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Retroverse: Envisioning Combined Physical Fitness and Embodied Learning

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Abstract. The concept of the Metaverse has been discussed and explored for several decades, with notable references in virtual reality (VR) and virtual social spaces. However, its applications in healthcare are still in their infancy. Researchers have explored its potential applications in smart healthcare from various angles, but few studies have shown how physical activity in virtual environments can support spatial learning. In this paper, we envision a new concept and application of the "Retroverse" characterized by embodied learning and incorporating virtual environments into a reality-based experience. Our main goal is to stimulate people's memory through physical fitness activities in the virtual environment. By intelligently optimizing the sports equipment and campus management system at Hong Kong University of Science and Technology (Guangzhou), we connected the "Campus Brain" with a stationary bicycle. Through the "Virtual Campus Ride"," visitors can get a 360-degree view of the campus while exercising either individually or in teams. This embodied learning experience allows users to interact with each other based on a digital representation of the real world. We believe that this interactive and physically engaging trend of smart healthcare can be further developed into simulation-based training and psychological therapy. In the future, such experiential learning or rehabilitation could be supported by AI-generated content in a computer-generated environment.

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1 Introduction

In its more than 30-year history (Lee et. al., 2021), the Metaverse has gradually evolved from virtual places where people could interact and conduct limited activities to places where people can socialize, learn, play, create content, and conduct business in real time. By masking out the real environment, VR can make the user feel as if they are in the simulated environment. Can we use the contextual memory created by VR to stimulate long-term memory?

The Metaverse is considered one of the new technological developments impacting smart health and intelligent health systems (Yang et. al., 2022; Wang et. al., 2022). Metaphysically, it integrates physical and virtual realities and enables interaction between humans and their avatars; technologically, it is the intersection of high-speed Internet, virtual reality(VR), augmented reality(AR), and mixed reality(MR). For example, the Metaverse can provide virtual environments that promote mental health and well-being such as mental disorders (Cerasa et. al., 2022), where the creation of a whole-body illusion via a digital avatar could promote health care and personal well-being. By engaging in virtual, users can use mindfulness exercises, relaxation techniques, and virtual support groups to promote mental health. However, the Metaverse's application scenarios currently mainly serve the young and middle-aged market and focus on reflecting the future fantasy world. Therefore, more visions that benefit broader populations need to be addressed.

Previous research shows that complex immersive learning environments are readily achievable but that high levels of interactivity remain a challenge (Schott et. al., 2018). Metaverse scenarios, for example, exaggerate the imagination rather than reflect what has been lost in people's memories. And few coherent, episodic events from the past could be found in the Metaverse context. Gravity and physical force are often ignored, resulting in separation between physical touch and the mind. The life space literature suggests that neighborhood walks that combine physical activity and real-world walks can slow cognitive decline and improve health in older adults (Holzschneider et. al., 2012, Wan et. al., 2013). Greater physical activity measured with an accelerometer is associated with better cognition and cerebrovascular health in older adults. However, more evidence is needed on how physical activity in virtual environments can support spatial learning. We therefore look at an educational approach, embodied learning that emphasizes the importance of physical experiences and bodily movements in the learning process may boost the effect of VR therapy. Through the use of VR, people can have simulated experiences that encourage active participation, sensory feedback, and physical movement, which can enhance the therapeutic process and prolong positive therapeutic effects (Manzoni et. al., 2016).

In this paper, we propose a new concept "Retroverse" and discuss its application in rehabilitation and physiotherapy developed in the Metaverse. Based on the teaching philosophy of Technology-Enabled Embodied Learning Environments (TEELEs), we develop an application of "Retroverse" in which learners undergo immersive exercises and simulations that support physical movement while recovering long-term memory in a familiar environment. This embodied learning equipment compensates for the disadvantage that the metaverse is always a "legless place" (Hutchinson, 2022), and we also present the technical design process of the first set of prototypes.

2 The Concept of Retroverse

The notion of "Retroverse" is rooted in the Metaverse. We introduce it in contrast to the "Metaverse" on the basis of two important pedagogical and technological premises.

The first is that the Metaverse has a weak connection to long-term memory. As a metaphor for reality, the Metaverse typically exhibits features of story worlds whose goal is to evoke symbolic images in users by immersing them in a virtual place. This feature would mitigate the Metaverse's association with what happened in the past, but instead focuses on future imaginings. Current discussions about mechanisms to store and retrieve users' long-term memories in the Metaverse include various technologies such as cloud storage, distributed ledger technologies such as blockchain, or advanced neurotechnology to capture and reproduce memories. In addition, memories could be stored as data in the Metaverse infrastructure and accessed by the user at any time. Future users could have the ability to store their experiences, interactions, and memories in the virtual environment. This could include personal achievements, virtual possessions, social connections, and even recorded sensory experiences. Before this goal is achieved, the "Retroverse", which contains scenes consisting of interrelated episodic events will create and immerse users in virtually familiar environments to help retrieve their long-term memory.

The second premise arises from the technological perspective. Retroverse and Metaverse evoke different physical experiences, although both rely on VR technologies to partially or fully block out the immediate environment. Metaverse coolly defies gravity and conventional physical limitations, such as jumping directly into a virtual lake without real water, though it is still subject to some physical limitations. At the same time, it remains a complex challenge for the Metaverse to replicate the full range of tangible forces in the physical world. Currently, most VR experiences focus primarily on visual and auditory immersion. Some devices and controllers with haptic feedback can simulate basic sensations such as vibration or resistance, but they cannot fully replicate the complexity and variety of forces in the real world. Ongoing research and development efforts are aimed at advancing haptic technologies and creating more sophisticated devices that can provide a broader range of tactile sensations. These include wearable haptic suits, gloves and other devices that provide users with a more immersive and physically interactive experience in virtual environments.

Retroverse, on the other hand, relies on gravity to physically connect to the world of VR. Retroverse emphasizes connection, experience; it requires some laws of physics to function. In the Metaverse, it would be difficult to play ping pong with physical force, but in Retroverse, players would experience a tangible force. Similarly, walking through the virtual neighborhood in the Retroverse requires physical effort. The exertion not only warms up neurons, but also links real experiences, images, and events from the past. This action triggers links of synopses in the brain that stimulate further connections. Although we can walk effortlessly, we cannot move freely and physically in the metaverse because we could hurt ourselves if we fall or bump into something. We also cannot move freely in the Retroverse because of limited space (as in the Metaverse) and the risk of injury, but the Retroverse is bringing advances in robotics, artificial intelligence, and sensing technologies to realize tangible forces in the metaverse. To simulate activities similar to those in the real world, it is necessary to develop additional gears to enable physics-based interactions.

3 Embodied Learning in Retroverse

As a contemporary pedagogy, embodied learning emphasizes the use of the body in the educational practice. "Learners are simultaneously sensorimotor bodies, reflective minds, and social beings" (Nguyen & Larson, 2015). A common theme among these studies is the embodied learning (Kosmas et. al., 2019; Alibali & Nathan, 2012; Georgiou et al., 2019; Lan et. al., 2018; Hung & Chen, 2018), which claims that body movements are part of the learning process that can provide unique features for learning. The researchers argue that cognition can actually emerge from our bodies. Typical TEELEs examples include mobile learning, game-based learning, and VR-based learning environments that can provide simulated and immersive experiences, facilitate collaboration, and thus enhance learning effects. One of the most salient features of TEELEs is Human Compupter Interaction (HCI), which allows users to interact with a computer system through body movements. This embodied interaction could be realized with affordable, commercially available devices. Some studies have shown that physical activity influences brain plasticity and affects cognition and well-being by increasing cerebral blood flow and maximum oxygen consumption (Zubala et. al., 2017).

Despite the wide use of VR simulations in research on mental health, the study of experiential learning through the use of VR environments is still at its dawn to offer increasingly challenging opportunities for the learners. Retroverse has a particular focus on providing learners with physical devices to practice and reinforce their learning. While the Metaverse typically revolves around computer-generated virtual environments for interaction, Retroverse offers a different approach by incorporating tangible devices or physical objects as part of the learning experience. These physical devices help learners solidify their understanding and retain their knowledge. It is interesting to see the potential combination of virtual and physical elements in the Retroverse, as it provides learners with a more hands-on approach to applying what they have learned. This concept could provide a unique and engaging learning experience that bridges the gap between virtual and real-world application of knowledge.

With the TEELEs-based strategy, we combine the Retroverse concept with physical applications. Our research assumes the impact of experiences with roads on our long-term memory. Roads are rich sensory environments. When we interact with roads, we perceive and process information with our senses, such as visual cues, sounds, and physical sensations. These sensory experiences become interwoven with cognitive representations of streets in our long-term memory. For example, we may remember specific landmarks or visual details of a road we frequently travel, the sound of traffic or footsteps, or the sensation of walking down a particular path. These sensory and motor experiences can serve as retrieval cues and trigger the recall of associated memories and information. In addition, streets often serve as a backdrop for various personal experiences and events, such as meeting friends, exploring new places, or experiencing memorable events. These experiences form a network of interconnected memories in our long-term memory.

The embodied nature of cognition suggests that people's memory of streets goes beyond purely visual or spatial representations. It encompasses the multisensory experiences, motor actions, and emotional responses associated with navigating and interacting with roads. These embodied aspects of memory are usually stored in the long-term memory.

To help older people, especially those who suffer from AD, better retain these memories before they are eventually lost, we use an intuitive method to navigate the mixed worlds between reality and virtuality in the Retroverse. Therefore, we designed, built, and pre-evaluated three generations of bike simulator prototypes that allow learners to freely navigate the Retroverse.

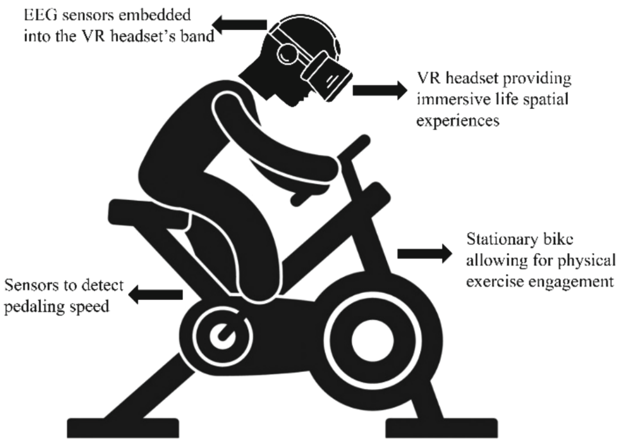

Fig. 1. Schematic diagram of embodied learning gear in the Retroverse

As is shown in Fig. 1, the Retroverse Embodied Learning Gear includes Combining EEG sensors, VR headset, and sensors that track pedaling speed on a stationary bike. EEG sensors measure brain activity and provide feedback on the user's cognitive state. This information can be used to adjust the difficulty of the workout or provide motivational cues to the user. The VR headset create an immersive training experience by simulating different environments and scenarios. For example, the user can be transported to a virtual cycling track or a race track. Pedaling speed sensors detect pedaling speed to track the user's progress and provide feedback on their performance. This information can be used to adjust the difficulty of the exercise or to motivate the user. By combining these technologies, it is possible to create an exercise experience that is both engaging and effective in memory stimulation. The EEG sensors could be used to assess the user's cognitive state, while the pedaling speed sensors could be used to track the user's progress and provide feedback on their performance.

4 Example: Bike Simulator System Design

4.1 Evolutionary Prototyping

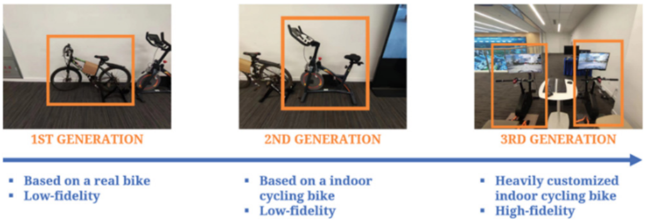

Fig. 2. Prototypes 1 to 3

Prototype 1, the first generation prototype, is a low-fidelity prototype to test the idea of cycling in the Retroverse. It is based on a real, normal sports bike. We mounted the bike on an indoor bike platform so that we can ride it without any real-world locomotion. We installed two infrared sensors near the pedals and a magnetic compass near the handlebars to measure the pedaling speed and the steering direction of the user. We used an Arduino-compatible MCU (microcontroller unit) to read and preprocess the signals from the infrared sensors and magnetic compass, and relayed these signals to our Windows PC via serial communication. Then, on our Windows PC (personal computer), we converted the serial data packets into UDP (User Datagram Protocol) network data packets and forwarded the UDP packets to our Retroverse 3D (three-dimensional) scenes. In this way, we implemented the basic function of controlling the movement of the virtual bicycle in the 3D scenes. During our preliminary evaluation, we found that the infrared sensors and magnetic compass had problems with accuracy in measuring user input. Therefore, we developed a new prototype to solve the accuracy problems (Fig. 2).

Prototype 2, the second generation prototype, is a low-fidelity prototype that we designed and built to improve the virtual cycling experience for the user. We mainly focused on increasing the measurement accuracy of the user input sensors in our prototype. This prototype is a modified version of an indoor cycling machine. To measure user inputs, the prototype uses an incremental encoder connected to the pedals and an absolute encoder connected to a mini-steering wheel as oppose to the previous infrared sensors on the pedals and the magnetic compass on the handlebars. We used an Arduino-compatible MCU to read and preprocess the encoder signals and forward these signals as TCP/IP (Transmission Control Protocol/Internet Protocol) packets to our Windows PC with LAN (Local Area Network) communication.

In our Retroverse 3D scenes, we use these signals to control the movement of our virtual bike. In this way, we can accurately measure the user's pedaling and steering actions. We used an Arduino-compatible MCU to read and preprocess the encoder signals and forward these signals as TCP/IP (Transmission Control Protocol/Internet Protocol) packets to our Windows PC with wired LAN (Local Area Network) communication. In our Retroverse 3D scenes, we use these signals to control the movement of our virtual bike. In this way, we can accurately measure the user's pedaling and steering inputs for controlling virtual bike's movements. However, during the preliminary evaluation of this prototype, we found that the initial seating position of the indoor cycling machine may be too high for older adults to ride on. This may cause safety issues for some older people when riding the virtual bike. We also found that the simulator's mini-steering wheel is not a good substitute for handlebars. A handlebar-controlled steering system can improve the user's experience. To solve the safety problem of the seat and the problem of the steering wheel versus the handlebar, we built a new generation prototype.

Prototype 3, the third generation prototype, is a high-fidelity, fully functional prototype that we designed and built to make our users' cycling experience even better. As the basis for this prototype, we heavily modified an indoor cycling machine. We changed the positions of the seat, handlebars, and pedals so that older adults could easily get on and off the bike. We replaced the mini steering wheel with a bicycle handlebar to give a classic riding experience. Similar to Prototype 2, we used an absolute handlebar encoder and an incremental pedal encoder to capture the user's steering and pedaling inputs. We incorporated an Arduino-compatible MCU into the prototype to read and preprocess the encoder signals and relay the signals to our Windows PC via wireless local area network (WiFi). The encoder signals determine the movements of the virtual bike in our Retroverse 3D scenes. We used a PC display mounted on the bike simulator to provide a relatively immersive VR bike experience.

4.2 System Design of Prototyping

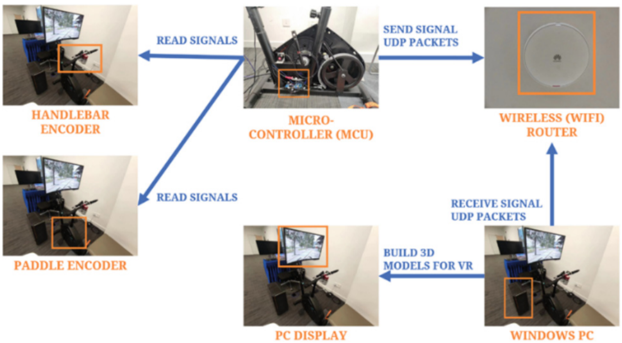

Fig. 3. Prototype 3's System Design

Prototype 3 is our original, fully functional prototype bicycle simulator. When the user turns the handlebars or pedals, he or she gives the bike simulator the handlebar direction and pedaling speed. The absolute handlebar encoder and incremental pedal encoder can sense the handlebar direction and pedaling speed and convert them into binary-valued digital signals. We programmed an Arduino-compatible MCU (microcontroller unit) to read these binary values as input signals and convert them into human-interpretable mathematical form. We used the unit degrees to represent handlebar direction and the unit laps per second to represent pedaling speed. The MCU puts the handlebar direction and pedaling speed into a UDP (User Datagram Protocol) network data packet and sends it to our Windows PC via a wireless (WiFi, WLAN) router (Fig. 3).

On our Windows PC, we programmed the virtual bike component in our Retroverse 3D (three-dimensional) scenes to constantly 'listen' for the bike simulator's UDP packets sent over the wireless router. Upon receiving a UDP packet, the virtual bike component unpacks the UTF-8-encoded (Unicode-transformation-format-8-encoded) packet contents and analyzes the handlebar direction and pedaling speed. The component then stores the parsed handlebar direction and pedaling speed as floating point numbers. Then, using a function in the virtual bike component, we vectorized and normalized the handlebar direction and pedal velocity into a 2D (two-dimensional) floating-point vector in the form (x, y), where x and y are in the range of $[-1, 1]$. We use this normalized vector to control the motion of the virtual bicycle in the X (handlebar direction, steering left or right) and Y (pedaling speed and direction, pedaling forward or backward) directions of the Retroverse 3D scenes (Fig. 4).

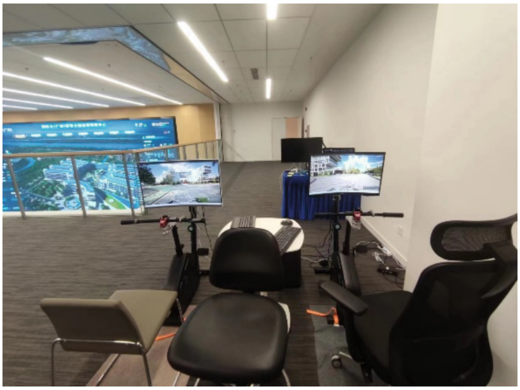

Fig. 4. Retroverse Stationary Bicycle at HKUST(GZ)

As the virtual bike component works on determining the virtual bike movement, the scene components of our Retroverse scenes are busy getting the 3D models ready for displaying virtual representation of 3D contents. As part of a large project 3D modeling of real cities, we piloted on an experiential campus tour of the Hong Kong University of Science and Technology (Guangzhou) or HKUST(GZ). To achieve a realistic representation, we leveraged building information modeling (BIM) data of the whole campus, and reconstructing the terrain and landscape in 3ds Max to ensure architectural accuracy and realism in our model. We also added details of the windows, walls, and doors accurately utilizing appropriate textures, materials, and real-world reference images and architectural plans. Light effects, shadows, colors, and materials were optimized using the Unreal Engine to enhance the appeal and believability of the model, thereby creating a digital twin of HKUST(GZ).

In addition, we equipped the bike with both a PICO4 VR headset and a curved PC monitor for VR contents user. For the experience user, the VR headset would be more appealing, but for a beginner, the curve window would provide a semi-immersive experience while riding the bike.

In sum, the stationary bike with the turntable handlebar (plus encoder, pedal encoder, MCU, wireless router) helps the navigation; the PICO headset and curved display 3D contents, the PC feeds the user according to his or her ‘wished campus tour scenes’ with an intuitive, immersive, and realistic Retroverse cycling experience.

5 User Study Hypothesis

In our user study, we compared retention of information while learning in two virtual environments: in an immersive context with embodied interaction (Virtual Campus Ride) with the stationary bike, and in a traditional metaverse (headset and handlebars) without the bike. We also examined long-term retention of spatial learning, lasting more than 1 month. The results show that users retain better memory with the embodied learning experience. We found that the stationary bike prototype can push the boundaries of the Metaverse from the following perspectives. We plan to use these perspectives as hypotheses in the future and study them after our prototype pre-evaluation phase. In our future user studies, we plan to test these hypotheses with our user data collected from our users’ responses to the System Usability Scale (Brooke, 1995), the Virtual Reality Sickness Questionnaire (Kim et al., 2018), the Igroup Presence Questionnaire (Schubert et al. 2003), and semi-structured interviews.

First, Retroverse realizes real-world simulations involving both short-term memory and long-term memory. Just like the Metaverse, Retroverse can be used to create simulations of real-world scenarios, such as medical procedures or engineering projects. In the Retroverse, learners can explore and interact with these simulations to gain a better understanding of the concepts and procedures, giving them a deeper understanding of the scenes they are immersed in.

Second, by moving around the Retroverse environment, users can experiment with different concepts and ideas. For example, learners can explore a virtual environment to learn about the interconnectedness between different blocks and street segments.

Third, the Retroverse environment enables better personalized learning. With the stationary bike, you can create personalized learning experiences that are tailored to learners’ individual needs and preferences. For example, learners can explore different virtual environments and activities based on their physical ability, learning style, and interests.

6 Conclusions

We present a vision and proof-of-concept based on the real product. We use real-world street scenes around a university campus to show that people have more embodied learning experiences when riding or navigating freely (on stationary bikes) compared to traditional metaverse products. This research addresses the possibilities of combining spatial learning and simultaneous physical skill recovery using virtual reality. Based on the embodied learning perspective, we propose the concept of “backward motion” to connect long-term memory, embodied cognition, and memory trace theories. We have also developed a prototype stationary bicycle. User studies show that our theory and the application of "Retroverse" can help create immersive experiences that can improve our memory and recall.

In our research, we proposed the concept of "Retroverse" for the first time and conducted a pilot study to illustrate it. Retroverse consists of three main components: a headset for visualization similar to the Metaverse environment, a set of hardware to realize embodied learning, and most importantly, content such as episodic events or real spatial scense to retrieve long-term memory.

Our research is based on the interdisciplinary innovative pedagogy of HKUST(GZ). After taking the Design Thinking course in the first semester to understand the steps of empathy - definition - idea - prototype - test - implementation, MPhil students can propose similar research interests or collaborate with professors in specific research projects in the next 18 months. Our research on the Retroverse involves scholars from education research, urban planning and design, engineers, and MPhil students with experience in entrepreneurship. The results of our Retroverse experiments are highly relevant to education and learning. Constructivist learning theory emphasizes that learners actively construct their understanding of knowledge through experience, interaction, and reflection. In Retroverse, constructivist learning principles were applied to design activities that encourage learners to actively engage with physical devices, experiment, and make connections to their prior knowledge. Learners can take an active role in using the devices, exploring different possibilities and building their own understanding of the concepts being taught.

Retroverse also draws on the theory of embodied learning, which is about creating realistic and engaging learning experiences where learners are immersed in a simulated or virtual environment and activate their bodies. In Retroverse, the principles of embodied learning were implemented in the design and implementation of the physical devices and accompanying activities to provide learners with a highly engaging and interactive experience. By incorporating elements of VR or AR, learners can feel a sense of presence and immersion even when using physical devices.

By combining the principles of constructivist learning and embodied learning, Retroverse can provide a rich and meaningful learning experience. Learners can actively engage with physical devices, explore virtual elements, collaborate with peers, and build their own understanding of the subject matter - all in a context that closely resembles real-world applications. Future research could focus on cognitive behavioral therapy supported by virtual reality, such as improving long-term memory through embodied learning. In addition, for a Retroverse ecosystem, we need efficient and economical 3D content generation for reality-based virtual environments, which is significantly lagging in developed countries. To learn how retroverse experiences can help stitch together memories, we need additional analytical tools (EEG, eye tracking) and analytical methods in product design. As more VR content becomes available, AI would effectively generate VR content that could be episodically and geometrically integrated into Retroverse.

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References

Lee, L., et al.: All one needs to know about metaverse: a complete survey on technological singularity, virtual ecosystem, and research agenda. ArXiv, abs/2110.05352 (2021)

Yang, Y., Siau, K., Xie, W., Sun, Y.: Smart health: intelligent healthcare systems in the metaverse, artificial intelligence, and data science era. J. organ. End User Comput. **34**(1), 1–14 (2022). https://doi.org/10.4018/JOEUC.308814

Holzschneider, K., Wolbers, T., Röder, B., et al.: Cardiovascular fitness modulates brain activation associated with spatial learning. Neuroimage **59**(3), 3003–3014 (2012)

Wan, N., et al.: Assessing smart phones for generating life-space indicators. Environ. Plann. B. Plann. Des. **40**(2), 350–361 (2013)

Wang, G., et al.: Development of Metaverse for intelligent healthcare. Nat. Mach. Intell. **4**(11), 922–929 (2022). https://doi.org/10.1038/s42256-022-00549-6

Cerasa, A., Gaggioli, A., Marino, F., Riva, G., Pioggia, G.: The promise of the Metaverse in mental health: the new era of MEDverse. Heliyon **8**(11), e11762 (2022). https://doi.org/10.1016/j.heliyon.2022.e11762. ISSN 2405-8440

Schott, C., Marshall, S.: Virtual reality and situated experiential education: a conceptualization and exploratory trial. J. Comput. Assist. Learn. **34**, 843–852 (2018). https://doi.org/10.1111/jcal.12293

Manzoni, G.M., Cesa, G.L., Bacchetta, M., Castelnuovo, G., Conti, S., Gaggioli, A., et al.: Virtual reality-enhanced cognitive-behavioral therapy for morbid obesity: a randomized controlled study with 1 year follow-up. Cyberpsychol. Behav. Soc. Netw. **19**, 134–140 (2016)

Hutchinson, A.: Zuckerberg Showcases advanced vr headsets, as part of continued showcase of his metaverse vision. Soc. Media Today (2022)

Nguyen, D., Larson, J.: Don't forget about the body: exploring the curricular possibilities of embodied pedagogy. Innov. High. Educ. **40**, 331–344 (2015). https://doi.org/10.1007/s10755-015-9319-6

Georgiou, Y., Ioannou, A.: Embodied learning in a digital world: a systematic review of empirical research in K-12 education. In: Díaz, P., Ioannou, A., Bhagat, K.K., Spector, J.M. (eds.) Learning in a Digital World. SCI, pp. 155–177. Springer, Singapore (2019). https://doi.org/10.1007/978-981-13-8265-9_8

Lan, Y., Fang, W., Hsiao, I., et al.: Real body versus 3D avatar: the effects of different embodied learning types on EFL listening comprehension. Educ. Tech Res. Dev. **66**, 709–731 (2018). https://doi.org/10.1007/s11423-018-9569-y

Hung, I., Chen, N.: Embodied interactive video lectures for improving learning comprehension and retention. Comput. Educ. **117**, 116–131 (2018)

Xu, X., Kang, J., Yan, L.: Understanding embodied immersion in technology-enabled embodied learning environments. J. Comput. Assist. Learn. **38** (2022). https://doi.org/10.1111/jcal.12594

Kosmas, P., Ioannou, A., Zaphiris, P.: Implementing embodied learning in the classroom: effects on children's memory and language Skills. Educ. Media Int. **56**(1), 59–74 (2019)

Alibali, M., Nathan, M.: Embodiment in mathematics teaching and learning: evidence from learners' and teachers' gestures. J. Learn. Sci. **21**(2), 247–286 (2012)

Zubala, A., et al.: Promotion of physical activity interventions for community dwelling older adults: a systematic review of reviews. PLoS ONE **12**(7), e0180902 (2017)

Ekstrom, A.D., et al.: Cellular networks underlying human spatial navigation. Nature **425**(6954), 184–188 (2003)

Kim, H.K., Park, J., Choi, Y., Choe, M.: Virtual reality sickness questionnaire (VRSQ): motion sickness measurement index in a virtual reality environment. Appl. Ergon. **69**, 66–73 (2018). https://doi.org/10.1016/j.apergo.2017.12.016

Brooke, J.: SUS - A quick and dirty usability scale (1995). https://www.researchgate.net/publication/228593520_SUS_A_quick_and_dirty_usability_scale. Accessed 12 Apr 2023

Schubert, T., Friedmann, F., Regenbrecht, H.: Igroup Presence Questionnaire (IPQ). (2003). http://www.igroup.org/pq/ipq/ipq_english.htm. Accessed 04 June 2023

Manzoni, G.M., Cesa, G.L., Bacchetta, M., et al.: Virtual reality-enhanced cognitive-behavioral therapy for morbid obesity: a randomized controlled study with 1 year follow-up. Cyberpsychol. Behav. Soc. Netw. **19**(2), 134–140 (2016). https://doi.org/10.1089/cyber.2015.0208