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Systematic Review of Nonverbal Communication in Virtual Reality Environments: Potentials for Inclusive Education

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Abstract

Nonverbal communication (NVC) is critical for fostering inclusive and collaborative learning environments, particularly in the context of immersive Virtual Reality (VR) settings. By using tracking technologies, VR enables embodied interaction, offering users opportunities for expressive and multimodal peer communication. This systematic review explores the potential of NVC in multi-user VR environments (MUVEs) for inclusive education, addressing two key research questions: (1) What is the current state and benefit of NVC in peer interaction within MUVEs? (2) How can inclusion-focused design guidelines for VR learning be expanded based on that?

The review synthesized findings from 23 papers, identifying a significant research gap in educational applications of NVC in VR. However, insights from non-educational contexts highlight the potential of avatars, gestures, facial expressions, and spatial interactions in fostering social presence, improving collaboration, and enabling diverse communication styles. The results underscore the role of NVC in enhancing emotional expression, mutual understanding, and creative problem-solving, while also offering tools for students with diverse communicative preferences.

Drawing on these findings, the review proposes expanded design guidelines for inclusive VR learning environments. These include options for customizable avatars, adaptive tracking of NVC features, and augmented nonverbal expressions such as emojis or gesture amplifications. Additionally, VR's unique capabilities to manipulate perspectives are highlighted for enhancing engagement and cooperation.

This review highlights the transformative potential of NVC in VR to approximate face-to-face interaction, promote diversity, and scaffold inclusive education. It concludes by emphasizing the urgent need for more empirical research on NVC in VR-based educational contexts and suggests pathways for future studies and application development to address these gaps.

Keywords: Virtual Reality; Nonverbal Communication; Inclusion; E-learning; Embodied Learning.

1. Motivation

Diverse communication plays a crucial role in achieving inclusive education (Rödel & Simon, 2019a). To foster an inclusive learning environment, it is essential to embrace diverse and multimodal communication styles, including verbal, written, and nonverbal channels. The Universal Design for Learning Guidelines advocate for offering multiple means for the engagement with learning content and the expression of ideas (CAST, 2024). Communication is also of paramount importance in collaborative e-learning, where it serves as the foundation for peer interaction among learners engaged in synchronous cooperation or collaboration within learning environments (Dillenbourg, 1999).

Immersive Virtual Reality (VR), especially when based on Head-Mounted Displays (HMDs), provides a method to engage the physical dimension of communication through embodied learning (Fortman & Quintana, 2023). By leveraging tracking in HMDs and controllers, VR captures users' head and hand movements, enabling the real-time display of multimodal embodied representations and 3D interactions mirroring real body movement in virtual space (Dörner et al., 2019; Olt et al., 2024), and with the aid of technologies like data gloves and camera-based tracking for more accurate hand tracking (Y. Li et al., 2019) and algorithms for interpolating realistic body movements from limited tracking points (inverse kinematics) (Liarokapis et al., 2024; Oliva et al., 2022), an even more authentic simulation of body language is achievable.

A review of design for inclusive VR learning applications highlighted nonverbal communication (NVC) as one benefit of VR, emphasizing the significance of avatars with detailed body language and facial expressions, while also highlighting the significance of cooperative and collaborative learning (Wehrmann & Zender, 2024a). The variety of embodied communication forms represents a research gap in multi-user VR learning contexts (Mayer et al., 2023), motivating this review.

This paper is a systematic review conducted to address these research questions:

RQ1: What is the current state of practice, and what are the potential benefits of NVC for peer interaction in multi-user VR environments for learning and inclusion?

RQ2: How can the preliminary Inclusion Guidelines for VR Learning (Wehrmann & Zender, 2024a) be expanded based on these findings?

This paper references a previously published conference paper (Wehrmann & Zender, 2024b), the review was extended and updated by conducting another literature review following the same methodology.

The review begins with a discussion of the literature to establish key concepts, followed by a brief presentation of the review methodology and a narrative synthesis of the findings. A significant research gap was found, as very few studies address educational contexts. These limited findings will be compiled and placed in the context of the literature on NVC in learning contexts to highlight unexplored potential in education. After a discussion of the limitations, RQ2 will be answered by presenting a concise list of new design guidelines derived from the findings. The conclusion will summarize the most critical insights and potentials and emphasize the need to address the identified research gap.

2 Background

2.1 Nonverbal Communication for Education and Inclusion

This review focuses on NVC for peer interaction, but past research has shown that nonverbal cues also provide teachers with insights into students' attitudes and emotions (Miller, 1988; O'Hair & Ropo, 1994), suggesting that teachers would also benefit from being able to observe NVC by students in Multi-User Virtual Environments (MUVEs). NVC plays a critical role in collaborative learning. Despite being an under-researched area (Zhou et al., 2024), insights from studies on collaboration in digital (Schneider & Pea, 2013) and face-to-face settings (Schneider et al., 2021) suggest a correlation between the quality of collaboration and gaze behavior. Another study highlights an increase in creativity associated with nonverbal synchrony between collaborators (Won et al., 2014). Moreover, Won et al. show that body language is correlated with mutual positive attitudes among peers, which, in turn, is linked to success in interpersonal interactions. Another study found that in cooperative tasks requiring spatial coordination, dyads developed spontaneous nonverbal coordination without prior verbal agreement (Parikh et al., 2014). Although this example pertains to spatially coordinated tasks, it indicates an intuitive aspect of NVC that could potentially facilitate various forms of cooperation and collaboration.

Inclusion is a comprehensive approach that addresses various inequalities, with a strong emphasis on providing equitable education for all. This approach focuses on processes such as interdependent cooperation, learner-driven communication, active and democratic participation, and self-reflection concerning biases (Frohn et al., 2019). While accessibility is often the first aspect associated with inclusion, it is encompassed within the broader concept of participation. The notion of inclusive education is thus expanded to promote a positive attitude towards diversity and to productively utilize existing diversity within learning contexts.

NVC interacts with multiple dimensions of diversity among learners. Culture and gender influence nonverbal behaviors (Correa-Chávez, 2016; Correa-Chávez & Mejía-Arauz, 2024; O'Hair & Ropo, 1994), and NVC enhances intercultural communication competency by offering a rich source of cultural and emotional information (Anderson, 2023). Verbal and NVC are not directly linked (Dey & Puntambekar, 2023); a student with low verbal participation might exhibit high nonverbal participation, indicating a preference for this communication style. Key functions of NVC include expressing emotions, conveying interpersonal attitudes, and presenting one's personality (O'Hair & Ropo, 1994). To include the real diversity of students in educational processes, it is essential to provide individual, multimodal, and diverse communication channels that allow them to fully participate and express themselves in meaningful ways.

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The link between communication and inclusion extends beyond the dimension of diversity. Inclusive education aims to develop students' communicative competence within the domain of the subject being taught (Rödel & Simon, 2019a, 2019b). The acquisition of subject-specific language (e.g., the language of physics, biology, chemistry) is compared to foreign language acquisition (Leisen, 2005; Rödel & Simon, 2019b). While this language is often conceptualized as written language, inclusive education emphasizes the importance of verbal communication (Fornol, 2017; Rödel, 2018). NVC is pivotal in transitioning from everyday speech to subject-specific language. Students move from context-dependent language use in everyday speech and nonverbal registers (e.g., pointing at an experiment and saying "that right there") to increasingly abstract and context-independent descriptions as they acquire the subject's vernacular (Fornol, 2017; Leisen, 2005, 2024). Gesture-based collaboration has been shown to enhance perceptual learning (Rau & Zahn, 2022), and children prevented from gesturing rely more on non-present information, reducing their reasoning based on perceptually present information (Goldin-Meadow & Alibali, 2013). These findings suggest the potential of NVC as scaffolding for the early stages of subject-specific language acquisition when students still benefit most from using perceptually present information for heavily context-dependent communication.

2.2 Nonverbal Communication and VR

A review of communication in VR underscores the importance of avatars and nonverbal cues in influencing user interactions in social VR settings. It also reveals that VR communication bears more resemblance to face-to-face interaction than other communication media (Wei et al., 2022). However, this review did not specifically focus on Multi-User Virtual Environments, nor did it discuss educational applications, underscoring the need for the present review.

The immersive nature of VR, particularly with advanced body-tracking technologies, facilitates a high degree of embodiment (Johnson-Glenberg et al., 2014). Embodiment is the process through which a user assumes a simulated body within a virtual environment, referred to as an avatar (Morie, 2014). Embodiment allows for the incorporation of sensorimotor activities into the learning process (Johnson-Glenberg et al., 2014) and enhances processes of implicit learning through a sense of body ownership (Slater, 2017). Beyond its value for individual learners, embodiment in VR can introduce new opportunities for communication during collaboration. For example, individuals tend to gesture more when establishing common ground in their exchanges, and gestures play a role in regulating turn-taking in discussions (Held et al., 2024) and directing attention towards objects (Nathan, 2021). Through all of this, embodied social interactions in VR provide a greater bandwidth of communication than traditional screen-based interactions (Barreda-Ángeles & Hartmann, 2022; Fox & McEwan, 2017).

Figure 1: Mapping of user's real-world eye and mouth movements onto an avatar. (Kimmel et al., 2023)

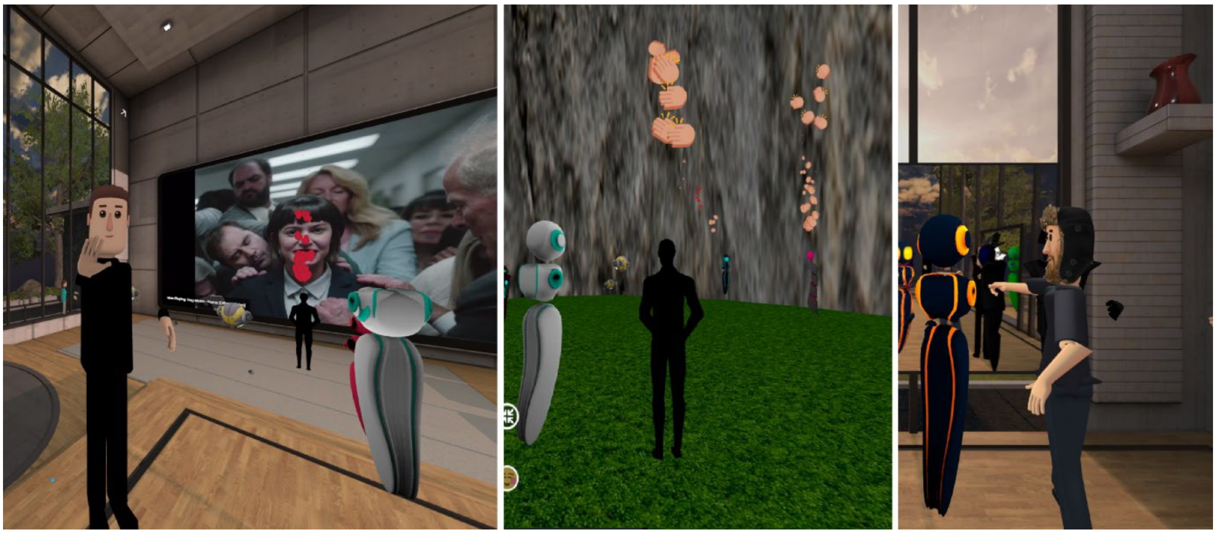

Figure 2: Nonverbal cues in VR: extended hand, non-isomorphic emoji use, and pointing. (Maloney, Freeman, et al., 2020)

Embodied learning spans a spectrum from no immersion to fully immersive motion-captured embodiment (Johnson-Glenberg et al., 2014). Depending on the extent of motion capture used, VR can achieve the highest level of embodiment within this spectrum. In the context of MUVEs, not only is the perception of the environment as real (presence) important, but also the perception of other users' avatars as real to create the sensation of sharing the embodied space with others, a phenomenon known as social presence (Kimmel et al., 2023) or also known as co-presence (Pidel & Ackermann, 2020). Factors influencing the degree of social presence include avatar representation (Roth et al., 2016), nonverbal cues such as facial expressions (Kimmel et al., 2023) (Figure 1) and body language (Sun & Won, 2021) (Figure 2). Moreover, avatars themselves can be viewed as a form of NVC (Morie, 2014), enabling uses to engage in a performance of selective self-presentation (Freeman & Maloney, 2021) enabling diverse expressions of self (Freeman et al., 2020) and identity (Maloney & Freeman, 2020) transcending the real identity as embodied outside the virtual world. Notably, users can adapt to more abstract avatars (Roth et al., 2016; Sun & Won, 2021) and can even embrace symbolic or non-isomorphic nonverbal expressions (Baloup et al., 2021; Ide et al., 2021). While full avatar realism is not mandatory, it is preferred for its superior representation of realistic body language (Aseeri & Interrante, 2021; Fraser et al., 2022; Rogers et al., 2022; Roth et al., 2016). This avatar-mediated communication plays a central role in the communicative dynamics of MUVEs, and VR seems to support more novel and complex forms of this (Freeman & Maloney, 2021).

Gesture interaction in VR, as a means of directly interacting with the virtual environment or applications (Y. Li et al., 2019), is not the primary focus of this review. Instead, this review emphasizes nonverbal cues used for peer communication, such as facial expressions, gaze, gestures, proximity to one another, emojis, drawing, and more (Wei et al., 2022). Communication is inherently multimodal, integrating various sensory modalities and body-based capacities for expression (Nathan, 2021). Consequently, the implementation of nonverbal cues in virtual environments is critical. For instance, emojis can be effectively used if a convenient selection menu is implemented (Tanenbaum et al., 2020), and while tracking facial expressions is challenging with HMDs, it is a highly desirable feature (Kimmel et al., 2023). The simplest gestures in VR environments involve proximity and basic hand gestures, requiring only the implementation of avatars that can be seen and interacted with by others sharing the same virtual space. Limited gesture tracking is available with most VR systems through the tracking of hand and head position, but increasingly more systems feature camera-based hand tracking, which can track hand gestures without relying on controllers.

3 Literature Review

Two literature reviews were conducted following the same methodology, adapted from the PRISMA methodology (Page et al., 2021). Both literature reviews are summarized in this flowchart (Figure 3) for readability. The first search date was the 3rd of April 2024, the second updated review covers new papers released between the 3rd of April and the 11th of November 2024. The second search was conducted to update and expand the findings in this highly dynamic field and yielded 9 additional papers, suggesting increased attention to the topic in 2024.

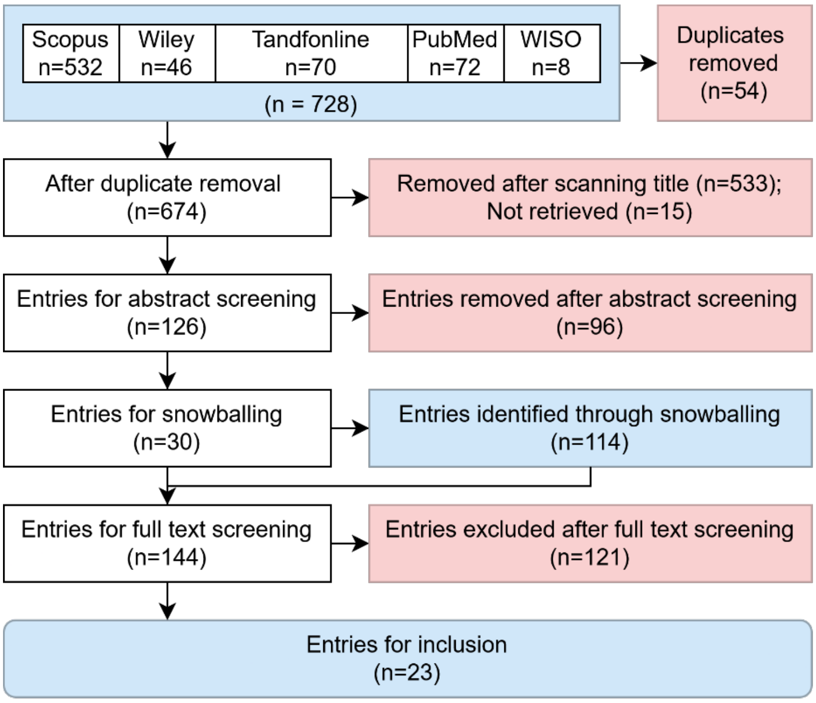

Figure 3: Literature Review Flowchart

The selection of databases to search was informed by recommendations (Gusenbauer & Haddaway, 2020) and prior experiences with these databases. Only works published from 2013 onward were considered, because the widespread availability of the proper HMD hardware started at that time, which is relevant because the emphasis of this review is on actual implementations of usable applications featuring NVC. Searches were further limited to peer-reviewed journal articles and conference papers, with further restrictions in Scopus to entries tagged with the “virtual reality” keyword. The ACM Digital Library was not searched directly due to an exceedingly high volume of irrelevant results with this search strategy, suggesting that the search string was not adequately suited to this database. Other databases, however, yielded numerous ACM articles, indicating that relevant literature from there was still captured. Forward and backward snowballing techniques were employed (Wohlin, 2014) to mitigate any limitations in the search strategy occurring from the aforementioned issue and the database selection. After a review of the full texts, a set of 23 papers was identified adhering to these inclusion criteria:

(1) Utilization of HMD-based VR, because this technology is uniquely equipped to create a sense of embodiment within a virtual environment. This excludes virtual worlds which are interacted with through a traditional computer screen as well as augmented reality and mixed reality settings.

(2) Multi-user social interaction among peers. Asymmetric interactions, like for example between patient and doctor (J. Li et al., 2020) are not included, because this paper’s emphasis lies on interactions between peers, not on relationships between teacher and student or other asymmetrical relationships.

(3) A context involving meaningful multi-user tasks, not strictly confined to educational or learning contexts, as preliminary searches indicated scarce literature focusing on these

areas specifically. A meaningful task here is defined as some collaborative or cooperative goal that needs to be carried out together with one or more peers.

(4) Documentation of the presence and relevance of NVC in communication while solving this task. The goal of this paper is to identify the way in which NVC is used in existing applications as well as experimental results which indicate the relevance of NVC, therefore only papers which describe this sort of information are included.

The search strategy was a modified Population, Phenomena of Interest, Context (PICo) framework (Munn et al., 2018), see Table 1.

Population	multi-user OR “multi user” OR cooper* OR collab* OR kooper* OR kollab* OR team* OR mehrspieler OR multiplayer OR multi-player
Phenomena of **I**n-terest	nonverbal OR non-verbal OR “non verbal” OR “body language” OR gestur* OR “facial expression” OR “eye movement” OR gaze OR “nicht verbal” OR körpersprache OR gest* OR mimik OR auge*
Context	“virtual reality” OR virtual-reality OR “virtuelle realität”

Table 1: Search string for the database searches

4 Results

Analysis of the identified records was done through a narrative synthesis (Rodgers et al., 2009). This approach was chosen because of the heterogeneous and mostly non-systematic nature of the data. The findings are divided into real-world applications, where actual case studies were conducted with implemented MUVEs, and experimental settings, where MUVEs were designed to gather data on a specific aspect of NVC. Applications are described in detail, to highlight the emergent usage of NVC they enable. Experimental results are synthesized to give an overview of the state of research. The synthesis of all records is focused on identifying the implementation or emergence of NVC in peer interactions within these papers.

Notably, among the identified records, there is a minimal focus on learning contexts, indicating a significant research gap. However, some findings highlight the potential of MUVEs with NVC for education and inclusion, which will be discussed following the presentation of the findings.

4.1 Applications

Krinkle Cube (Lages et al., 2016) is a multiplayer game that incorporates gesture interaction. It utilizes cartoon-style avatars that lack facial expressions but are tracked through HMD position and Leap Motion controllers for hand movements. Despite the avatars' positive reception, a desire for more facial expressiveness was noted. This is not an educational application, but players are able to see each other and spontaneously communicate through gestures within the game, suggesting that coexistence in a shared space for task collaboration fosters emergent communication forms which were not part of the game’s rules or task instructions. This paper presents its insights qualitatively while not providing any quotations of what the players said, instead summarizing them.

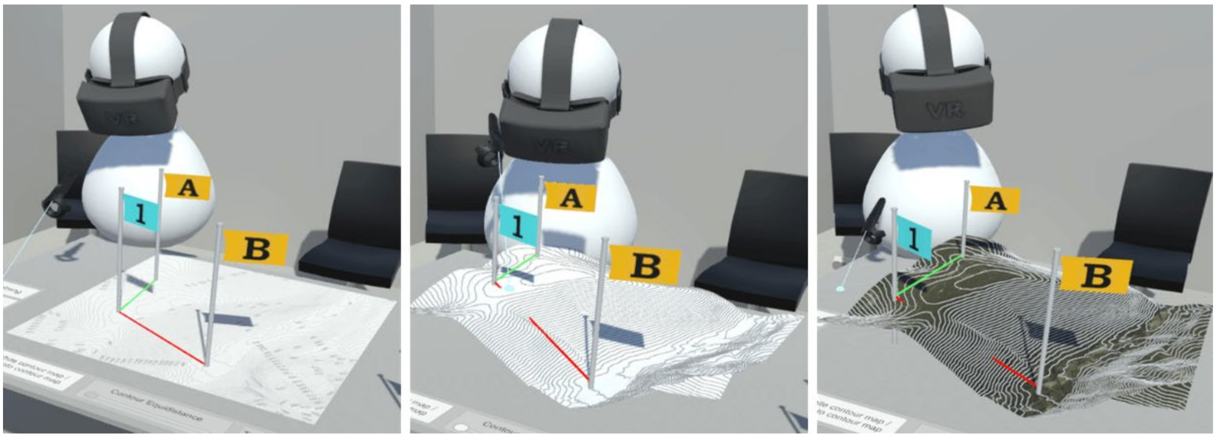

Figure 4: Use of an abstract avatar and laser pointer in a geography education application (Šašinka et al., 2018)

A **collaborative geography education application** (Šašinka et al., 2018) employs abstract avatars to interact with authentic geospatial data. It features a shared virtual room for multiple users, tracking head and hand movements. Hands are represented as floating controllers with a laser pointer functionality (Figure 4). The paper uses qualitative methodologies. Users reported that the lack of facial features hindered emotion perception, yet they adapted their communication strategies to operate based on posture and proximity. The implementation of objects within the virtual environment led to instances where users would obstruct each other’s view by standing inside objects. The study suggests that despite these challenges, user adaptability helped them overcome some communication barriers and the authors suggest that initial adaptation problems would disappear during long-term educational interventions as users get used to the application.

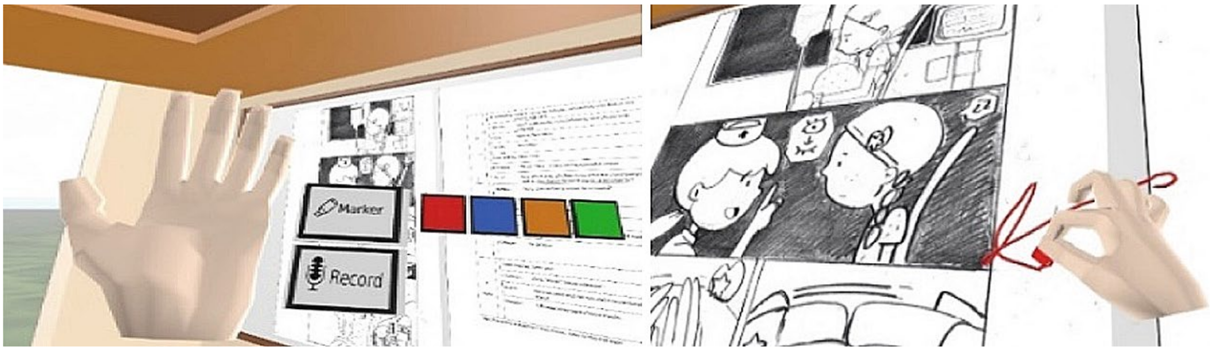

Figure 5: Collaborative manga creation in SyncMeet with an annotation tool (Tenorio Morales et al., 2020).

SyncMeet (Tenorio Morales et al., 2020) is a virtual work environment designed for collaborative manga creation (See Figure 5). This is not an educational application, but educational usage for collaborative creative tasks is possible. It features simplistic avatars with head tracking and detailed hand models for gestures tracked through Leap Motion controllers. This application allows users to collaboratively work on manga, annotating it with a drawing tool. Data was collected through a mixture of qualitative and quantitative data. Users found the VR meetings to be almost as engaging as face-to-face interactions. The lack of facial expressions was noted again. The process of discussing and annotating comics, while pointing at specific image elements, presents an interesting case for task-specific NVC, though the paper does not elaborate on these interactions. Quantitative insights of the paper focused on mental workload comparing different forms of interaction, noticing no significant findings.

A **Construction Sector Occupational Health and Safety VR experience** (Taylor et al., 2022) supports up to twenty users in a shared VR space with basic avatars that feature floating heads and hands tracked through the HMD and controllers. The hands can use laser pointers. Some hand gestures are tracked using Meta Quest controllers, which enable simple gestures like thumbs-up and pointing. Avatars can be customized with a nametag on their helmets, and movement within the VR environment is facilitated through walking (short distances) and teleportation (long distances). This application is not educational in nature, but its emphasis on collaborative virtual design processes could be valuable for educational contexts. The methodology of this paper is qualitative, presenting this application as a case study and conducting a thematic analysis. Users found that shared spatial visualization enhanced communication by offering nonverbal cues such as head direction and hand gestures. They suggested that avatar improvements could lead to a stronger sense of presence and richer NVC, such as blinking, gaze tracking, and lip syncing.

Figure 6: Theatre rehearsal space and avatar appearance in VR Chat (Levordashka et al., 2023).

The use of social VR platforms Altspace VR and VR Chat for **theatre rehearsals** (Levordashka et al., 2023) showed that users preferred full-body avatars (see Figure 6) employing inverse kinematics over floating torsos with hands. Because of the avatars' limited capability for NVC, particularly facial expressions, users felt the experience was akin to performing a radio drama rather than a stage play. Presence issues arose from avatars behaving unrealistically, e.g., through glitches, physics violations, and teleportation. However, VR rehearsals were beneficial for learning blocking (actor positioning in a scene), embodying characters, and fostering social bonds among participants. Users were able to memorize blocking positions and replicate them on a real stage, suggesting that MUVEs can effectively represent the nonverbal dimension of proximity. The study concludes that VR is beneficial for theatre rehearsals, even with limited gesturing and positioning capabilities, suggesting that advanced technologies like haptics and facial tracking might not be essential for creating valuable MUVE experiences. Most of the data gathered was qualitative, but some quantitative data was gathered as well. A high degree of engagement, presence, co-presence and a low degree of motion sickness were measured through questionnaires. This application is not strictly educational, because it was aimed at professional actors, but educational use for actors in training and theatre classes is possible.

Figure 7: Mooring requires spatial awareness (Bjørn et al., 2024)

An application for **maritime safety training** (Bjørn et al., 2024) was designed to develop a high degree of social fidelity in VR. The cooperative task of mooring involves constant awareness of the position of other cooperators in the virtual space (See Figure 7), thus the developers included full-body avatars and the ability to see these avatars as they walk across the deck of a ship with a free motion range and interact with objects and artifacts such as winches and ropes. The authors conclude that awareness is a feature of social fidelity in VR environments: Through being aware of other cooperators, users changed how they positioned themselves to accommodate other users' safety. The authors also note that users used body language proper for the maritime context, such as the hand gesture usually associated with the "all stop" order. Overall, they note that a beneficial effect of the high social fidelity of the VR application is that participants develop the social skill of enacting awareness. To accommodate this, the authors note that photorealistic avatars were not needed, merely the ability to see the digital bodies, which were represented more abstractly.

4.2 Experiments

The papers covered in this section are experimental MUVEs, designed and used for gathering data about peer interaction using NVC. As such they are not educational applications, but their findings can highlight educational benefits. Overall, 17 papers identified in the systematic review are covered in this section through a narrative synthesis of the findings.

Research consistently demonstrates the effectiveness of MUVEs for communication, highlighting their resemblance to face-to-face interactions (Coburn et al., 2018; Greenwald et al., 2017; Le Tarnec et al., 2023; Smith & Neff, 2018) and how embodiment positively affects cooperative tasks (Coburn et al., 2018; Giovannelli et al., 2023; Pan & Steed, 2017; Wu et al., 2021). Avatar embodiment can also play a role in reducing social anxiety (Greenwald et al., 2017), fostering positive attitudes towards collaborators (Herrera et al., 2018; Pan & Steed, 2017; Wu et al., 2021), and effectively transmitting emotional cues (Hart et al., 2018). Drawing and sketching activities particularly benefit from VR's interactive capabilities (Coburn et al., 2018).

In terms of gaze behavior, findings are mixed. One study reported minimal impact from the realism of gaze (Seele et al., 2017), yet another indicated that more expressive avatars can encourage active gaze engagement (Le Tarnec et al., 2023). An experiment evaluating whether or not autistic individuals use gaze information when solving a collaborative VR task has found that gaze information was significant, and at times was used more than more salient available pointing gestures (Caruana et al., 2024), however another experiment found head gaze to be insufficient if not supported by other modalities (Ghamandi et al., 2024). Eye gaze was shown to be quite significant in collaboratively solving object based tasks in virtual environments (Liu et al., 2024).

A lack of embodiment features can diminish the positive effects and the resemblance to face-to-face interaction (Smith & Neff, 2018). The expressiveness of avatars, even beyond simple gestures, significantly influences the usage of nonverbal expressions, especially in direct social interactions (Herrera et al., 2018), with limited facial expressiveness reducing perceived social presence (Moser et al., 2024; Smith & Neff, 2018). Interestingly, a lower degree of avatar realism may be beneficial here, as it could lead to a greater tolerance for tracking inaccuracies (Herrera et al., 2018) and does not significantly impact social presence negatively by itself (Wu et al., 2021).

Figure 8: Facial expressions on an avatar (Le Tarnec et al., 2023).

More expressive avatars are generally linked to an enhanced sense of social presence (Le Tarnec et al., 2023; Wu et al., 2021). For tasks that lack social interaction, facial expressions may not significantly affect performance (Le Tarnec et al., 2023), indicating the nuanced role of nonverbal cues in different contexts. The need for nonverbal cues seems to vary across applications; some necessitate realistic cues for effective communication, while others do not (Adkins et al., 2023; Greenwald et al., 2017; Hart et al., 2018; Le Tarnec et al., 2023) and at least one study found no significant difference between hand tracking and VR controllers (Adkins et al., 2023). Multimodal communication (voice and gestures) enhances task performance while gestures as the sole form of communication would not perform worse than solely voice, but neither individually perform as well as the combination of both (Ghamandi et al., 2024). In applications which rely on more social interactions, exaggerated expressive facial features (see Figure 8) can enhance collaboration and social presence (Le Tarnec et al., 2023). Multiple papers suggest enhancing NVC through technological means to further improve these interactions (Giovannelli et al., 2023; Hart et al., 2018).

The experimental applications MAGIC (Fidalgo et al., 2023) and SPARC (Simões et al., 2024) experiment with “above-the-table” shared workspace awareness by manipulating participant’s gestures to create more accurate pointing awareness between collaborators (See Figure 9). They seek to address the problem that when one collaborator points to a part of the object, the other collaborator may not be able to see because it is occluded or too far away. To this end they are manipulating the perspective of each client and the tracked body language to flip the object and interpolate the new finger/arm position to create a more seamless pointing agreement. The evaluation of MAGIC concluded that the system significantly increases pointing agreement, as well as improving co-presence and awareness of interactions. SPARC approaches this differently, permitting very distorted avatars but thereby facilitating a change in appearance that works generically and beyond the limiting setting of two users on opposite sides of the same object (See Figure 10). Like MAGIC, SPARC led to a higher task performance. However, there was no increase in co-presence, perception of other users and workspace awareness (Simões et al., 2024).

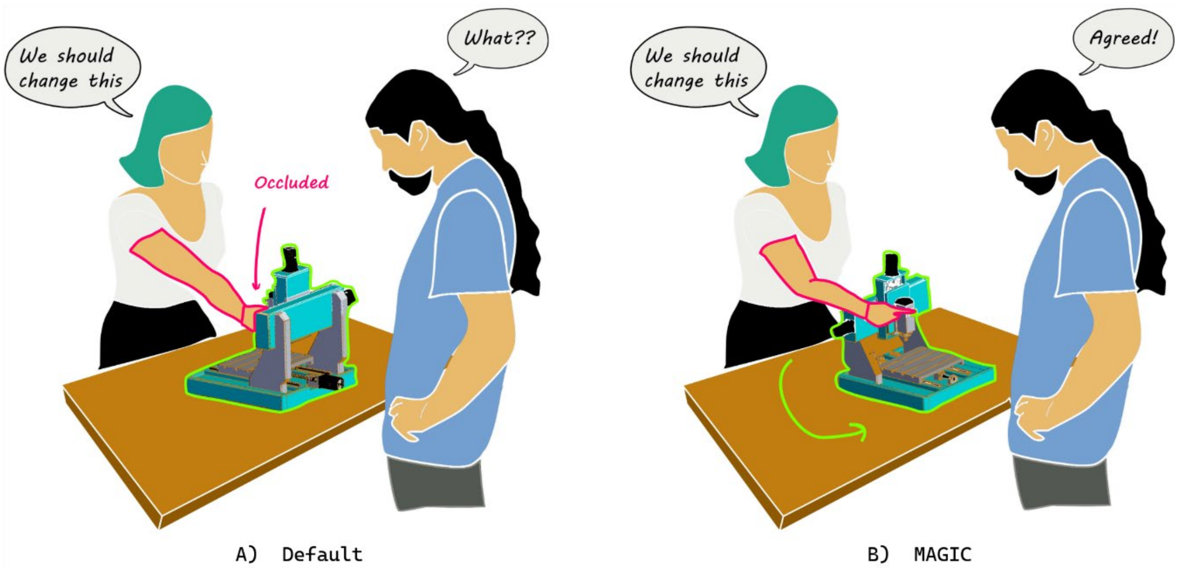

Figure 9: Pointing agreement in MAGIC (Fidalgo et al., 2023)

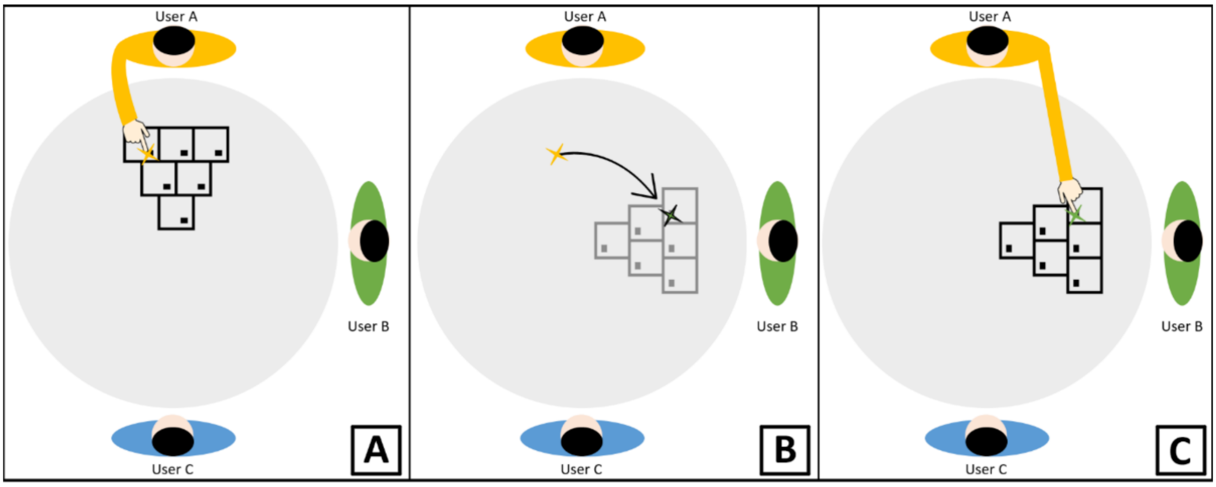

Figure 10: SPARC distorts the arm length and position to more accurately convey pointing information to another user's viewpoint (Simões et al., 2024)

MAGIC and SPARC represent strong use cases for VR, because beyond merely representing real body language in virtual space, they make use of the ability to manipulate perception and position in the virtual environment to create an illusion of shared space that exceeds the affordances of co-located face-to-face interactions. The authors detail that interactions in the MAGIC space consisted primarily of pointing gestures with verbal cues only being used to confirm understanding between partners. No participant used relative position words, such as left and right, during the experiments. While these findings are limited to object-centered collaboration and as of now limited to working at a virtual table with an object on it, it reveals great potential use cases for manipulating user perspectives in VR.

5 Potentials for Education and Inclusion

The findings presented permit several observations about the potential of MUVEs with NVC for education and inclusion. The existing studies do not enable a comprehensive empirical evaluation of these observations, and as such, they are subject to future assessment. Nonetheless, they provide a means to address the research gap identified by this review.

Approximating Face-to-Face Interactions in Virtual Environments appears possible based on numerous accounts previously described. While VR offers significant value across various learning scenarios, its effectiveness in creating sufficiently communicative learning environments largely depends on the design of the applications. The findings presented suggest that VR can create a sense of co-presence and social presence that enhances positive attitudes between collaborators and allows learners to express their emotions and their own personality. An aspect related to the capacity for self-expression is **the ability to read emotions and foster social bonding** through NVC in VR. As noted by many articles discussed, the absence of facial expressions was a common critique. The availability of facial expressions would facilitate the perception of emotions and enhance social presence, a feature users desired. During VR theatre rehearsals, users reported a high degree of social bonding among participants (Levordashka et al., 2023). Other studies demonstrated that avatar embodiment could promote positive feelings towards collaborators (Herrera et al., 2018; Pan & Steed, 2017; Wu et al., 2021) and assist in conveying emotional cues (Hart et al., 2018). An additional potential benefit for inclusion is the enhancement of facial expressions by some studies (Hart et al., 2018; Le Tarnec et al., 2023), which could enable learners who struggle to express emotions in face-to-face interactions to rely on technological support to communicate their feelings to collaborators.

Communication About Perceptually Present Information in VR Visualizations represents a domain where one of VR's primary advantages—innovative ways of visualizing information—converges with the educational benefits of learning through perceptually present information, which is facilitated by gesture interactions (Goldin-Meadow & Alibali, 2013; Rau & Zahn, 2022). This benefit has been observed in interactions with geospatial data (Šašinka et al., 2018), manga creation (Tenorio Morales et al., 2020), and construction safety (Taylor et al., 2022), where users were provided with tools such as laser pointers or drawing capabilities. MAGIC (Fidalgo et al., 2023) and SPARC (Simões et al., 2024) represent an especially interesting use case of this, as the element of pointing agreement was directly aided by technological affordances unique to VR. These tools enhance communication by enabling users to directly point to or interact with objects that are perceptually present.

The **utilization of avatars provides benefits for self-expression**, potentially even surpassing the capabilities of face-to-face interactions. One study highlighted that the “masking” effect facilitated by an avatar led to a reduction in social anxiety during collaborative tasks (Greenwald et al., 2017). Moreover, a different study (Maloney & Freeman, 2020) observed that social VR with avatars fosters experimentation with self-expression. They noted that users of social VR platforms experimented with avatars of different genders, potentially enhancing inclusion for queer individuals (Freeman et al., 2020). All of this suggests that the ability to hide one’s body behind an avatar, and to communicate not verbally but through NVC, can provide a feeling of safety to the users and helps them overcome social anxiety (Maloney, Freeman, et al., 2020; Maloney, Zamanifard, et al., 2020). However, not all users experimented with their self-expression, one study finds that especially VR based avatar-mediated communication shifted some users’ concern primarily to consistency of their avatar with real characteristics they embody (Freeman & Maloney, 2021). Another study discovered that marginalized users of a social VR platform utilized NVC as a means to shield themselves from undesired behaviors and to overcome biases and communication barriers associated with not being native English speakers (Maloney, Freeman, et al., 2020). This indicates advantages for intercultural communication skills, aligning with research on NVC in face-to-face language learning (Anderson, 2023). Beyond self-expression through avatars, Slater (Slater, 2017) discussed how VR embodiment could reduce racial bias when users assume perspectives of bodies outside their in-group. This finding should be contrasted with Freeman and Maloney noting that social VR seems equipped to cater to diverse user’s needs to represent their own race and culture (Freeman & Maloney, 2021) to highlight that the advantages don’t end at erasing visible markers of diversity, but are able to serve diverse needs for self-expression. These findings, primarily within the realm of social VR, suggest potential benefits that could extend to learning applications, provided avatar customization is adequately implemented. Such an approach could facilitate aspects of participation (through self-expression) and reflection (towards bias reduction), which are essential to inclusive education (Frohn et al., 2019).

Higher quality of collaboration and cooperation through nonverbal VR interaction has been observed in multiple studies (Coburn et al., 2018; Pan & Steed, 2017; Wu et al., 2021) and appears to align with the positive effects NVC has on face-to-face interactions, as discussed in prior research (Parikh et al., 2014; Schneider et al., 2021; Schneider & Pea, 2013; Won et al., 2014; Zhou et al., 2024). This may stem from the cumulative effects of all previously mentioned benefits, such as positive social attitudes towards collaborators, enhanced trust, a greater degree of self-expression, communication about perceptually present information, and spontaneous NVC strategies. The ability to exaggerate and manipulate gestures and body language seems to aid social presence, pointing agreement and attention (Fidalgo et al., 2023; Giovannelli et al., 2023; Herrera et al., 2018). This manipulation could potentially be used to enable more reluctant students to communicate more expressively. Overall, there appears to be an interdependence between cooperation and communication, a theme also explored in the inclusive education literature, which emphasizes the significance of cooperation and communication among other processes (Frohn et al., 2019) and these findings suggest that VR NVC contributes to this aspect. Another aspect of collaboration in **VR is emergence of spontaneous NVC strategies**, as observed with Krinkle Cube (Lages et al., 2016), which mirrors previously referenced findings (Parikh et al., 2014). In instances where NVC supplements verbal communication, users have also positively acknowledged this as added value (Taylor et al., 2022). The inclusive emphasis on enabling diverse communication methods suggests that students who could benefit from this style of communication might increasingly utilize it if provided with options, thereby enabling a type of interaction otherwise inaccessible. It is conceivable that, due to the lack in detail of descriptions provided about the precise nature of nonverbal interactions in many of these studies, more such emergent interactions occurred but were not documented.

6 Discussion

Some findings appear in conflict with each other, suggesting that the interactions between these variables have a lot of complexity and can depend heavily on the specific use-case.

While some papers argue that high co-presence yields positive results for collaborative and cooperative use cases (Coburn et al., 2018; Pan & Steed, 2017; Wu et al., 2021), other papers suggest that it may not even be that important (Pidel & Ackermann, 2020). The absence of some social cues can shift attention to other available cues, while leaving the task performance unimpeded (Pidel & Ackermann, 2020; Roth et al., 2016; Steed & Schroeder, 2015). Depending on the context, realistic avatar gaze might matter for conversations between two peers, but in groups other variables, such as avatar distinctiveness might matter more (Pidel & Ackermann, 2020; Steed & Schroeder, 2015).

Similarly, studies tend to find conflicting results on preferences with regards to avatar design: Some indicate that realism is paramount (Pakanen et al., 2022), other’s suggest various advantages of more abstract avatars (Adkins et al., 2023; Herrera et al., 2018; Le Tarnec et al., 2023). One primary advantage of abstract avatars seems to be that the uncanny valley effect (Mori & Macdorman, 2017) is mitigated, because a mismatch in fidelity of tracking the subtle body movements is more noticeable on a realistic avatar than on an abstract avatar representation (Fidalgo et al., 2023; Herrera et al., 2018). One study noticed that user's felt a mismatch between their real intended gesture and the "clunky hand movements" reproduced in VR (Olt et al., 2024). What stays unclear is whether this effect disappears when the fidelity of tracking technology matches photorealistic avatar fidelity. Another apparent contradiction is that one study found that hand tracking and VR controllers are not significantly different in the context of a collaborative task that involves object manipulation, though the authors do note that this may be different with more realistic avatars and tasks that require more communication (Adkins et al., 2023).

Another area that is still uncertain is the manipulation and enhancement of avatars, body language and facial expressions. The two conflicting tendencies in this field are on the one hand a user's identification with their own avatar and on the other hand there are several reasons why the manipulation of avatars beyond mirroring the users' real movements is promising. MAGIC and SPARC provide strong use cases for manipulating perspectives. Other research has suggested that amplifying facial expressions and head visibility (Choudhary et al., 2023; Le Tarnec et al., 2023), adding generated or exaggerated body language animations (Giovannelli et al., 2023), use of abstract NVC such as emojis (Giovannelli et al., 2023) and manipulation of certain gestures (Fidalgo et al., 2023) can lead to beneficial effects. While avatar embodiment can enable users to feel more present with others, it can also make them feel more exposed and threats to the virtual body can be experienced as threats to the real body, for example personal space violations (Barreda-Ángeles & Hartmann, 2022). To this end it was also suggested that options should be present that enable users to control their avatar in a less embodied fashion (Freeman & Maloney, 2021). This highlights a tension at the core of VR embodiment: Should developers aim to mirror real movements onto the virtual body as accurately as possible or should they provide various interaction modes which maintain the separation between real body and virtual body, either through manipulation and enhancement or through options for "dis-embodiment"?

The focus of this paper is on how NVC is used in MUVEs, but it is necessary to acknowledge that this all happens within the limitations of current day technologies for tracking. As technologies improve and become more standardized, while developers and designers become increasingly proficient in implementing them, a diminishment of the negative effects may occur. Therefore, it is hard to predict the future trajectory of this field. The limited amount of data points in this emergent field allows very low certainty on these issues, but the trends that have emerged in this review may be able to inform future research and design of new MUVEs for learning that enable NVC.

7 Design Implications

A general principle of inclusive education is adaptivity and providing options (CAST, 2024; Frohn et al., 2019). Based on this principle, work on the Inclusion Guidelines for VR Learning (Wehrmann & Zender, 2024a) was continued. The following design guidelines are synthesized from the review:

- Provide options for avatar design, ranging from abstract to photoreal, and enable a diverse range of facial features, outfit options and non-gender specific options to

enable users to represent a wide range of cultural and gender identities. Allow abstract avatars and floating torsos as well as full-body avatars. Different users have different avatar preferences and needs.
- Design for social fidelity within the spatial dimension. In MUVEs, users share a virtual space. Account for that by incorporating spatial and workplace awareness as well as co-presence into application design.
- Implement options for tracking NVC features such as hands, feet, facial expression, gaze and lip syncing as appropriate for the task. Implement inverse kinematics to generate a full range of body movements from limited data points. Provide options for users to enable and disable the tracking options that suit their preferences for privacy and comfort. Mind the heterogeneous needs of users: some prefer a fuller range of expression, some experience discomfort with full tracking.
- Provide options for augmented, enhanced and abstract NVC. Allow users to choose if they want their peers' NVC to be displayed authentically or exaggeratedly. Give users the ability to set preferences for perspective changes and transformations of avatars. Provide interaction mechanisms beyond mirroring of body language. Include the option to use emojis, to simulate facial expressions and to play animations of standard gestures instead of having the user do them. Providing options for diverse kinds of communication allows users to develop individual communication strategies that suit their needs and preferences.
- Provide options for visualization tools beyond body language tracking. Provide users with laser pointers, pens, other tools or the ability to shift perspectives, manipulating the actual position of objects and body parts to enhance communication abilities.

8 Limitations

Several methodological limitations constrain the scope and generalizability of this review's findings. Search and coverage limitations first arose from the exclusion of the ACM Digital Library database, where the high volume of false positives indicated that the search strategy was inadequately suited for this highly relevant database. While snowballing techniques and ACM papers indexed in Scopus provided some mitigation, it remains unclear whether this sufficiently compensated for the potential loss of relevant records. Additionally, the restriction to peer-reviewed publications may have excluded valuable insights from industry reports, grey literature, and commercial applications that could have provided practical perspectives on NVC implementation.

Content and scope constraints further limited the review's educational relevance. Most critically, the scarcity of studies conducted specifically in educational contexts forced the authors to extrapolate educational implications from non-educational applications, creating a substantial gap between identified potential and demonstrated educational benefits. The temporal restriction to post-2013 publications, while justified by the focus on actual HMD implementations, may have excluded foundational work from earlier prototype systems that could have informed the analysis.

Analytical limitations also affected the synthesis process. The heterogeneous nature of the included studies led the authors to opt for narrative synthesis, which is inherently more subjective than more rigorous synthesis methods. The absence of formal quality assessment for individual records further compounds this subjectivity, potentially affecting the reliability of the synthesized findings.

Finally, the emerging nature of the field itself presents fundamental limitations. The numerous conflicting findings and limited empirical validation across studies suggest that research on NVC in VR remains in its infancy, lacking established consensus on key design principles. Consequently, the proposed design guidelines represent theoretical extrapolations rather than empirically validated recommendations, highlighting the substantial research gap that this review identifies rather than resolves.

9 Conclusion

This review underscores the capability of MUVEs to foster a level of social presence comparable to that of face-to-face communication through the implementation of NVC features. It has been observed that users are adaptable to varying levels of avatar fidelity, encompassing aspects such as gaze, gestures, and bodily realism, tailored to the context of the task at hand. Tasks that demand a higher degree of social attentiveness benefit from greater levels of embodiment. Nonetheless, across many studies there is a prevalent call for avatars with more expressive facial features, highlighting an area ripe for technological advancement and reflecting users' desire for enhanced social presence with their collaborators. Future research could explore whether less realistic avatars might offer benefits that outweigh the noted value of realistic representation, or how more realistic avatar implementations could be made widely accessible.

Furthermore, it has been noted that specific tasks stand to benefit from the unique effects of nonverbal interactions, such as the use of blocking in theatre rehearsals, laser pointers in 3D visualizations, and drawing in collaborative creative projects. Beyond this, the spontaneous emergence of NVC strategies in collaborative scenarios hints at potential widespread benefits beyond specialized solutions.

The potential advantages for education and inclusion derived from these observations were explored to address RQ1. MUVEs with nonverbal interaction capabilities offer a resemblance to face-to-face interactions, enable the spontaneous emergence of NVC strategies, facilitate communication about perceptually present information in VR visualizations, allow for creative self-expression through avatars, enhance the ability to perceive and express emotions, strengthen social bonds, and foster higher-quality collaboration and cooperation through nonverbal interactions. These insights suggest that NVC in MUVEs represents a promising area for future research, which should examine these aspects in greater detail. The scarcity of empirical studies specifically within educational contexts and the lack of applications explicitly designed for educational purposes limit this review, underscoring a significant research gap.

Initially aimed at highlighting the role of NVC in MUVEs for learning, this review instead revealed a considerable gap in research on this topic. While most identified studies focused on non-educational tasks, their core findings stay pertinent to the exploration of NVC for peer interaction in educational settings. In addressing RQ2, added design guidelines for the Inclusion Guidelines for VR Learning were synthesized. These cover areas such as providing options for NVC, avatar design, tracking options, and various augmentation and enhancement features for educational MUVEs. The development of VR applications tailored to specific educational scenarios across various disciplines could use these findings for more comprehensive evaluations and to generate empirical results validating, expanding, or challenging these findings.

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