Peer Relatedness in 3D: A Virtual Reality Paradigm to Simulate and Assess Social Dynamics in Educational Settings

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Abstract

Despite the well-documented effects of social inclusion and exclusion on students' emotional and cognitive development, current research lacks immersive methodologies capable of capturing the dynamic and real-time nature of peer interactions in educational settings. This work addresses this gap by presenting a Virtual Reality (VR) paradigm designed to simulate and assess social relationships in a controlled yet ecologically valid environment. The contribution is structured into several four sections: First, it discusses the importance of social relationships and belonging in educational contexts, focusing on the impact of peer inclusion and exclusion on students' motivation and well-being. Secondly, it highlights the limitations of traditional research methods like the Cyberball paradigm, which fail to account for the complexities of verbal communication and peer interactions. Thirdly, the work explores how VR offers a more effective platform for studying social inclusion and exclusion, allowing for the manipulation of social cues in immersive, interactive environments. Finally, the contribution provides a detailed overview of a conversational VR paradigm powered by AI, designed to replicate real-world classroom interactions and measure the effects of social inclusion and exclusion on students. The findings of this study contribute to the emerging field of social XR, offering novel insights into how immersive technologies can be leveraged to foster inclusive learning environments and enhance social connections in educational settings.

Keywords

Social relationships, Human-computer interaction, VR, Artificial Intelligence, Education

1. Introduction

Social relationships and a sense of belonging are central to students' well-being and academic success, particularly during childhood and adolescence, when peer interactions significantly influence cognitive, emotional, and social development [1]. The satisfaction of relatedness needs, as outlined in Self-Determination Theory (SDT), plays a fundamental role in fostering intrinsic motivation and psychological well-being [2]. Conversely, frustration of these needs can lead to disengagement, reduced self-esteem, and heightened anxiety or depression [3]. In educational settings, students' social experiences—ranging on the continuum from inclusion to exclusion—shape their motivation, self-esteem, and academic engagement [4], with peer acceptance or rejection being a key determinant of emotional and academic outcomes [5].

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Although the effects of peer relatedness satisfaction and frustration are well-documented [3, 6], there remains a significant gap in understanding how these dynamics work in naturalistic, interactive settings like classrooms. Traditional methods, such as self-reports or observational studies, often fail to capture the subtleties of real-time peer interactions [7]. Paradigms like the Cyberball paradigm [8] have been used to simulate peer exclusion through ball-passing games, but they do not address the complexities of verbal communication and peer dynamics essential to social belonging. While the Cyberball paradigm manipulates peer inclusion and exclusion by controlling how often participants are included or excluded, it lacks the richness of conversational interactions that shape real-life social experiences.

This gap can be addressed by innovative methodologies that aim to replicate the complexity of real-time peer interactions while maintaining experimental control. Virtual Reality (VR) offers immersive environments that mirror real-world social settings, allowing researchers to manipulate social cues—such as conversational turn-taking and acknowledgment—while preserving ecological validity [9]. By immersing participants in interactive scenarios with virtual peers, VR enables a deeper understanding of how social exclusion and inclusion unfold in dynamic, complex interactions. Our work leverages a conversational VR paradigm driven by AI to examine how children and adolescents experience these social dynamics in classroom-like settings. This novel methodology, integrating VR and AI-generated dialogue, allows precise manipulation of social cues while preserving the richness of human interaction, offering new insights into how immersive technologies can be used to foster inclusive learning environments and promote positive social behaviors in educational contexts.

2. Theoretical Background

Within educational settings, peer relatedness, that is, the sense of connection and acceptance among peers, is a central component of students' psychological well-being and social development. According to SDT [10], individuals have fundamental psychological needs for relatedness, competence, and autonomy, which are essential for optimal growth and motivation [2]. Peer relatedness satisfaction occurs when these needs are met within the context of peer relationships, fostering feelings of belonging, security, and emotional connection. Conversely, peer relatedness frustration arises when these needs are thwarted, particularly through negative social experiences like exclusion, rejection, or neglect. In the school context, this frustration can have immediate and long-lasting consequences on emotional and cognitive functioning [3, 11].

Key manifestations of peer relatedness satisfaction and frustration are social inclusion and exclusion [12]. Social inclusion refers to a state where an individual is actively engaged, acknowledged, accepted and valued by their peers. The presence of social inclusion fulfills fundamental psychological needs, contributing to positive emotional states and a sense of belonging within the group [13]. Social exclusion, on the other hand, refers to situations where an individual feels ignored, rejected, or marginalized by peers. This can occur explicitly, through direct verbal or behavioral rejection, or implicitly, when peers fail to acknowledge or respond to the individual's attempts to engage [14].

Research consistently showed that social inclusion leads to positive outcomes such as improved mood, greater self-esteem, and satisfaction of basic psychological needs like belonging, nurturance, and companionship [15, 16]. In contrast, social exclusion has been associated with negative mood, frustration, and unmet psychological needs, manifesting as feelings of rejection, sadness, and anxiety [17, 18]. Over time, chronic experiences of exclusion can lead to long-term consequences, including loneliness, school disengagement, and mental health issues such as anxiety and depression [19]. Therefore, the experience of social exclusion directly threatens children's emotional well-being and academic success, underscoring the importance of understanding how these social processes unfold in real-life contexts.

With increasing experiences of being included, students show higher levels of school engagement and academic performance [15], cooperation with classmates, cognitive development improving attention and perception, and academic skills useful for learning outcomes [20] and general school wellbeing, including learning motivation, goals, and feelings [16]. On the contrary, excluded students feel not related to other peers, have no competence in entering social relationships, and experience no autonomy

and control of the situation [17]. Excluded students, compared to included ones, show more learning difficulties and academic problems in the long-term time, concurrently with absenteeism, discipline problems, poor academic skills, and higher dropout [19].

Recent research has started investigating the effects of social dynamics like social inclusion and exclusion on cognitive performance, particularly in working memory (WM), with differing outcomes observed across these contexts. WM, as conceptualized by Baddeley [21], refers to the system responsible for temporarily holding and manipulating necessary information for cognitive tasks like reasoning and comprehension. Baddeley divides WM into verbal and visuospatial components, which are thought to operate independently of each other. Verbal WM deals with the processing and manipulation of language-related information, while visuospatial WM is responsible for handling spatial and visual data. Studies examining the link between social exclusion and WM have shown that exclusion seems to negatively impact WM in children and adolescents [22, 23], while inclusion may improve WM across age groups [24], suggesting a differential effect of social experiences on various types of cognitive processes. This emerging area of research provides valuable insights into the intersection of social dynamics and cognitive functioning in educational contexts, but we still lack sufficient or clear evidence of both their short- and long-term effects on learning and WM performance. More research is needed to definitively understand how social experiences shape cognitive outcomes in real-world educational settings.

To study social inclusion and exclusion, researchers have developed experimental paradigms that are assumed to simulate social interactions. One of the most widely used paradigms is the Cyberball paradigm, a 2D ball-tossing game designed to simulate social dynamics by controlling the frequency of participant inclusion in the game. The participant assumes they play with two other individuals, but, actually, they interact only with agents. In the exclusion condition, the participant is deliberately ignored after a few initial interactions, while in the inclusion condition, they receive the ball frequently. The Cyberball paradigm has proven effective in demonstrating the immediate emotional and psychological effects of exclusion, such as negative mood, reduced self-esteem, and diminished sense of belonging in both children and adolescents [25].

However, while the Cyberball paradigm has proved to be valid for assessing and measuring social exclusion, it has notable limitations. First, the interaction is based on a simple, non-verbal task of ball passing, which does not replicate the complexity of real-world social interactions, where inclusion and exclusion are often conveyed through subtle verbal cues, body language, and social acknowledgment. This limits the ecological validity of the paradigm, making it less representative of the types of exclusion that children and adolescents experience in naturalistic settings, such as school classrooms or peer group discussions [26]. Furthermore, the minimalistic design of the Cyberball paradigm can be unengaging, particularly for younger participants accustomed to more interactive and immersive environments [27].

To address these limitations, researchers have explored alternative paradigms that incorporate richer social interactions, such as chatroom tasks and virtual environments [28, 29]. These methods provide more complex, socially meaningful scenarios that better capture the dynamics of social inclusion and exclusion, particularly through conversational interactions [30]. However, while these systems offer improvements over the Cyberball paradigm, they still face challenges in terms of ecological validity and engagement, especially when targeting young participants [9].

VR represents a significant advancement in the study of social inclusion and exclusion. Unlike traditional paradigms, VR allows for the creation of immersive, 3D environments where participants can interact with virtual peers in ways that more closely resemble real-world social dynamics [31]. VR enables the simulation of social interactions—such as group discussions or peer activities—allowing for a more naturalistic exploration of social inclusion and exclusion while maintaining the experimental control required for psychological research [32].

The primary advantage of VR lies in its ability to enhance ecological validity [33]. VR environments can replicate real-world settings, such as school classrooms or playgrounds, and incorporate complex social cues, including verbal exchanges, body language, and eye contact, which are essential for understanding social exclusion and inclusion. Moreover, VR allows for AI-driven agents that can adapt their behavior in real-time based on participant input, offering a level of interaction that traditional

Figure 1: Screen Capture of the Virtual Classroom.

paradigms cannot provide [34]. This dynamic ability to simulate social interactions, including subtle cues such as conversational neglect or acknowledgment, is crucial for studying the psychological and emotional effects of peer inclusion and exclusion in a controlled, yet ecologically valid, manner [35].

Recent reviews have demonstrated that VR-based paradigms are effective in eliciting authentic emotional responses, such as increased feelings of social presence, connectedness, and engagement, which are critical for studying peer relatedness [36]. By providing a more realistic context for social interactions, VR paradigms offer a promising approach for investigating the complex interplay between social inclusion, exclusion, and psychological outcomes such as mood, self-esteem, and cognitive performance [37]. This makes VR a powerful tool for advancing our understanding of how social dynamics affect children and adolescents, offering valuable insights into how these experiences shape learning, emotional well-being, and social development.

3. 3D VR Paradigm's Development and Assessment to Simulate and Assess Social Exclusion and Inclusion in Educational Settings

The VR paradigm, which is at the core of this presentation, was designed to simulate social inclusion and exclusion in a classroom-like setting using immersive VR. The objective was to create a highly engaging, naturalistic environment where participants could experience social interactions that mirrored real-world and school-related social dynamics. Central to the design was the integration of conversational interactions between participants and virtual peers, where inclusion or exclusion was conveyed through the agents' responses and interactions. The process of developing the paradigm involved three main stages: conceptualization, technical development, and iterative refinement.

3.1. Conceptualization of the VR Environment

The initial design phase focused on defining the virtual environment and the types of interactions that would elicit social inclusion and exclusion [38]. The VR scenario was modeled after a typical classroom setting, where students engage in group discussions, making it a familiar and realistic context for the participants. This setting was chosen to align with the real-life experiences of children and adolescents, ensuring ecological validity [37]. The virtual classroom included basic elements such as desks, a blackboard, ambient lighting, and wall posters, creating a school environment that was both simple and relatable to the target age group of 8–16 years (see Figure 1).

To enhance the ecological validity (i.e., generalisability of findings to real-life contexts; [33]), the environment was kept minimalistic and visually clear, so as not to overwhelm younger participants with too much detail. The agents representing the participants and their virtual peers were designed to

be age-matched, ensuring the agents' appearance and behavior closely matched that of the children interacting with them. This design was essential to maintaining the immersion of the experience while allowing the participants to feel comfortable in the environment.

3.2. Technical Development and Implementation

The Unity engine was used for developing the VR scenario due to its flexibility in creating interactive 3D environments. The VR experience was optimized for the Meta Quest 2 headset, chosen for its portability and ease of use without external controllers, which minimized physical discomfort and cognitive load for participants. The entire interaction took place while participants were seated, with no object manipulation required, to further reduce discomfort and focus attention solely on the social interaction.

AI-driven agents were integrated into the system to simulate dynamic, naturalistic conversations. These agents used large GPT-4o language models (LLMs) to generate context-appropriate responses based on the participant's verbal input, ensuring that each interaction felt authentic and responsive. The LLM-based agents could engage in adaptive dialogue, responding to participants in real-time and adjusting their responses according to the conversational flow. This feature was particularly crucial for simulating social inclusion and exclusion through conversational cues.

For instance, in the inclusion scenario, agents would ask the participant questions, respond positively to their contributions, and maintain a balanced conversational flow. In the exclusion scenario, agents would deliberately ignore the participant, fail to respond to their statements, or provide minimal, non-engaging answers, simulating a lack of interest and social neglect. The manipulation of social exclusion was subtle yet impactful, focusing on the virtual peers' behavior in a way that reflected common, everyday social exclusion, such as ignoring or not acknowledging someone's presence or comments in a group discussion [14].

The agents were designed to be highly expressive to ensure that their non-verbal cues contributed to the social dynamics of the interaction. Each agent had a set of idle animations that conveyed passive engagement, such as slight movements, breathing, and small gestures, contributing to the realism of the interaction. Additionally, each agent was programmed with emotion-specific animations that would trigger based on the content of the conversation. For example, when the agents responded positively to the participant's statements, their body language would reflect happiness or interest, with animations such as nodding, leaning forward, or showing facial expressions of joy and agreement. In contrast, when the agents ignored the participant, their body language would reflect disinterest or detachment, with animations like turning away or shifting focus towards the other peer.

The conversation flow was designed so that agents would ask questions or provide comments, creating natural conversation pauses that allowed participants to respond verbally. The system monitored speech activity to maintain the pacing of the conversation, ensuring that the agents didn't interrupt the participant prematurely, which is a common issue in less refined VR systems. This attention to timing was particularly important for children and adolescents, whose speaking speeds can vary widely.

3.3. Interaction and AI Response System

The system employed real-time voice recognition using Whisper, an automatic speech recognition model, which converted the participant's spoken responses into text. This text was then processed by the GPT-4o model to generate a coherent, contextually appropriate response. The use of these advanced models allowed for the creation of more authentic conversations, where agents could adapt their responses to the topic at hand and the participant's verbal cues.

The conversation was structured so that the agents could engage in a back-and-forth dialogue, which, depending on the condition (inclusion or exclusion), either encouraged the participant to keep contributing or subtly discouraged them by responding minimally or ignoring them. The manipulation of social inclusion and exclusion was designed to be gradual, where agents would shift from actively

engaging to gradually withdrawing attention or engagement, ensuring that the participant did not immediately realize the manipulation, thus preserving the integrity of the experimental condition.

4. Methodological and Ethical Aspects

The overall assessment of our VR paradigm was conducted across three studies, each refining the paradigm and addressing specific research questions regarding the emotional and cognitive effects of social inclusion and exclusion. The research involved about 450 participants, with a balanced mix of students (ages 8–16). Each study assessed a specific VR experimental condition: social inclusion (active engagement in conversation) or social exclusion (virtual peers ignoring the participant).

All participants received clear informed consent from their legal guardians, and informed assent was obtained from the participants themselves. Given the nature of the manipulation (social exclusion), it was crucial to ensure that participants were debriefed immediately after the session. Participants were provided with an explanation of the VR task, with a focus on ensuring that the exclusion manipulation did not cause lasting emotional harm. Additionally, the system was designed to avoid any potentially distressing outcomes by keeping the exclusion periods brief and moderate, ensuring that no participant was left feeling severely isolated or rejected.

After entering the virtual classroom, participants were asked to explore the space for about five minutes to become familiar and acclimatized to their surroundings. The task then transitioned to interaction with two virtual peers. The conversation began with a greeting, followed by an invitation for participants to share a school activity they had participated in, creating a natural conversational opening. The interaction was structured so that in the exclusion condition, the agents were designed to ignore the participant's input following a pre-set script systematically. In contrast, in the inclusion condition, the agents responded in a way that actively engaged the participant, responding to their contributions and maintaining a reciprocal dialogue. This dynamic allowed the agents to either provide acknowledgment, fostering feelings of belonging, or to withhold responses, inducing a sense of inclusion or exclusion.

The task thus replicated the social dynamics of inclusion and exclusion, which Piaget viewed as essential in shaping cognitive and emotional development through social learning [39]. By facilitating these interactions within a controlled virtual environment, the paradigm provided a clear structure for observing how these social experiences influence mood, behavior, and cognitive processes.

The system was designed with careful attention to usability to ensure that participants could comfortably engage with the VR experience. Measures were taken to minimize simulator sickness, with the VR scenario tested for comfort and usability prior to the study. Participants were seated during the interaction, with the experience lasting no longer than 10 minutes for exclusion and 20 for inclusion to avoid fatigue or discomfort. The interface was designed to be intuitive, requiring minimal prior experience with VR, which allowed even younger children to engage without extensive training.

The three-study research followed an iterative process to refine the VR paradigm, in line with established guidelines for developing VR scenarios in educational settings [40]. After the initial testing phase, feedback was gathered from participants to evaluate the realism and emotional engagement of the social scenarios. Based on the feedback, a focus group was conducted with groups of students to further refine the social dynamics within the VR environment. These focus groups provided valuable insights into how the social inclusion and exclusion scenarios were perceived by students, allowing the research team to adjust the social interactions, content, and topics to better align with the expectations and experiences of the target audience.

In addition to refining the social situations, the second phase of the paradigm refinement involved recording the VR conversation using students' voices. This step was critical for ensuring that the dialogue in the VR environment felt authentic and contextually relevant. By involving students in the creation of voice recordings, the researchers ensured that the language, tone, and background voices in the conversation were appropriate for the age group, and that the content was reflective of real-life social interactions. This approach not only enhanced the realism of the conversation but also

contributed to a more immersive experience, as the voices matched the participants' expectations of social exchanges in a school context.

The final version of the VR paradigm, which incorporated these refinements, was used in the subsequent studies. These improvements ensured that the social dynamics and interactions within the VR environment were both realistic and relevant to the participants, enhancing the ecological validity of the experiment while maintaining control over the social manipulations of inclusion and exclusion.

5. Preliminary Outcomes, Discussion, and Future Work

Preliminary findings from our studies have demonstrated the effectiveness of the VR paradigm in eliciting emotional and cognitive responses associated with social inclusion and exclusion. In the social inclusion condition, participants showed a decrease in negative mood ($MD_{diff} = -0.35$, $SD = 0.31$), while in the social exclusion condition, a decrease in positive mood ($MD_{diff} = -4.26$, $SD = 2.04$) and an increase in negative mood ($MD_{diff} = 1.99$, $SD = 1.51$) were observed [41]. These changes were particularly pronounced in adolescents, who demonstrated stronger emotional reactions than children, supporting the developmental sensitivity to peer evaluations [42].

Qualitative feedback from students emphasized the immersive nature of the VR experience [43, 44]. Many students highlighted the realism of virtual interaction, noting the sense of presence and engagement with the avatars. However, some adolescents pointed out that the avatars' responses were not always natural and suggested improvements in dialogue authenticity. These insights underscore the need for further refining the realism of social cues, particularly for older participants, whose developmental stage makes them more sensitive to inconsistencies in social interactions [45].

After refining the VR environment as suggested by students' feedback and following established guidelines for developing VR scenarios in educational settings [40], cognitive performance outcomes revealed distinct effects of social inclusion and exclusion on verbal and visuospatial WM. In the social inclusion condition, participants across both age groups showed an increase in verbal WM performance ($MD_{diff} = 0.56$, $SD = 0.23$), suggesting that students benefit from social inclusion in terms of verbal cognitive processing. This improvement was consistent across age, highlighting the positive impact of social inclusion on cognitive flexibility and verbal task performance. In the social exclusion condition, the effects were more pronounced and divergent between age groups. Children showed a significant decline in visuospatial WM performance ($MD_{diff} = -1.51$; $SD = 0.52$), while adolescents exhibited an increase in visuospatial WM ($MD_{diff} = 1.21$; $SD = 0.49$). This age-related difference suggests that adolescents may experience heightened emotional responses to social exclusion, which may activate cognitive resources such as emotional regulation and attention control, as shown in previous research on adolescent social cognition [46], whereas younger children are more vulnerable to the negative effects of social exclusion on visuospatial tasks. These findings underscore the role of social dynamics in influencing cognitive performance differently across developmental stages.

These outcomes highlight the potential of VR as an effective tool for studying social relationships in educational contexts. Unlike traditional methods like the Cyberball paradigm, VR offers a more ecologically valid simulation of social dynamics, including conversational cues and peer interactions [9, 31]. The findings suggest that social inclusion and exclusion can lead to opposite outcomes in terms of mood but diverse outcomes in terms of cognitive performance, highlighting the difference between these social dynamics. VR environments provide an opportunity not only to study these phenomena but to intervene in real-time, fostering positive emotional and cognitive outcomes [47, 48]. This capacity for controlled, personalized experiences makes VR a promising tool for advancing research in social and emotional learning and educational interventions, offering a rich platform for understanding and improving social relationships in school settings.

Looking forward, further research is essential to refining the VR paradigm and expanding its applicability in educational settings. Future work should not only focus on adapting the VR environment to various age groups and educational contexts, but also on exploring how VR can support collaborative learning and foster social interactions in a dynamic, personalized manner. One promising direction

involves using the VR system for longitudinal studies, examining how repeated interactions in VR impact social skills development over time, particularly in contexts of social inclusion and exclusion. This would allow researchers to assess how sustained exposure to immersive social dynamics could promote long-term improvements in empathy, communication, and social relationship management.

Moreover, the VR system can be enhanced to include adaptive interventions that respond in real time to signs of social exclusion or isolation. By integrating real-time emotional and cognitive monitoring, the system could provide personalized feedback or adjust social cues to foster more inclusive social interactions, offering a novel tool for social-emotional learning. This could lead to the development of VR-based interventions that provide individualized support to students experiencing social difficulties.

Furthermore, expanding the scope of the VR paradigm to include cross-cultural studies will be crucial for understanding how social dynamics vary across different cultural contexts. Additionally, the integration of physiological and behavioral metrics, such as heart rate variability or eye-tracking, could provide a more comprehensive understanding of peer dynamics in immersive educational environments. By combining these physiological responses with behavioral data, we can gain deeper insights into how social inclusion and exclusion affect students' psychological and physiological states, further optimizing VR interventions for educational purposes. Ultimately, the goal is to develop VR systems that can be seamlessly incorporated into classrooms, promoting inclusivity, empathy, and social competence among students, while offering real-time, data-driven interventions to support positive peer interactions.

Declaration on Generative AI

The authors have not used any Generative AI tools.

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