. Data Extraction. A narrative report was produced to synthesize the extracted data concerning several key outcomes: study characteristics, features of the technology employed, intervention objectives, associated outcome measures, and characteristics of the metaphor employed. These findings are described in connection with the research subquestions and within the broader context of the study's purpose.

The relevant articles span a range of publication years from 2012 to 2024. For each study deemed eligible for inclusion, a predetermined set of elements was extracted, that is: (a) metadata (i.e., authors and publication year), (b) sample characteristics, (c) cognitive or emotional processes under investigation, (d) type of technology used (e.g., immersive VR and desktop), (e) type of metaphor employed (e.g., embodied or enacted), and (f) primary outcomes. A summary of the extracted data for each article included is presented in Table 1. The extracted data was then subsequently employed to address the research questions by synthesizing findings across included sources.

3. Results

3.1. Study Characteristics. Overall, 19 studies met the inclusion criteria and were included in the present review. Table 1 presents a synthesis of the data extracted from each paper included in the review.

Concerning the sample populations, 11 studies [32–42] included adult participants ($n = 453$, aged between 19 and 32 years), 4 papers [43–46] reported studies conducted among underage populations ($n = 531$, aged between 12 and 15 circa), and 4 papers [26, 47–49] did not report the age of the sample ($n = 276$). Notably, all the studies included in the review involved healthy participants, apart from one that included children with autism spectrum disorder (ASD) [43].

Most studies [26, 33, 36–44, 48] used immersive VR through head-mounted displays. However, nonimmersive VR devices such as desktop screens [32, 34, 45, 46, 49] and tablets [47] were also employed. Finally, one study used AR glasses [35].

All the studies assessed the impact of embodying metaphors in technology-mediated experiences from a cognitive and behavioral perspective. Specifically, six articles measured behavioral variables such as the accuracy and reaction time of the responses [33, 35, 39, 40, 47, 48]. Eleven studies used self-report questionnaires [32, 36–38, 41, 43, 44, 46–49]. Finally, only one study [41] included neuroimaging measurements, specifically the use of fNIRS to investigate the activation and inhibition of different brain areas during the activity of virtually embodying the metaphor "breaking the walls," symbolizing breaking the rules.

3.2. Synthesis of Results. To systematize the data obtained from the included studies, first the type of metaphors employed is described, and then the results are grouped together according to the target outcomes (perception, cognition, and emotion).

Among the included articles, three studies investigated creative cognition [26, 41, 42], five studies focused on learning [44–47, 49], six studies investigated perception, specifically concerning color [35], numbers [34], time [33, 48], and peripersonal and interpersonal space [39, 40], and one study focused on perspective-taking and empathy [43], while the remaining four studies investigated emotions [32, 36–38].

The synthesis of findings from the included studies provides a comprehensive overview of how embodied and enacted metaphors significantly impact cognition and emotions through technology-mediated experiences; therefore, it addresses the core research questions of this review. Across a variety of technological modalities (i.e., immersive VR, AR, and desktop interfaces), the studies collectively demonstrate that the embodiment and enactment of metaphors can influence cognitive processes such as memory performance, problem solving, creative thinking, and affective abilities such as emotional regulation.

Concerning the metaphors used in the included studies, the commonalities among them lie in their capacity to leverage technology-mediated environments to embody and enact abstract concepts, thereby making them accessible and experientially real to participants.

For instance, Löffler [35] proposes the embodiment of the metaphors that view concepts such as difficulty, importance, guilt, and sadness as visually heavy and saturated, while activity, happiness, and intimacy are warm and bright. Therefore, the study consisted of asking participants to associate different concepts with colored spheres, whose intensity, saturation, and hue changed. Similarly, Ruggiero and colleagues [40] used the metaphor of closeness as warmth and distance as cold to study peripersonal and interpersonal space. To enact the metaphorical experience, participants were asked to hold a cup of water with different temperatures (hot, cold, and room temperature) and carry out a task determining reachability (peripersonal) and comfort (interpersonal) distances from virtual people. Qin and colleagues [39] introduced the metaphor "a safety boundary is a breached wall" to study how visual cues influenced participants' perception and intruder detection in virtual environments, showing the metaphor's effectiveness in focusing attention and enhancing response efficiency. Kopiske and Franz [34] investigated the embodied perception of numerical concepts through the metaphor according to which numbers appear

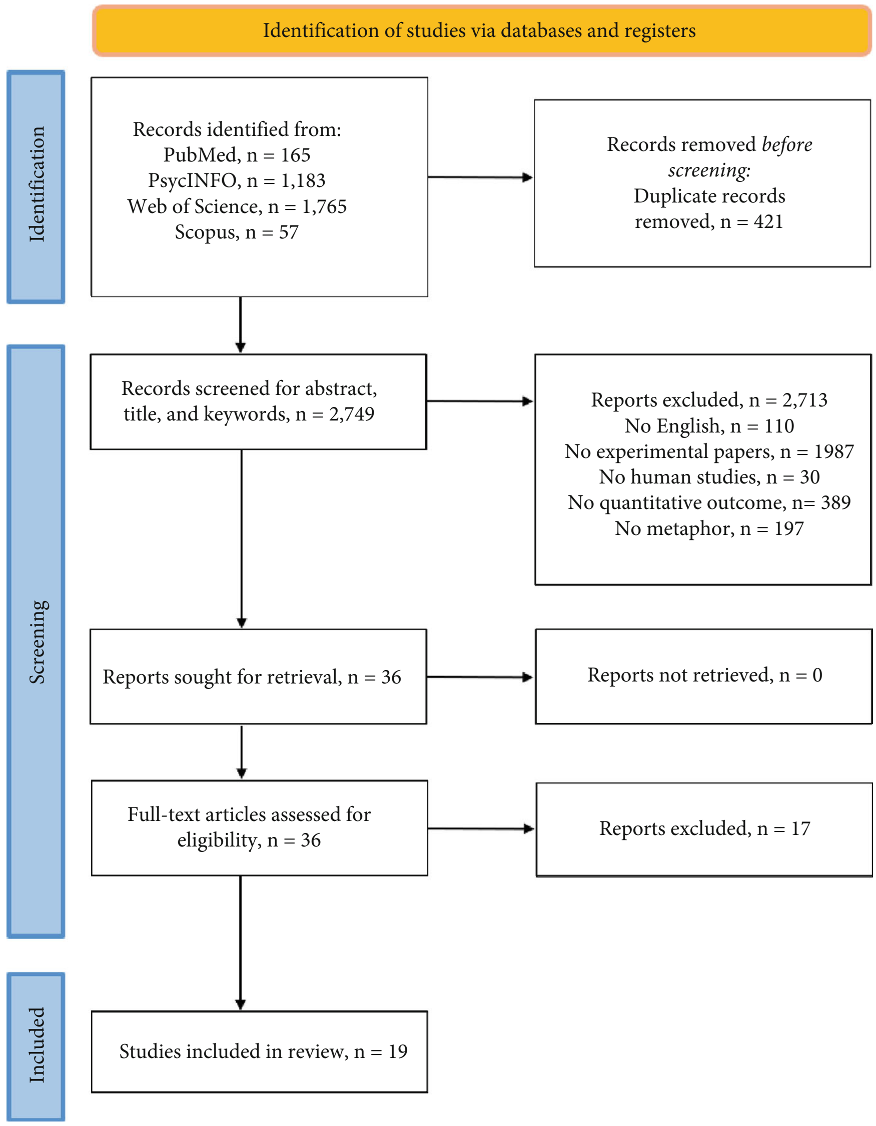

Figure 1: PRISMA flow diagram of study selection.

in a linear manner, comparing symbolic and nonsymbolic number lines as viewed on a desktop screen. Their findings showed that symbolic magnitudes were consistently perceived as linear and accurate, while nonsymbolic magnitudes were often underestimated, suggesting the relevance of framing magnitudes as linear. Two studies [33, 48] explored the embodiment of the metaphor of time, where the future is ahead and the past is behind. The former focused on the influence of the movement experience on space–time mapping on the lateral and sagittal axes, therefore immersing participants in a virtual environment moving forwards or backwards and investigated the psychological distance perceived from past and future events [48]. The latter investigated the temporal Doppler effect, which suggests that, just as they move through space, individuals also move through time, both on a lateral and sagittal axis, and this affects their perception of past and future events. Specifically, it proposes that future events feel psychologically closer to us than past events [33].

Two studies by Wang and colleagues [41, 42] examined the metaphor of breaking the walls to symbolize thinking freely, with both embodied and enacted experiences in which participants walked in a virtual corridor and encountered a brick wall. To keep walking, they had to destroy it either with a movement of their hand or by getting close to it. Similarly, Sidekerskienė and Damaševičius [49] explored breaking down barriers in STEM (i.e., science, technology, engineering, and mathematics) education, embodying the metaphor by developing a digital escape room where groups of students were asked to solve complex problems in the STEM subjects in order to win. The improvements in students' understanding and motivation following the experience show the potential of the embodied metaphor for enhancing learning. Leung and colleagues [26] used the enacted metaphor of thinking outside the box to enhance creative problem solving by asking participants to walk freely in a virtual environment as opposed to following a standard path. Two studies [45, 47] used the metaphor of

TABLE 1: Relevant data extracted from each included study.

Year	Authors	Sample (country)	Processes investigated	Technology used	Type of metaphor	Aims of the study	Data results	Primary outcomes
2015	Löffler, Paier, Toriizuka, Ikeda, Hurtienne	14 ($M_{age} = 22.7$, SD = 0.8; 7 males) (Japan)	Perception	AR	Embodied; difficulty, importance, guilt, and sadness are heavy and saturated; activity, happiness, and intimacy are warm and bright	Testing of the embodied cognition view on color and its influence on cognitive processing of abstract information metaphorically linked to tactile properties. It is hypothesized that specific color characteristics related to tactile properties will trigger choices consistent with metaphorically related abstract concepts	M = 0.67, SD = 0.26	Across all 23 color-to-abstract concept mappings, at least 83% of the participants' choices were consistent with the conceptual metaphor. There was no difference between the different hues tested across the weight and size condition
2018	Kopiske, Franz	Study 1: 6 ($M_{age} = 32.2$; 4 females) Study 2: 8 ($M_{age} = 22.9$; 6 females) Study 3: 8 ($M_{age} = 23.9$; 6 females) Study 4: 6 ($M_{age} = 25.7$; 4 females) Study 5: 36 ($M_{age} = 24$; 24 females) (Germany)	Perception	Desktop	Embodied; numbers are perceived as a line and not a magnitude	Investigation of the mapping from stimulus to internal magnitude representation and from internal representation to response. The study seeks to understand the robustness of the nonlinear shape to calibration and the influence of both stimuli and output measures on this shape	Study 2, symbolic: $R^2 = 0.99$; nonsymbolic: $R^2 = 0.91$ Study 3, sym: $R^2 = 0.99$; nonsym: $R^2 = 0.77$ Study 4, sym: $R^2 = 0.99$; nonsym: $R^2 = 0.50$	Across five experiments, responses to symbolic magnitudes were consistently linear and accurate, whereas responses to nonsymbolic magnitudes showed underestimation for larger numbers and variability in accuracy, particularly when tasks became more complex. Experiment 5 revealed task-specific feedback improved the accuracy of ruler-based tasks, without affecting typed responses, indicating calibration effects were task-specific and did not generalize across different response modalities

TABLE 1: Continued.

Year	Authors	Sample (country)	Processes investigated	Technology used	Type of metaphor	Aims of the study	Data results	Primary outcomes
2023	Jiang, Hao, Huang, Chen, Cheng, Fan, Ding	Study 1: 44 (M_{age} = 20.07; 36 females) Study 2: 44 (M_{age} = 19.84; 29 females) (China)	Perception	VR + HMD	Embodied; the future is ahead; the past is behind	Investigation of how movement experience influenced the space–time mapping on the lateral and sagittal axes using VR	Study 1: rightward M_{cong} = 98.48, SD = 1.13 M_{inc} = 97.5, SD = 2.68 leftward M_{cong} = 96.7, SD = 3.6 M_{inc} = 97.5, SD = 2.68 Study 2: M_{cong} = 97.95, SD = 1.65 M_{inc} = 97.08, SD = 2.99	Experiment 1 found a significant space–time congruency effect in rightward movements with faster response times (RTs) and marginally higher accuracy in congruent conditions, which was not observed in leftward movements, suggesting lateral movement direction influences space–time mapping. Experiment 2 revealed a consistent space–time congruency effect on the sagittal axis, unaffected by movement direction, contrasting with lateral axis findings and indicating that incongruent sensorimotor experiences impact spatial time mapping differently across dimensions
2019	Ruggiero, Rapuano, Iachini	34 (M_{age} = 23.78, SD = 3.8; 17 females) (Italy)	Perception	VR + HMD	Enacted; closeness is warm; distance is cold	Investigation of the influence of perceived temperature on peripersonal and interpersonal spaces, hypothesizing a relation between physical experience and social interactions	Reachability: M_{cold} = 57.7, SD = 37.9 M_{warm} = 53.3, SD = 41.4 $M_{roomtemp}$ = 39.2, SD = 22.9 Comfort: M_{cold} = 64.7, SD = 45.5 M_{warm} = 52.3, SD = 42.2 $M_{roomtemp}$ = 43.6, SD = 28.3 Gender effect: M_{male} = 53.9, SD = 43.1 M_{female} = 49.9, SD = 38.1	Temperatures influenced peripersonal and interpersonal distances differently by gender, with cold increasing reachability and comfort distances more than warm temperatures. Gender of participants and virtual confederates

TABLE 1: Continued.

Year	Authors	Sample (country)	Processes investigated	Technology used	Type of metaphor	Aims of the study	Data results	Primary outcomes
								also affected preferred distances, illustrating temperature's complex impact on personal space regulation
2013	Caruso, Van Boven, Chin, Ward	Study 3: 80 (USA)	Perception	VR + HMD	Embodied; the future is ahead; the past is behind	Investigation of the temporal Doppler effect, hypothesizing the existence of an analogy between movement through time and space. Exploration of the influence of spatial embodiment on temporal psychological distance	Past: $M_{forward} = 6.06$, SD = 1.68 $M_{backward} = 4.96$, SD = 2.14 Future: $M_{forward} = 4.78$, SD = 1.83 $M_{backward} = 5.41$, SD = 1.46	Spatial movement influenced psychological distance to the past and future, with forward movement making the future seem closer. This "temporal Doppler effect" suggests spatial metaphors impact temporal perception, altering perceived distances to past and future events based on movement direction
2024	Qin, Qin, Su, Tian	30 ($M_{age} = 21.5$; 26 males) (not available)	Perception	VR + HMD	Embodied; a safety boundary is a breached wall	Investigation of how the BrokenWall awareness cue impacts the speed and efficiency of intruder detection in VR compared to existing cues	Average time—human detection $M_{BrokenWall} = 1.97$, SD = 0.6 $M_{Halo} = 2.37$, SD = 0.6 $M_{Radar} = 2.66$, SD = 0.7 Average time—pet detection $M_{BrokenWall} = 1.88$, SD = 0.5 $M_{Halo} = 2.13$, SD = 0.5 $M_{Radar} = 2.63$, SD = 0.8	The BrokenWall cue significantly reduced detection time compared to other existing cues, enhancing user response efficiency
2018	Wang, Lu, Runco, Hao	41 ($M_{age} = 21$, SD = 1.98; 38 females) (not available)	Creativity	VR + HMD	Enacted; breaking the walls as thinking freely	Investigation of the impact of embodying the metaphor "breaking the rules" through the experience of "breaking the walls" in a VR context on creative performance. It is hypothesized that participants in the "break" condition	$R^2 = 0.76$	Breaking the walls significantly enhances creative originality, without being affected by the mode of reporting. Creative performance improves under the break condition, evidenced by longer reporting durations and a correlation between

TABLE 1: Continued.

Year	Authors	Sample (country)	Processes investigated	Technology used	Type of metaphor	Aims of the study	Data results	Primary outcomes
						would exhibit better creative performance		originality and both flexibility and persistence. However, the impact of the break condition on originality becomes nonsignificant when considering flexibility and persistence as mediators, indicating their full mediation role in enhancing creative outcomes
2012	Leung, Kim, Polman, Ong, Qiu, Goncalo, Sanchez-Burks	73 (38 males) (not available)	Creativity	VR + HMD	Enacted; thinking outside the box as thinking freely	Investigation of the effects of embodying metaphors for creativity on creative problem solving and of the connection between concrete bodily experiences and creative cognition. It is hypothesized that cognitive processes facilitating the generation of new ideas are activated	$M_{free-walk} = 5.71$, SD = 2.63 $M_{fixed-path} = 7.00$, SD = 2.78	Fluency and flexibility did not differ between conditions, but in the free walking condition, participants generated ideas that were more unconventional and more original
2019	Wang, He, Lu, Deng, Qiao, Hao	Study 3: 90 ($M_{age} = 21.55$, SD = 1.98; 67 females) (China)	Creativity	VR + HMD	Embodied and enacted; breaking the walls as thinking freely	Exploration of the neural correlates of the embodied metaphor "breaking the rules" and its effects on creativity using fNIRS, with specific hypotheses regarding creative performance and brain activation in different conditions	Novelty - Break wall: $R^2 = 0.947$ - Autowall: $R^2 = 0.628$ - No wall: $R^2 = 0.607$ Numerosity - Break wall: $R^2 = 0.883$ - Autowall: $R^2 = 0.654$ - No wall: $R^2 = 0.726$	Breaking walls led to higher originality, fluency, and flexibility in creative tasks than autowall and no-wall conditions, with originality increasing and fluency decreasing over time. Frontopolar areas showed less activation in the break-wall condition, indicating less effort or engagement was required. Task-specific

TABLE 1: Continued.

Year	Authors	Sample (country)	Processes investigated	Technology used	Type of metaphor	Aims of the study	Data results	Primary outcomes
								feedback significantly improved creative performance in the break-wall condition, demonstrating the positive effects of active engagement and feedback on creativity
2019	Alyami, Alawami, Lyndon, Alyami, Coomarasamy, Henning, Hill, Sundram	45 (34 females) (New Zealand)	Learning	iPads	Enacted; learning is a game	Comparison of the effectiveness of a 3D serious game with a text file in teaching history-taking content of a cardiac system to medical students	$M_{control} = 14.33$, $SD = 4.52$ $M_{game} = 15.04$, $SD = 4.28$	Both groups showed significant within-group differences, yet no significant differences were found between them in cognitive load, level of difficulty, or OSCE performance postintervention. The VMG group reported significantly higher satisfaction levels than the PDF group, aligning with literature on medical education SGs being as effective as traditional methods, with VMG showing greater satisfaction benefits
2023	Sidekerskienė, Damaševičius	77 (Lithuania)	Learning	Desktop	Enacted; breaking down barriers in STEM education	Exploring the application of digital escape rooms in STEM education, evaluating their impact on student engagement and learning outcomes	$M_1 = 4.20$, $SD = 0.89$ $M_2 = 4.61$, $SD = 0.69$ $M_3 = 4.52$, $SD = 0.66$ $M_4 = 2.05$, $SD = 0.27$ $M_5 = 4.66$, $SD = 0.62$ $M_6 = 4.72$, $SD = 0.57$	91.2% of students reported improved understanding from digital escape rooms, highlighting their effectiveness in enhancing engagement, motivation, critical thinking, problem solving, and collaborative skills

TABLE 1: Continued.

Year	Authors	Sample (country)	Processes investigated	Technology used	Type of metaphor	Aims of the study	Data results	Primary outcomes
2015	Reese, Tabachnick, Kosko	Study 1: 267 ($M_{age} = 14.8$); Study 2: 90 ($M_{age} = 11.5$) (not available)	Learning	Desktop	Enacted; learning is a game	Investigation of the utility of the videogame in learning scientific notions	Study 1 $M_{rate-1} = 1.47$, SD = 1.17 $M_{acc-1} = 0.05$, SD = 0.32 $M_{rate-2} = 0.47$, SD = 1.5 $M_{acc-2} = -0.02$, SD = 0.71 $M_{rate-3} = 1.06$, SD = 1.04 $M_{acc-3} = 0.05$, SD = 0.53 $M_{rate-4} = 1.32$, SD = 1.11 $M_{acc-4} = -0.01$, SD = 0.34 Study 2 $M_{rate-1} = 1.40$, SD = 1.17 $M_{acc-1} = 0.04$, SD = 0.32 $M_{rate-2} = 1.37$, SD = 0.01 $M_{acc-2} = 1.74$, SD = 0.56 $M_{rate-3} = 0.88$, SD = 1.00 $M_{acc-3} = -0.10$, SD = 0.59 $M_{rate-4} = 1.33$, SD = 1.18 $M_{acc-4} = 0.00$, SD = 0.42	The videogame facilitated learning across four dimensions, with 12-year-old facing slightly more challenges in understanding heat than 15-year-old. Progress rates varied by age and dimension, suggesting age-related differences in conceptual grasp and learning pace
2024	Martins Nunes Avellar, Fioravanti, de Deus, Castelo Branco, Barbosa	Study 3: 31 ($M_{age} = 12.74$) (Brazil)	Learning	VR + HMD	Enacted; programming is a puzzle game	Exploration of the impact of metaphorical enactment on knowledge retention of programming concepts. It is hypothesized that participants engaging with SSPOT-VR will demonstrate improved retention of programming knowledge	$M_{pre} = 3.9$, SD = 1.16 $M_{post} = 6.55$, SD = 1.23	Both the students' retention of knowledge and their ability to express the programming concepts learned improved after the use of SSPOT-VR, as shown by significant increases in posttest scores compared to pretest scores
2024	Zhang, Chen, Hu, Bao, Tu, Hwang	118 ($M_{age} = 5.71$; 61 males) (China)	Learning	Desktop; screen-free robot	Enacted; programming is daily life	Exploration of whether a metaphor-based robot programming approach can enhance young children's computational thinking and promote positive learning behaviors compared to	$M_{experimental} = 11.98$, SD = 1.48 $M_{control} = 10.33$, SD = 1.77	The experimental group showed higher computational thinking scores and demonstrated more positive learning behaviors than the control group

TABLE 1: Continued.

Year	Authors	Sample (country)	Processes investigated	Technology used	Type of metaphor	Aims of the study	Data results	Primary outcomes
						a conventional approach		
2024	Lee, Yang	5 ($M_{age} = 8$; 3 males) (not available)	Perspective-taking; empathy	VR + HMD; desktop	Enacted; understanding others is seeing through their eyes	Investigation of how asymmetric VR combined with peer collaboration can enhance perspective-taking and empathy in children with ASD	Correct response rate $Avg_{baseline} = 0.31$ $Avg_{intervention} = 0.49$ $Avg_{maintenance} = 0.69$	Improvement in participants' social cognitive performance, specifically in perspective-taking and empathy, observed through increased scores from baseline to intervention and maintenance phases
2022	Malighetti, Villani, Bernardelli, Garbarino, Maestri, De Gasperi, Riva	42 ($M_{age\ exp} = 23.67$, $M_{age\ con} = 24.10$; 32 females) (Italy)	Emotion	VR + HMD	Embodied; life is a journey	Exploration of the feasibility and preliminary effectiveness of a self-help VR intervention in promoting emotional and psychological well-being in university students during the COVID-19 pandemic	Experimental IMH-EW $M_{pre-exp} = 11.90$, SD = 2.96 $M_{post-exp} = 12.67$, SD = 2.28 $M_{pre-con} = 11.90$, SD = 3.75 $M_{post-con} = 11.10$, SD = 2.73 IMH-PW $M_{pre-exp} = 24.95$, SD = 6.02 $M_{post-exp} = 26.90$, SD = 5.22 $M_{pre-con} = 26.48$, SD = 5.66 $M_{post-con} = 24.38$, SD = 5.30 ERQ-CR $M_{pre-exp} = 4.84$, SD = 0.73 $M_{post-exp} = 5.21$, SD = 0.61 $M_{pre-con} = 5.01$, SD = 1.01 $M_{post-con} = 4.98$, SD = 0.92 ERQ-ES $M_{pre-exp} = 3.33$, SD = 1.24 $M_{post-exp} = 3.23$, SD = 1.18 $M_{pre-con} = 3.22$, SD = 0.98 $M_{post-con} = 3.26$, SD = 1.17	Significant increase in emotional and psychological well-being in the experimental group compared to the waiting list group; the experimental group showed an increase in positive attitude about the future that decreased in the waiting list group
2023	Malighetti, Bernardelli, Pancini, Riva, Villani	42 ($M_{age\ exp} = 24.1$, $M_{age\ con} = 23.7$; 32 females (Italy)	Emotion	VR + HMD	Embodied; life is a journey	Investigation of the feasibility and preliminary effectiveness of a self-help VR intervention in promoting	IMH-EW $M_{pre-exp} = 3.96$, SD = 2.96 $M_{post-exp} = 4.22$, SD = 2.28 $M_{pre-con} = 3.96$, SD = 3.37 $M_{post-con} = 3.7$, SD = 2.73	Significant increase in both emotional and psychological well-being in the experimental group compared to the

TABLE 1: Continued.

Year	Authors	Sample (country)	Processes investigated	Technology used	Type of metaphor	Aims of the study	Data results	Primary outcomes
						emotional and psychological well-being in university students during the COVID-19 pandemic	IMH-PW $M_{pre-exp} = 4.15$, SD = 6.02 $M_{post-exp} = 4.48$, SD = 5.22 $M_{pre-con} = 4.41$, SD = 5.66 $M_{post-con} = 4.06$, SD = 5.30 PSS $M_{pre-exp} = 2.09$, SD = 7.24 $M_{post-exp} = 1.97$, SD = 7.00 $M_{pre-con} = 2.14$, SD = 6.65 $M_{post-con} = 2.07$, SD = 4.21	control group, but not in perceived stress
2017	Prpa, Tatar, Riecke, Pasquier	22 ($M_{age} = 22.3$, SD = 8.03; 14 females) (Canada)	Emotion	VR + HMD	Enacted; more is up; less is down	Investigation of how different mappings of embodied interaction design can enhance the affective properties of the system, explore the impact on user engagement and affective states, and understand the potential benefits of predictable, embodied interaction through breathing on a user's affect, enjoyment, engagement, and presence		Environmental reactivity perception increased on second exposure, with participants preferring longer experiences in metaphorically mapped conditions. Attention to audio differed by mapping, and baseline STAI-6 scores varied between groups, indicating nuanced responses to environmental manipulation and metaphorical mapping
2020	i Badia, Quintero, Cameirao, Chirico, Triberti, Cipresso, Gaggioli	20 ($M_{age} = 28.15$, SD = 4.15; 11 males) (not available)	Emotion	Desktop	Embodied; anger is fire, sadness is rain, fear is nightfall, and happiness is flowers	Assessment of the effectiveness of selected metaphors in inducing target emotions, hypothesizing the existence of a framework for affective-driven procedural content generation in VR through the identification of relevant	VAS-anger: $f^2 = 0.7835$ VAS-fear: $f^2 = 1.0238$ VAS-joy: $f^2 = 0.6253$ VAS-pleasure: $f^2 = 0.3098$ VAS-arousal: $f^2 = 0.8592$ VAS-dominance: $f^2 = 0.3958$	Procedural metaphors significantly influenced emotions, eliciting strongest responses for targeted emotions. Fear and anger metaphors induced fear; sadness elicited higher sadness ratings, and joy induced higher joy levels. Physiological responses aligned with subjective emotional

TABLE 1: Continued.

Year	Authors	Sample (country)	Processes investigated	Technology used	Type of metaphor	Aims of the study	Data results	Primary outcomes
						psychophysiological markers of the emotional experience		reporting, demonstrating the Emotional Labyrinth's capacity to evoke distinct emotional states through procedural virtual metaphors

Abbreviations: AR, augmented reality; ERQ-CR, emotion regulation questionnaire–cognitive reappraisal; ERQ-ES, emotion regulation questionnaire–expressive suppression; IMH-EW, Italian mental health continuum–emotional well-being; IMH-PW, Italian mental health continuum–psychological well-being; PSS, perceived stress scale; VAS, visual analog scale; VR + HMD, virtual reality + head-mounted display.

learning as a game, both enacting the experience in serious and educational games concerning medical and scientific themes. In particular, Alyami and colleagues [47] developed a desktop-based serious game that assimilated the activity of cardiac history-taking to an adventure game, while Reese [45] focused on fundamental geology and space science. Martins Nunes Avellar et al. [44] integrated the metaphor "programming is a puzzle game" in a VR environment to investigate its impact on students' programming knowledge retention, highlighting the potential of metaphor enactment to reinforce learning outcomes, while Zhang and colleagues [46] enacted the metaphor "programming is daily life" through interactions with a screen-free robot, illustrating how everyday routines (e.g., washing clothes, traffic signs for representation, and fixing a car for debugging) could enhance computational thinking in young learners. Additionally, Lee and Yang [43] applied the metaphor "understanding others is seeing through their eyes" in an asymmetric VR game, exploring how experiences lived in first or third perspective fostered perspective-taking and empathy in children with ASD, therapy expanding the review's exploration into clinical applications and social cognition.

A study carried out by Prpa and colleagues [38] investigated the metaphor viewing more as up and less as down, through an enactment supported by the interaction with participants' affective states. Specifically, participants saw themselves floating higher or lower in a body of water based on their breathing rhythm. Similarly, another study focused on the affective sphere by applying a mechanism of biofeedback in order to create a virtual environment that actively responded to users' affective states, implementing the metaphor that views emotions as natural elements (e.g., anger is fire, sadness is rain, fear is nightfall, and happiness is flowers) [32]. Two studies carried out by Malighetti and colleagues [36, 37] employed the metaphor of life as a journey through different virtual scenarios representing metaphorical stories, investigating the embodiment of this metaphorical experience on emotional well-being.

The studies, however, differ in the specific cognitive, emotional, or perceptual domains they aim to explore, reflecting the tailored approach of each study to investigate aspects of human experience through metaphor.

3.2.1. Cognition. Under the dimension of cognition, two main constructs were addressed by the included studies: creative cognition and learning.

3.2.2. Creative Cognition. Studies on creative cognition used the metaphors "breaking the walls" and "thinking outside of the box" to symbolize overcoming creative barriers, showing significant improvements in problem solving and creative performance [26, 41, 42]. These studies demonstrated that physically enacting metaphors in VR actively engages participants in cognitive flexibility, making abstract concepts more tangible. For instance, Wang and colleagues [41, 42] found that metaphorical enactment led to a stronger enhancement of creative performance compared to the embodied and the nonmetaphorical condition. Neural activation, measured with fNIRS, showed weaker activations in the frontopolar cortex, the dorsolateral prefrontal cortex, and the somatosensory association cortex in the metaphorical condition compared to the virtual experience of simply walking through a corridor. These areas correspond to those activated by rule-breaking behaviors and creative performance, suggesting that the physical action of breaking a wall activates the conceptual metaphor and the corresponding brain activities. Similarly, Leung [26] showed that individuals who freely navigated a virtual space, embodying the idea of "thinking outside the box" performed better on creative problem-solving tasks than those confined to a fixed path. Expanding this research, Lee and Yang [43] implemented the metaphor "understanding other is seeing through their eyes" within a VR game designed for children with ASD. By embodying different perspectives, participants improved in perspective-taking and empathy, highlighting the potential of metaphor enactment in fostering social understanding. Across these studies, physical engagement with metaphorical experiences proved effective in stimulating the characteristics considered at the foundation of creativity.

3.2.3. Learning. In the domain of learning, the studies explored how embodied metaphors enhance educational outcomes, particularly through spatial navigation and interaction with virtual objects [45, 47, 49]. These studies leveraged metaphorical experiences to improve retention, engagement, and understanding of complex subjects. Several studies used serious games to enact the metaphor "learning is a game." Alyami and colleagues [47] demonstrated that a metaphor-enhanced medical training game was as effective as traditional text-based study methods, while offering higher satisfaction and engagement levels but no significant differences in cognitive load, level of difficulty, or performance postintervention. Similarly, Reese et al. [45] showed that metaphor-based virtual serious games help improve learning of scientific subjects, with effectiveness varying depending on the specific educational context. Sidekerskienė and Damaševičius [49] found that digital escape rooms, used as metaphors for breaking down barriers in STEM education, effectively promote active learning and engagement. Other studies examined metaphorical representations of programming. Martins Nunes Avellar et al. [44] considered the activity as a puzzle game and found that enacting the metaphor led to significant improvements in programming knowledge retention, demonstrating the efficacy of metaphorical enactment in reinforcing learning. Zhang et al. [46] implemented the metaphor "programming is daily life," showing higher computational thinking and positive learning behaviors in young learners compared to traditional learning approaches. Overall, these embodied metaphors, by leveraging the spatial and kinesthetic affordances of VR, helped with both the learning, retention, and understanding of complex subjects, offering compelling evidence for the technology's role in enhancing the learning experience through metaphorical embodiment. Therefore, these studies highlight the potential of immersive environments to provide a more engaging and effective learning experience, particularly for abstract concepts that benefit from spatial representation, with mean values showing an improvement in learning outcomes compared to traditional learning methods.

3.2.4. Perception. Concerning perception, studies examining color perception [35], numerical representation [34], and temporal and spatial awareness [33, 40, 48] used metaphors that directly interact with the participants' sensory experiences. For instance, Löffler [35] demonstrated that AR interventions using simple color changes (e.g., hue and saturation) seem to significantly influence users' conceptual choices concerning the perception of weight and temperature, while research from Kopiske and Franz [34] which compared symbolic and nonsymbolic number lines to understand nonlinearity in magnitude estimation found that responses to the former were almost linear, while responses to the latter showed characteristic underestimation for larger magnitudes. Furthermore, Ruggiero and colleagues [40] showed that perceived temperatures modulate performance in a virtual peripersonal and interpersonal assessment task, with differences between genders. Specifically, in both types of space, warmth elicited a stronger sense of closeness in women and more distance in men, while coldness induced more distance in women and stronger closeness in men. Qin et al. [39] studied the metaphor "a safety boundary is a breached wall" in a VR setting, demonstrating how such metaphors could enhance participants' perception and attention through rapid detection cues. This study emphasized the role of embodied metaphors in influencing perceptual efficiency and attention, showcasing how metaphorical designs can significantly impact sensory processing.

Finally, two studies investigated the metaphor "the past is behind, the future is ahead": Caruso and colleagues [48] discovered that future events feel psychologically closer than past events of equivalent objective distance, while Jiang's study [33] examined movement along both the lateral and sagittal axis and found results suggesting that virtual movement significantly impacts space–time mapping in the lateral but not in the sagittal direction. This indicates that the lateral mental timeline originates from sensorimotor experiences, whereas the sagittal timeline is more influenced by spatial metaphors and cultural factors. In other words, studies focusing on altering sensory experiences highlight how embodied metaphors can recalibrate participants' perceptions of weight, temperature, and numerical concepts. These findings, particularly those concerning altering perceptions of time and space [33, 39, 40, 48], illustrate the significant potential of embodied metaphors in reshaping sensory and perceptual experiences, thus addressing how metaphors impact cognitive and perceptual processes.

3.2.5. Emotions. The studies targeting emotional processes explored how virtual environments that react to or evoke specific emotional states can facilitate emotional regulation, including affective states measured by the participants' perceived arousal [38] and psychophysiological markers [32], as well as the overall emotional well-being [36, 37].

The studies focusing on emotional aspects explored metaphors as not only reflecting but also actively influencing and embodying participants' emotional states. For instance, I Badia et al. [32], by applying a mechanism of biofeedback in order to create a virtual environment actively responding to the user's affective states, showed that emotionally adaptive VR benefits from the use of behavioral and physiological data to enhance mental health intervention by tailoring emotional experiences to individual needs. In particular, results showed an overall subjective agreement that each metaphor corresponds to the expected emotion, with the exception of *anger*, whose metaphor elicits both *fear* and *anger*. Similarly, Prpa [38] demonstrated that embodied interactions based on users' breathing patterns significantly influenced their affective states, engagement, and overall experience. Additionally, metaphoric mappings (i.e., inhaling corresponded to rising and exhaling to sinking deeper) felt more intuitive and calming than the opposite. However, detailed information concerning the emotional states and the metaphor's influence on them was not obtained, due to significant baseline differences between the groups despite random assignment to the condition (metaphor vs. nonmetaphor). These metaphorical mappings, such as virtual environments that respond to users' emotional states through the real-time analysis of physiological and behavioral parameters, allow for the enactment of emotional regulation strategies, thereby providing the possibility to investigate the interplay between technology, metaphor, and emotional experience. Finally, the two studies carried out by Malighetti and colleagues [36, 37] suggest that embodying a metaphorical experience can significantly increase both emotional and psychological well-being. However, no significant results were obtained comparing pre- and postresults concerning emotional regulation abilities. Therefore, environments that adapt to the user's affective states [32] or activities designed to elicit empathy led to observable changes in emotional expression and self-reported emotional well-being, but not on emotional regulation [36–38]. These outcomes provide evidence for the use of embodied metaphors in emotional learning and regulation, with mean sizes concerning the measured outcomes (i.e., self-report questionnaires on psychological and emotional well-being and awareness) indicating a positive impact on participants' ability to manage and understand their emotional responses. Indeed, the enactment of emotional experiences within these environments led to notable improvements in emotional well-being and expression, enhancing the role of embodiment and enactment in understanding and interpreting metaphors within emotional experiences but suggesting more in-depth research on their role for emotional regulation abilities.

4. Discussion

The present scoping review of the literature aimed at presenting the state of research regarding embodied and enacted metaphors in technology-mediated experiences and their effect on cognitive and emotional abilities. Overall, 19 studies were identified that respected the inclusion criteria, which demonstrate the impact of embodied and enacted metaphors on cognition and emotions.

According to the CMT framework, metaphors play an integral role in structuring our understanding and interaction with complex concepts. Through the application of metaphors, the studies collectively demonstrate how metaphorical constructs, deeply rooted in bodily experiences and sensorimotor systems [10, 12], facilitate a richer comprehension and engagement with abstract concepts. This aligns with the theoretical propositions of embodied metaphorical cognition [2], which posits that our bodily experiences, represented through the body schema and the body image, are foundational to the metaphorical mapping processes that shape our cognitive and emotional landscapes.

The empirical findings reported across the studies confirm that bodily experiences shape cognitive and emotional processes, including creativity, learning, perception, and emotional regulation. This corroborates Lakoff and Johnson's [1] assertion that conceptual and perceptual processes share physiological mechanisms, thereby anchoring abstract cognitive functions in embodied experiences. The observed improvements in creative cognition, learning outcomes, perceptual shifts, and emotional well-being suggest that embodied metaphors not only convey information but also actively structure cognitive and emotional processes [50]. Indeed, the synthesis of findings from the included studies provides a comprehensive overview of how embodied and enacted metaphors through technology-mediated experiences significantly impact cognition and emotions, addressing the core research questions and objectives of this review. Across a variety of technological tools (i.e., immersive VR, AR, and desktop interfaces), the studies collectively demonstrate that the embodiment and enactment of metaphors can influence cognitive and affective processes. Overall, the modality through which metaphors are experienced—whether more passively embodied through sensory experiences or actively enacted through physical interaction—affects their impact on cognitive processing and emotional resonance. Studies employing active enactment, requiring participants to physically perform actions that represent metaphorical concepts, tend to yield stronger effects on outcomes such as creative thinking [26, 41, 42] or learning gains [44–47, 49]. Conversely, metaphors that are embodied in sensory experiences, such as color and spatial manipulations, produce subtler but equally impactful effects on perception and interpretation. While enactment-based metaphors tend to yield more immediate and quantifiable effects, sensory-based metaphors still significantly shape cognitive and emotional processes, reinforcing the integral role of embodied experiences in structuring abstract thought.

Therefore, the collective results affirm that the use of various technological modalities to embody and enact metaphors has a significant, measurable impact on both cognitive and emotional processes. This impact is consistent across similar demographic groups, highlighting the applicability and potential of embodied metaphors in enhancing human cognition and emotional regulation through technology-mediated experiences on both teenagers and adults. These influences manifest in enhanced creative cognition, improved learning outcomes, altered perceptual experiences, and augmented emotional regulation, offering valuable insights into the application and efficacy of embodied and enacted metaphors in technology-mediated environments. Indeed, advanced technologies such as VR, with their ability to create real-time embodied simulations, can foster a sense of immersion into a virtual space that has the potential to represent different situations and concepts [17]. In the context of metaphorical thinking, this ability allows for a deeper exploration of how metaphors affect cognitive and emotional processes by simulating environments where physical actions and perceptions closely mimic real-life experiences. The ability of VR to generate embodied experiences with a high sense of agency and potential for enactment is thus crucial for advancing the study of embodied metaphors.

Furthermore, the notion of embodied agency discussed in the context of these studies highlights the active role of participants in engaging with metaphors, thereby not just receiving information passively but shaping their understanding and interaction with the world. This is supported by the active inference principle and the Bayesian brain approach, which together propose that the comprehension of metaphors involves the activation of stored perceptual maps and sensorimotor simulations [51, 52]. Specifically, according to these theoretical frameworks, the brain actively seeks to minimize prediction errors by constantly updating its internal models of the world based on sensory input. When discrepancies occur, the brain adjusts its internal model to reduce the prediction error, effectively learning from experience [53]. Indeed, the reviewed studies indicating enhanced creative output, improved learning retention, altered sensory perceptions, and better emotional regulation underscore the enactment of agency through metaphorical engagement. Technology-mediated metaphors, such as "breaking walls" to symbolize overcoming obstacles, actively engage participants' sensorimotor systems, thus enhancing creative cognition and problem-solving abilities through embodied simulations [42]. By incorporating Bayesian principles, these metaphors can be seen as prior beliefs that shape sensory experiences and cognitive interpretations, effectively guiding participants' interactions within the virtual environments to align with their predictive models. The active inference approach further suggests that the comprehension of metaphors involves the activation of stored perceptual maps and sensorimotor simulations, enabling individuals to predict and interpret abstract concepts through concrete and embodied experiences [51]. For example, Jiang and colleagues [33] demonstrated that interacting with time-related metaphors in VR significantly altered participants' perception of temporal flow, as measured by reaction times and accuracy in time estimation tasks. This finding underscores the role of predictive processing in metaphor comprehension, where participants' prior experience and sensorimotor engagements are integrated to refine their predictions and cognitive responses (see Figure 2 for a visual representation of the integration of these frameworks). Moreover, the experience of metaphors in virtual environments supports the idea that embodied metaphors facilitate not only cognitive enhancements but also emotional regulation. Studies have shown that virtual environments that

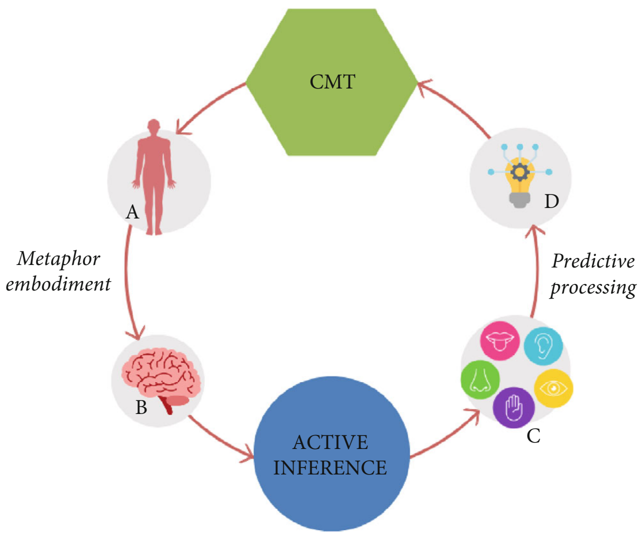

Figure 2: Theoretical frameworks in metaphor comprehension. This diagram illustrates the interconnected roles of Conceptual Metaphor Theory (CMT) and active inference in explaining the understanding and embodiment of metaphors. CMT emphasizes how (a) the body shapes metaphor comprehension by grounding abstract concepts in bodily experiences. (b) The brain processes these embodied metaphors through sensorimotor simulation and predictive processing, as described by active inference. (c) Sensory inputs are then used for informing predictions and gaining (d) cognitive insights. These insights then circle back to CMT, refining and enhancing metaphorical understanding through dynamic and embodied interactions with the environment.

adapt to users' emotional states through real-time analysis of physiological and behavioral parameters can effectively evoke and modulate emotional experiences [32, 38]. This adaptive interaction can be understood through the lens of active inference, where the brain's predictive models are continuously updated based on sensory feedback, allowing for dynamic emotional regulation and enhanced empathy.

Findings from this review suggest that embodied and enacted metaphors through technology-mediated experiences influence various aspects of cognition [26, 33–35, 39–49]. Indeed, there is substantial evidence indicating that engagement with metaphors significantly enhances creative cognition, improves problem-solving abilities, and boosts learning outcomes. Studies consistently demonstrate that through the enactment of metaphors, participants not only conceptualize abstract ideas but also embody them, leading to measurable enhancements in cognitive abilities. However, there is some variability in the degree to which different studies report improvements in cognitive functions, such as learning outcomes, suggesting that while the embodiment of metaphors uniformly impacts creative and problem-solving tasks, its influence on other cognitive functions might be moderated by the nature of the task or the metaphor involved. This variability could be explained by the theoretical underpinning that cognition is deeply influenced by bodily experiences, as argued by Lakoff and Johnson [1]. The extent of cognitive enhancement may depend on how closely a metaphor aligns with participants' bodily experiences and sensorimotor schemas. For example, metaphors that engage motor skills or spatial navigation might more directly influence memory and attention through embodied simulation, activating neural pathways associated with these cognitive processes. This aligns with findings from neuroscience, suggesting that the engagement of sensorimotor systems in metaphor comprehension can enrich cognitive functioning by leveraging the brain's inherent embodied structures [2, 52].

In the domain of emotions, the included studies suggest that embodied and enacted metaphors may significantly impact affective abilities such as emotional regulation and well-being. The enactment of emotional states through metaphors in virtual environments—where participants interact with scenarios that evoke or mirror their emotional experiences—consistently leads to improved emotional regulation and enhanced empathy. This is particularly evident in studies where metaphors allow participants to navigate through emotional experiences in a controlled, yet deeply immersive manner [32, 38]. Despite the overall positive findings, there appears to be a range of effectiveness regarding emotional state alterations, with some studies reporting more profound impacts than others. This discrepancy could stem from the subjective nature of emotional experiences and the diverse methodologies employed to measure mood states. The theoretical framework of embodied cognition offers a plausible explanation for these findings, suggesting that emotional experiences are not merely cognitive appraisals but are deeply intertwined with bodily states [54]. Therefore, the embodiment of metaphors can evoke more potent emotional responses by simulating the physical sensations associated with those emotions. This idea is supported by neural studies showing activation in areas linked to emotions, such as the amygdala, during the engagement with metaphorical content, indicating a biological basis for the emotional impact of embodied metaphors [55]. Furthermore, the variance in emotional state alterations across studies could be explained by individual differences in emotional processing and the degree of embodiment offered by different metaphors and technologies, highlighting the complexity of translating embodied experiences into emotional outcomes.

4.1. Limitations and Future Directions. While providing valuable insights into the impact of embodied and enacted metaphors on cognition and emotions through technology-mediated experiences, the current scoping review presents several limitations that need to be acknowledged. First, a lot of the included studies did not report effect sizes or data from which effect sizes could be extracted. This omission, together with the broad research question typical of the scoping review, meant that a quantitative data synthesis was not performed. Future research should prioritize the reporting of detailed quantitative outcomes, including effect sizes. This would facilitate meta-analyses and more precise comparisons across studies, enhancing our understanding of the effects that embodied metaphors have on various psychological constructs.

In addition, the studies included in the review focused on healthy participant samples. On the one hand, this can be a strength point that consolidates the impact of embodied metaphors on the general population. On the other hand, it represents a missed opportunity to explore the potential impacts of embodied metaphors on clinical populations. For instance, research could include participants with conditions that typically challenge metaphor comprehension, such as autism and schizophrenia, to determine how these groups experience and respond to embodied metaphors [56–60]. Additionally, some protocols were developed in order to implement embodied metaphors in the health journey of different medical conditions, such as cancer, perinatal loss, and stroke, in order to support the emotional and psychological impact of these experiences and enhance engagement in treatment (e.g., [61–63]). However, the present review only found one study investigating their application and effectiveness on patients.

The role of culture was also not investigated in the studies included in this review. Despite literature showing that culture plays a significant role in cognitive processes, including those related to embodied cognition [64, 65], most of the selected articles did not specify the ethnicity of the populations they investigated nor the country where the study was carried out (as shown in Table 1). Future studies should therefore take into consideration the cultural diversity of their sample, in order to control this aspect and prevent overlooking variation in metaphorical understanding and usage.

Another important limitation lies in the theoretical framing of the search strategy, which may have excluded relevant studies investigating concepts akin to embodied metaphors but not explicitly theorized as such. The reason for this choice is rooted in the desire to focus on studies explicitly grounded within the selected theoretical approach (i.e., the CMT; [1]). Despite this, the phenomenon of virtual body swapping represents a compelling case of an experience that, while not traditionally framed as a metaphor within existing literature, has intrinsic metaphorical qualities. Indeed, participants experience the world from the perspective of another body, therefore embodying the metaphor of "walking in someone else's shoes" [66, 67]. The potential reframing of such phenomena through the lens of CMT presents an interesting suggestion for future research in areas such as cognition [68, 69], perception [70, 71], and emotion [72]. This approach aligns with the growing evidence from neuroscience and cognitive science that supports the embodied basis of conceptual understanding and metaphor comprehension [10, 11]. Reframing these phenomena as metaphors could therefore provide a novel framework for examining the effectiveness of embodied metaphors in eliciting cognitive and emotional changes, enriching the theoretical and practical applications of CMT in understanding the profound impact of embodied experiences on human psychology.

5. Conclusion

To our knowledge, this scoping review represents the first systematic attempt to explore the intricate interplay between embodied and enacted metaphors and their impact on cognitive and emotional processes through the lens of technology-mediated experiences. By validating the embodied nature of metaphorical cognition and highlighting the dynamic nature of metaphor comprehension as evidenced by neuroimaging and behavioral studies, this review opens new avenues for exploration into how metaphors influence our understanding, perception, and emotional engagement with the world.

Further research is essential to deepen our understanding of these processes, particularly through the investigation of metaphors within clinical populations and the exploration of phenomena akin to embodied metaphors but not traditionally framed as such within the CMT. Additionally, future studies could benefit from integrating the Bayesian brain framework more explicitly, examining how predictive processing and perceptual inference contribute to the comprehension and embodiment of metaphors. This approach would not only extend the theoretical landscape but also enrich our understanding of how metaphors shape cognitive and emotional experiences at both the individual and societal levels. Indeed, the relationship between embodied metaphors, active inference, and the Bayesian brain approach lies in how these concepts collectively explain the dynamic interplay between perception, cognition, and action. Embodied metaphors highlight the importance of bodily experiences in shaping our conceptual understanding, aligning with the active inference principle's emphasis on the brain's proactive role in minimizing prediction errors through sensorimotor interactions. Moreover, the Bayesian brain approach provides a framework for understanding how the brain integrates past experiences, such as embodied metaphors, with current sensory inputs to make predictions about the future. This allows for a more nuanced understanding of how metaphors are not merely static representations but are dynamically constructed and interpreted through ongoing interactions with the environment. Therefore, the integration of active inference and the Bayesian brain framework into the study of embodied metaphors offers a compelling point of view that elucidates how metaphors influence cognitive and emotional processes through predictive coding and sensorimotor simulations.

Therefore, the present scoping review proposes a framework that situates the study of embodied and enacted metaphors at the intersection of cognitive science, neuroscience, cognitive linguistics, and technology studies. By validating the embodied nature of metaphorical cognition and highlighting the dynamic and interactive nature of metaphor comprehension as evidenced by neuroimaging studies (e.g., [73, 74]), this review opens new avenues for exploration into how metaphors profoundly influence our understanding, perception, and emotional engagement with the world. Thus, this scoping review lays the groundwork for future interdisciplinary research at the intersection between cognitive science, neuroscience, and technology studies, aiming to understand how embodied metaphors can enhance cognitive and emotional well-being across diverse populations and settings.

Data Availability Statement

All relevant data are within the manuscript and supporting information.

Ethics Statement

The authors have nothing to report.

Consent

The authors have nothing to report.

Conflicts of Interest

The authors declare no conflicts of interest.

Author Contributions

Conceptualization and methodology: G.M. and C.R.; supervision: S.F.M.P., E.S., and C.R.; literature search, data analysis, and interpretation of results: G.M. and S.F.M.P.; writing: G.M.; revision and editing of manuscript: all authors.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. *(Supporting Information)* The supporting information shows the exact search strings used for each database included in the review, together with a summary for each database of the number of articles found, how many were relevant, and how many were included in the final review.

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