ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

in cotutela con KATHOLIEKE UNIVERSITEIT LEUVEN

DOTTORATO DI RICERCA IN

PSYCHOLOGY

Ciclo 38

Settore Concorsuale: 11/E2 - PSICOLOGIA DELLO SVILUPPO E DELL'EDUCAZIONE

Settore Scientifico Disciplinare: M-PSI/04 - PSICOLOGIA DELLO SVILUPPO E PSICOLOGIA DELL'EDUCAZIONE

THE SIGNIFICANCE OF PEER RELATIONSHIPS FOR EXECUTIVE FUNCTIONS AND LEARNING OUTCOMES

Presentata da: Giuseppe De Luca

Coordinatore Dottorato

Mariagrazia Benassi

Supervisore

Elvis Mazzoni

Supervisore

DIETER BAEYENS

Co-supervisore

Martina Benvenuti

Esame finale anno 2026

KU LEUVEN

FACULTY OF PSYCHOLOGY AND
EDUCATIONAL SCIENCES

Parenting and Special Education Research Unit

The significance of peer relationships for executive functions and learning outcomes

Giuseppe De Luca

Doctoral thesis offered to obtain the degree of
Doctor of Educational Sciences (PhD)

Supervisors: Prof. Dr. Dieter Baeyens
Prof. Dr. Elvis Mazzoni
Co-supervisor: Dr. Martina Benvenuti
2026

Summary

This PhD thesis examines the effects of peer exclusion on working memory and academic achievement across childhood and adolescence. Peer exclusion (being ignored or left out of activities, play, or conversation; Riva & Eck, 2016)—is pervasive in schools, yet its impact on executive functions such as working memory(Miyake et al., 2000) remains underexplored due to the lack of ecologically valid paradigms across age groups (Parsons, 2015; Tuijnman et al., 2021), limited research on immediate versus daily effects (Dirk & Schmiedek, 2016; Galeano-Keiner et al., 2022), and insufficient integration of emotional and cognitive outcomes in developmental trajectories (Vandenbroucke et al., 2018; Fuhrmann et al., 2019). Grounded in Ecological Systems Theory (Bronfenbrenner, 2005), Attachment Theory (Bowlby, 1969, 1982), and Self-Determination Theory (Deci & Ryan, 1985), the PhD thesis investigates how immediate episodes (i.e., short-term effects observable right after an event) and daily fluctuations (i.e., fluctuations in experiences across days in natural school settings) in peer exclusion affect students' working memory and academic success.

The thesis is structured into six chapters. **Chapter 1** provides the general introduction, outlining the conceptual and empirical background on peer relationships, working memory, and the neural and affective mechanisms underlying peer exclusion. **Chapter 2** presents a peer-reviewed literature review on immersive Virtual Reality (VR) as an educational resource, covering its theoretical and applied foundations and highlighting its potential for operationalising peer exclusion with greater ecological validity than traditional paradigms. **Chapter 3** presents an interview study, which explores subjective experiences of exclusion in a 3D immersive VR classroom paradigm and in the classical Cyberball task. Both paradigms successfully elicited feelings of exclusion, but the responses differed developmentally: children focused more on playful and graphical aspects, whereas adolescents reported deeper emotional insight and more critical reflections on rejection in VR, alongside stronger concerns about realism. **Chapter 4** builds on the previous one by quantitatively contrasting the effects of Cyberball and the 3D VR paradigm in an experimental design, showing that while Cyberball elicited stronger immediate emotional distress, the 3D VR paradigm— particularly for adolescents—provided markedly greater realism and ecological validity. **Chapter 5** examines the immediate effects of peer exclusion on mood and working memory using the 3D VR paradigm in an experimental design. Peer exclusion reduced positive mood and increased negative mood, especially in girls and adolescents. Cognitively, children's visuospatial working memory declined, whereas adolescents' one improved, highlighting developmental differences. Higher WM decline was predicted by higher teacher support, stronger VR presence and realism, lower socioeconomic status, weaker baseline WM, and greater behavioural difficulties**. Chapter 6** examines two intensive longitudinal studies with daily measurements over a 28 school-day period at the end of primary and beginning of secondary school. Findings reveal that daily peer relatedness satisfaction and frustration dynamically predict working memory updating and self-perceived academic success by following different trajectories. Finally, **Chapter 7** integrates the findings across studies, discussing their theoretical contributions, methodological implications, and relevance for educational practice.

Together, the PhD thesis shows that peer exclusion has both immediate emotional and cognitive consequences and dynamic day-to-day effects on working memory and perceived academic success. These effects are moderated by developmental stage as well as by contextual and individual factors. By integrating immersive VR paradigms with intensive longitudinal studies, this dissertation advances the study of peer exclusion methodologically, theoretically, and practically, offering a more nuanced understanding of its role in learning and development.

Samenvatting

Dit proefschrift onderzoekt de effecten van uitsluiting door leeftijdsgenoten op executieve functies en academisch succes tijdens de kindertijd en adolescentie. Uitsluiting door leeftijdsgenoten (i.e. het genegeerd worden of buitengesloten worden van activiteiten, spelletjes of gesprekken; Riva & Eck, 2016) komt veel voor op scholen, maar de impact ervan op executieve functies (i.e. hogere cognitieve processen die doelgericht gedrag mogelijk maken; Miyake et al., 2000) is nog onvoldoende onderzocht vanwege (1) het gebrek aan ecologisch valide paradigma's voor verschillende leeftijdsgroepen (Parsons, 2015; Tuijnman et al., 2021), (2) beperkt onderzoek naar directe versus dagelijkse effecten (Dirk & Schmiedek, 2016; Galeano-Keiner et al., 2022) en (3) onvoldoende integratie van emotionele en cognitieve uitkomsten in ontwikkelingstrajecten (Vandenbroucke et al., 2018; Fuhrmann et al., 2019). Gebaseerd op de ecologische systeemtheorie (Bronfenbrenner, 2005), de hechtingstheorie (Bowlby, 1969, 1982) en de zelfdeterminatietheorie (Deci & Ryan, 1985), onderzoekt het proefschrift hoe directe episodes (i.e. kortetermijneffecten die meteen na een gebeurtenis waarneembaar zijn) en dagelijkse schommelingen (i.e. fluctuaties in ervaringen gedurende dagen in natuurlijke schoolomgevingen) in uitsluiting door leeftijdsgenoten het werkgeheugen -de meest stabiele voorspeller van leren- en academisch succes van leerlingen beïnvloeden.

Het proefschrift is opgebouwd uit zes hoofdstukken. **Hoofdstuk 1** omvat een algemene inleiding, waarin de conceptuele en empirische achtergrond van relaties tussen leeftijdsgenoten, executieve functies, en de neurale en affectieve mechanismen die ten grondslag liggen aan uitsluiting door leeftijdsgenoten worden geschetst. **Hoofdstuk 2** betreft een peer-reviewed hoofdstuk over immersieve virtual reality (VR) als educatief hulpmiddel, waarin de theoretische en toegepaste grondslagen worden besproken en het potentieel wordt benadrukt om uitsluiting door leeftijdsgenoten met een grotere ecologische validiteit te operationaliseren dan de traditionele paradigma's doen. **Hoofdstuk 3** presenteert het eerste empirische artikel, dat kwalitatief de subjectieve ervaringen van uitsluiting onderzoekt in een 3D-immersief VR-klaslokaalparadigma en in de klassieke Cyberball-taak. Beide paradigma's slaagden er met succes in gevoelens van uitsluiting op te wekken, maar de reacties verschilden volgens leeftijd van de deelnemers: kinderen concentreerden zich meer op speelse en grafische aspecten, terwijl adolescenten diepere emotionele inzichten en meer kritische reflecties over afwijzing in VR rapporteerden, naast sterkere bezorgdheid over het realisme. **Hoofdstuk 4** bouwt voort op het vorige hoofdstuk door de effecten van Cyberball en het 3D VR- paradigma kwantitatief met elkaar te vergelijken. Hieruit blijkt dat Cyberball weliswaar een sterker direct emotioneel leed opriep, maar dat het 3D VR-paradigma – met name voor adolescenten – een aanzienlijk groter realisme en ecologische validiteit bood. **Hoofdstuk 5** onderzoekt de onmiddellijke effecten van uitsluiting door leeftijdsgenoten op de emotionele stemming en het werkgeheugen met behulp van het 3D VR-paradigma. Uitsluiting door leeftijdsgenoten verminderde de positieve stemming en verhoogde de negatieve stemming, vooral bij meisjes en adolescenten. Cognitief gezien nam het visueel-ruimtelijk werkgeheugen van kinderen af na uitsluiting, terwijl dat van adolescenten verbeterde, wat de ontwikkelingsverschillen benadrukt. Een grotere afname van het werkgeheugen werd voorspeld door meer ondersteuning van leerkrachten, een sterkere VR-aanwezigheid en realisme, een lagere sociaaleconomische status, een zwakker basiswerkgeheugen en grotere gedragsproblemen. **Hoofdstuk 6** beschrijft twee intensieve longitudinale studies, bestaand uit metingen tijdens 28 schooldagen aan het einde van de basisschool en het begin van de middelbare school. De bevindingen tonen aan dat de dagelijkse tevredenheid en frustratie met betrekking tot leeftijdsgenoten op dynamische wijze het updaten van het werkgeheugen en het zelfgepercipieerde academische succes voorspellen. Ten slotte integreert **hoofdstuk 7** de bevindingen van de verschillende studies en bespreekt het hun theoretische bijdragen, methodologische implicaties en relevantie voor de onderwijspraktijk.

In zijn totaliteit toont het proefschrift aan dat uitsluiting door leeftijdsgenoten zowel directe emotionele en cognitieve gevolgen heeft als dynamische dagelijkse effecten op het werkgeheugen en het waargenomen academisch succes. Deze effecten worden gemodereerd door de ontwikkelingsfase en door contextuele en individuele factoren. Door immersieve VR-paradigma's te integreren met intensieve longitudinale studies, bevordert dit proefschrift het onderzoek naar uitsluiting door leeftijdsgenoten op methodologisch, theoretisch en praktisch vlak, en biedt het een meer genuanceerd inzicht in de rol ervan in leren en ontwikkeling.

Published or accepted journal articles, and/or articles submitted for or worthy of publication

- Chapter 2: Immersive Virtual Reality as Educational Resource.
    - Authors: De Luca, G., Benvenuti, M., Blume, F., Baeyens D., Gerrit, M., Khau, T., Mazzoni, E.,
    - Original title: Virtual reality as educational resource
    - First author: De Luca, G.
    - Publication status: Manuscript published at *Research Handbook on Cyberpsychology*, Edward Elgar Publishing
- Chapter 3: Exploring Social Exclusion Through Immersive Virtual Reality: A Qualitative Comparison with the Cyberball Paradigm in Children and Adolescents
    - Authors: De Luca, G., Baeyens, D., Meixner, G., Khau, T., Benvenuti, M., & Mazzoni, E., Original title: Exploring Social Exclusion Through Immersive Virtual Reality: A Qualitative Comparison with the Cyberball Paradigm in Children and Adolescents
    - First authors: De Luca, G.
    - Publication status: Manuscript published at *European Journal of Psychology of Education*
- Chapter 4: Experiencing Peer Exclusion in 3D: An Immersive Virtual Environment Study
    - Authors: De Luca, G., Benvenuti, M., Baeyens, D., Meixner, G., Khau, T., Mazzoni, E., Blume, F.
    - Original title: Experiencing Peer Exclusion in 3D: An Immersive Virtual Environment Study
    - First author: De Luca, G.
    - Publication status: Manuscript under review at *Acta Psychologica*
- Chapter 5: The Cognitive Cost of Being Left Out: Immediate Effects of Peer Exclusion on Working Memory in Children and Adolescents Using Immersive Virtual Reality
    - Authors: De Luca, G., Mazzoni, E., Benvenuti, M., Blume, F., Meixner, G., Khau, T., Baeyens, D.
    - Original title: The Cognitive Cost of Being Left Out: Immediate Effects of Peer Exclusion on Working Memory in Children and Adolescents Using Immersive Virtual Reality
    - First authors: De Luca, G.
    - Publication status: Manuscript to be submitted to an international peer-reviewed journal
- Chapter 6: How Peers Shape the Mind: Affective and Cognitive Consequences of Daily Relatedness in Children's School Lives
    - Authors: De Luca, G., Irmer, A., Schmiedek, F., Blume, F.
    - Original Title: How Peers Shape the Mind: Affective and Cognitive Consequences of Daily Relatedness in Children's School Lives
    - First author: De Luca, G.
    - Publication status: Manuscript to be submitted to an international peer-reviewed journal

Additional forms of publications, or papers with more than two first authors

- None

Relationship between doctoral thesis and master's theses or other papers

- **Chapter related to the own master's thesis or paper**
    - None
- **Chapter related to another master's thesis or paper**
    - Giuseppe De Luca was the daily supervisor of two master's thesis students (Beatrice Fabri and Francesca Tosco), who quantitatively assessed the immediate effects of peer exclusion on working memory (Chapter 5). Their theses explored some initial ideas, some of which were discarded while others were further developed and significantly expanded by Giuseppe De Luca. The aforementioned theses were submitted and defended in the Master's program in School and Community Psychology at the Department of Psychology, University of Bologna.

Statement about the use of Gen-AI

- I hereby declare that generative artificial intelligence (Gen-AI) tools were used solely for the purposes of grammar checking, language translation, and text revision during the preparation of this dissertation. The intellectual content, research design, data analysis, interpretation of results, and all substantive contributions are entirely my own work and that of my co-authors.

Table of contents

Chapter 1	General introduction
Chapter 2	Immersive Virtual Reality as Educational Resource
Chapter 3	Exploring Social Exclusion Through Immersive Virtual Reality: A Qualitative Comparison with the Cyberball Paradigm in Children and Adolescents
Chapter 4	Experiencing Peer Exclusion in 3D: An Immersive Virtual Environment Study
Chapter 5	The Cognitive Cost of Being Left Out: Immediate Effects of Peer Exclusion on Working Memory in Children and Adolescents Using Immersive Virtual Reality
Chapter 6	How Peers Shape the Mind: Affective and Cognitive Consequences of Daily Relatedness in Children's School Lives
Chapter 7	General discussion

CHAPTER 1

General Introduction

School represents a developmental environment where students spend a substantial amount of time. It is not merely a place for academic instruction but also a critical social setting in which students build relationships with teachers and peers (Eccles & Roeser, 2011). Consequently, the quality of these relationships plays a central role in students' personal development and psychological well-being (Sandilos et al., 2017). Peer relationships represent a fundamental aspect of the school experience for children and adolescents (Rubin et al., 2011). These relationships are defined as the interactions that students have with their same-aged peers. Given that children spend a considerable amount of time surrounded by peers within the school environment, these interactions become pivotal to their social and emotional development (Martin & Lease, 2022). The formation of positive peer relationships, whether with classmates or other same-age individuals, facilitates the development of shared behaviours and, consequently, a common peer culture and environment (Rudolph, 2021). Within this social context, students internalise shared habits and values and shape their identity and personality by comparing themselves with others. As such, peer relationships exert a direct influence on students' development.

Peer relationships are instrumental in the development of self-perception and identity. Their formation primarily occurs during childhood and adolescence, with school serving as the primary social context for this developmental process (Eccles & Roeser, 2011). Peer relationships are especially important during adolescence, as there is a marked increase in the need for relatedness and peer reliance during late childhood, particularly in the transition to adolescence (Rudolph, 2021). In this period, peers emerge as crucial social figures, offering emotional support, modelling behaviours, and fulfilling the need for belonging and companionship (Gempp & González-Carrasco, 2021). Furthermore, research has consistently shown that peer relationships at school are key determinants of children and adolescents' academic motivation and learning outcomes (for a systematic review, see Li et al., 2024).

A large body of evidence supports the notion that academic success is strongly influenced by the school environment, particularly by the quality of social interactions (Roorda et al., 2011). Indeed, a robust body of literature has demonstrated that peer relationships significantly impact students' well-being and overall learning experiences (Wentzel & Muenks, 2016). A positive school climate—characterised by positive peer relationships—has been associated with greater academic motivation and improved learning outcomes (Thapa et al., 2013). Conversely, negative peer interactions can contribute to a hostile school climate, ultimately hindering students' academic performance (Juvonen et al., 2011). Among the various forms of negative peer dynamics—such as victimisation and rejection—peer exclusion refers to situations in which students are ignored or left out of activities, play, or conversation (Killen et al., 2013). This type of social exclusion has been shown to provoke negative emotional states and interfere with school engagement (Platt et al., 2013).

Despite its demonstrated effects, peer exclusion remains underexamined in comparison to other forms of negative peer dynamics, and its impact has often been underestimated (Sentse et al., 2017). Moreover, most studies on peer dynamics have primarily examined socio-emotional consequences (e.g., mood changes, frustration of relatedness), while effects on cognition—and especially on executive functions (EFs)—remain largely unexplored (Masten et al., 2013). Yet, meta-analytic reviews confirm robust relations between EF and both academic and socio-emotional outcomes, underscoring why cognition (and specifically EF) is a critical outcome to study in relation to peer exclusion (Cortés-Pascual et al., 2019; Spiegel et al., 2021; Ahmed et al., 2019). To address this gap, it is imperative to examine how specific episodes of peer exclusion during single peer interactions affect both students' socio-emotional functioning and their cognitive performance (Buelow et al., 2015). The present work seeks to fill this void.

The overarching aim of the research presented in this dissertation is to simulate and replicate peer exclusion dynamics in school-aged populations and to assess their affective and cognitive consequences. To achieve this, this dissertation employs a multimethod approach, integrating

qualitative, quantitative, experimental, and intensive longitudinal designs. The experimental manipulation of peer exclusion's specific episodes during single peer interactions serves as the primary independent variable, while outcome variables include mood, psychological needs, EFs, and academic achievement. This integrated approach allows the research to capture the multifaceted nature of peer exclusion and its effects on students from different methodological perspectives.

Before moving to the main essence of the present work, this introductory chapter lays the theoretical and empirical foundation for understanding peer exclusion as a critical, yet underexplored, factor in students' emotional and academic development. Grounded in Ecological Systems Theory, Attachment Theory, and Self-Determination Theory, the dissertation positions peer relationships as key developmental contexts that may directly influence EFs and academic achievement.

Theoretical Background

The three main theoretical backgrounds guiding this dissertation are Ecological Systems Theory, Attachment Theory, and Self-Determination Theory. In what follows, each background will be shortly introduced with respect to (a) its theoretical rationale, (b) its preferred focus or methods in studying development, and (c) its relevance for understanding peer exclusion.

First, the Ecological Systems Theory posits that children's developmental outcomes are significantly shaped by their environment, with the strength of influence depending on the proximity of each contextual factor to the child (Bronfenbrenner, 1992; 2005). Within this framework, "contexts" are specific systems: the microsystem (e.g. family, classroom, peer groups) exerts the most immediate influence, while more distal systems (e.g. culture, societal institutions, economy) shape development more indirectly. These contexts interact dynamically so that distal contexts both contain and shape proximal ones, and proximal interactions (with parents, teachers, peers) are the daily settings in which development and school learning occur.

Second, the Attachment Theory, developed by John Bowlby (1969), describes the relationship between children and their caregivers as being shaped by the caregiver's emotional availability, responsiveness, and sensitivity. Caregivers serve as secure bases, enabling children to explore their environment and engage in novel or challenging activities both at home and in school (Greenberg, 1999). In addition to serving as secure bases, caregivers also act as safe havens—providing emotional comfort and reassurance when children experience distress or uncertainty. This dual function allows children to alternate between exploration and proximity seeking, ensuring both confidence in autonomy and access to emotional regulation when needed (Ainsworth et al., 1978). As a consequence of establishing secure attachments, children develop internal working models—cognitive representations of self and others—that facilitate the building of favourable relationships with teachers and peers (Bowlby, 1982; Bretherton & Munholland, 2008). Moreover, secure attachment figures can buffer children's academic stress by acting as safe havens. Conversely, when attachment figures are emotionally unavailable or express negative emotions, children tend to exhibit less favourable developmental and academic outcomes (Bowlby, 1982).

Third, the Self-Determination Theory (Deci & Ryan, 1985) posits that individuals experience optimal development when their basic psychological needs—autonomy, competence, and relatedness—are satisfied. Autonomy refers to the perception that one's actions are self-endorsed rather than externally controlled; competence reflects the belief in one's ability to handle challenges effectively; and relatedness involves feeling connected and accepted by others. In educational contexts, the satisfaction of these needs is considered critical for students' well-being, engagement, and learning outcomes (Ryan & Deci, 2000). Recent studies show that when these needs are not met, students suffer lower motivation, increased academic stress or burnout, poorer cognitive performance, and reduced well-being (Du et al., 2025).

Each of the three central theoretical backgrounds in this dissertation thus highlights the importance of proximal social relationships—parents, teachers, peers—for children's development

and school learning. Yet, they underscore somewhat different mechanisms: Ecological Systems focuses on context proximity; Attachment stresses the quality of the relationship with caregivers and their emotional and cognitive effects; Self-Determination Theory centres on internal basic psychological needs and how social relationships satisfy or frustrate them. Together, these theories offer an integrative framework for understanding how peer relationships shape developmental outcomes. Research has consistently shown that peer interactions are essential to children and adolescents' development (Weyns et al., 2018).

According to Bronfenbrenner (2005), peer relationships, much like those with parents and teachers, form a critical component of the microsystem and can exert comparable influence on developmental outcomes. Building on Ecological Systems Theory, empirical research has consistently demonstrated that peer relationships function as a proximal developmental context with immediate and sustained effects on children's and adolescents' adjustment. Within the microsystem, peers constitute a salient source of daily social interaction, co-regulation, and feedback, shaping behavioural, emotional, and cognitive development through repeated, reciprocal exchanges (Bronfenbrenner & Morris, 2006). School-based studies grounded in Ecological Systems Theory show that peer acceptance, inclusion, and classroom social integration predict academic engagement, motivation, and well-being above and beyond distal contextual influences (Juvonen et al., 2011; Wentzel et al., 2014). Conversely, adverse peer experiences—such as exclusion or marginalisation—represent proximal ecological stressors that directly disrupt students' adaptive functioning by altering the immediate social climate in which learning occurs (Eccles & Roeser, 2011). From an ecological perspective, peer relationships thus operate as a key microsystem mechanism through which broader contextual influences are translated into individual developmental outcomes.

Within Attachment Theory, research indicates that during the transition from childhood to adolescence, the primary focus of social relationships shifts from caregivers to peers, who increasingly serve attachment-like functions (Lila et al., 2020). In this role, peers provide both

affective support and behavioural models for navigating the social world (Telzer et al., 2015). Attachment-theoretical research further supports the view that peers increasingly assume attachment-relevant functions during late childhood and adolescence, acting not only as sources of companionship but also as secure bases and safe havens in emotionally salient contexts. As internal working models become generalised beyond primary caregivers, adolescents draw on peer relationships to regulate distress, seek reassurance, and explore social and academic challenges with greater autonomy (Allen & Tan, 2016). Empirical studies grounded in Attachment Theory indicate that secure peer attachments are associated with better emotion regulation, lower stress reactivity, and greater engagement in school-related tasks, whereas insecure or disrupted peer bonds are linked to heightened vulnerability to social stressors and poorer adjustment (La Guardia et al., 2000; Zimmermann, 2004). In this sense, adverse peer experiences can be conceptualised as a disruption of attachment-relevant functions at a developmental stage in which peers have become central figures for emotional security and exploration.

Within the Self-Determination Theory framework, peers are shown to satisfy adolescents' needs for relatedness, intimacy, emotional security, and belonging (Rubin et al., 2011). Therefore, peer relationships are conceptualised as primary social contexts through which adolescents' basic psychological needs—particularly relatedness, but also autonomy and competence—are either satisfied or frustrated. Need-supportive peer interactions, characterised by inclusion, mutual respect, and emotional availability, have been shown to foster intrinsic motivation, engagement, and psychological well-being in school settings (Ryan & Deci, 2017; Vasquez et al., 2016). Conversely, adverse peer experiences represent a salient form of need thwarting, directly undermining relatedness and indirectly constraining autonomy and competence by limiting opportunities for meaningful participation and social agency (Bartholomew et al., 2011; Vansteenkiste et al., 2020). Research explicitly grounded in Self-Determination Theory has demonstrated that students who experience chronic peer-related need frustration exhibit lower motivation, reduced cognitive engagement, and

poorer academic adjustment, underscoring the central role of peer dynamics in motivational and learning processes (Bartholomew et al., 2011; Jang et al., 2016; Vansteenkiste et al., 2020).

A substantial body of school-based research has demonstrated that the quality of peer relationships can predict a wide range of developmental outcomes, similar to those linked to parent-child and teacher-student relationships. First, positive peer relationships are associated with prosocial behaviours such as cooperation, sharing, and helping, whereas poor-quality relationships correlate with reduced prosocial engagement (Rubin et al., 2011). Second, positive peer relations (e.g., acceptance, inclusion, friendship; cf. infra) have been linked to better classroom engagement and higher academic achievement (Yu et al., 2023). Third, children and adolescents who experience negative peer relationships (e.g., rejection, exclusion, victimisation; cf. infra) often display lower levels of social competence and higher rates of behavioural problems, including aggression, inattention, and social immaturity (Rytioja et al., 2019). Negative peer relationships also contribute to internal distress, including anger, sadness, and anxiety, and are predictive of internalising difficulties such as depression, social withdrawal, and loneliness, which can manifest in symptoms like shyness, unsociability, and social avoidance (Ladd et al., 2017). Fourth, negative peer relationships have been associated with school disengagement—characterised by boredom, detachment from class activities, and increased risk of school dropout—while positive peer relationships have been linked to higher school engagement and academic motivation (Yang et al., 2018). Fifth, negative peer experiences have been experimentally associated with poorer cognitive performance on tasks such as logical reasoning, especially for vulnerable subgroups of children (Tobia et al., 2017). Finally, in general, negative peer relationships are associated with lower academic achievement (Caemmerer & Keith, 2015).

From a neurodevelopmental standpoint, peer experiences exert a formative influence on the developing brain, shaping both structural plasticity and functional specialisation. Contemporary neuroscience highlights that peer interactions—whether supportive or exclusionary—are among the

most powerful environmental inputs driving adolescent brain development (Guyer et al., 2018). During this period of heightened neural plasticity, peer acceptance and belonging experiences promote the maturation and integration of fronto-limbic and prefrontal networks that underpin emotional regulation, flexible reasoning, and social cognition. Conversely, repeated exposure to peer exclusion and social marginalisation has been associated with altered activation and structural changes in brain regions implicated in affective processing and cognitive control, including the anterior cingulate cortex and ventromedial prefrontal cortex (de Water et al., 2017; Raufelder et al., 2021). Such relational deprivation can thus limit opportunities for adaptive neural reorganisation, fostering a relative "cognitive rigidity" that constrains the ability to flexibly engage in complex reasoning and problem-solving. Over time, these neural adaptations may translate into fewer socio-cognitive strategies and a diminished capacity to navigate novel or demanding learning contexts, potentially hindering the progression toward the advanced logical–formal reasoning described by Piaget (1972). Accordingly, peer interactions should be regarded not only as psychosocial experiences but also as neurobiological mechanisms that shape the architecture of cognitive development and learning outcomes.

Despite the evidence about peers' effects on cognitive development and learning outcomes, relatively few studies have investigated peers' effects on cognition, specifically on EFs (e.g., Vandenbroucke et al., 2018a). Because EFs are strong predictors of later learning outcomes, this knowledge gap matters: understanding how peer contexts affect EFs is essential to explain how peer relations translate into longer-term cognitive and academic development. This project addresses this gap by focusing on peer exclusion in the school context, highlighting its influence on students' EFs and academic achievement.

Conceptualisation of negative peer relationships: the phenomenon of Peer Exclusion

In the field of education, efforts have been made to distinguish and compare negative peer relationships by focusing on specific peer interactions or dynamics. Most conceptual frameworks

have differentiated between peer rejection, peer victimisation, and peer exclusion. Peer rejection refers to a low social status defined by disapproval or dislike from peers or the broader peer group (Coie & Dodge, 1983). Peer victimisation describes the broader phenomenon of aggression directed at a peer by others in the school context (Hawker & Boulton, 2000). In contrast, peer exclusion refers to experiences in which an individual feels ignored, left out, or excluded from activities, games, or conversations by peers (Riva & Eck, 2016). Research has shown that children and adolescents are particularly susceptible to peer exclusion, which may manifest as emotional exclusion (e.g., lack of acknowledgement) or physical exclusion (e.g., isolation from the group; Williams, 2007). Peer exclusion can be direct (e.g., being told one cannot join a group), indirect (e.g., being ignored by the group), implicit (occurring without verbalisation), or explicit (accompanied by a clear statement of rejection; Williams et al., 2005; Williams & Zadro, 2005).

The predominant body of literature on peer exclusion within educational contexts is grounded in the conceptualisation of social exclusion as ostracism (Williams, 2001). In this framework—commonly referred to as Williams' Temporal Need-Threat Model (2009)—peer exclusion is understood as an experience that immediately threatens mood and four basic psychological needs: the need for belonging (feeling accepted and part of a group), the need for control (feeling able to influence one's social situation), the need for self-esteem (feeling valued and respected), and the need for meaningful existence (feeling acknowledged and significant to others). This model is particularly relevant for the present work, as it provides the main theoretical and methodological foundation guiding our operationalisation and experimental manipulation of peer exclusion throughout the dissertation. This model has also been applied and adapted to educational settings (e.g., Williams & Nida, 2022; Wang et al., 2024).

Building on this model, research has documented both the immediate and chronic effects of peer exclusion on students' socio-emotional and cognitive outcomes. The immediate effects refer to short-term consequences that emerge directly following an exclusion episode (e.g., within minutes or

hours), whereas chronic effects of peer exclusion refer to the cumulative impact of repeated or sustained exclusion across weeks, months, or years. In literature investigating the immediate effects, experimental studies demonstrated that peer exclusion provokes negative emotional states such as sadness, tension, and anger, alongside acute frustration (Hartgerink et al., 2015), and simultaneously undermines basic psychological needs for belonging, control, self-esteem, and meaningful existence (Lei et al., 2024). In school-based experiments, peer exclusion has been shown to disrupt learning-relevant processes almost instantly, including poorer performance on logic and reasoning tasks (Vandenbroucke et al., 2018a; Tobia et al., 2017; Hawes et al., 2012). These findings emphasise that even brief exclusion episodes can impair students' emotional balance and cognitive engagement in classroom contexts. The literature on the chronic effects of peer exclusion extends these findings over longer time frames. Chronic exposure to peer exclusion has been linked to internalising problems (e.g., anxiety, depression, withdrawal, loneliness, suicidal ideation) and school disengagement (Williams & Nida, 2011). Because peer exclusion rarely comes with feedback or explanation, children experience ambiguity and unpredictability in their social environment, impairing their ability to self-regulate (Büttner et al., 2024). Excluded children and adolescents often report impaired relatedness, diminished competence in forming social bonds, and reduced autonomy in social participation (Abrams et al., 2011). Compared with their included peers, they are more likely to show learning difficulties, absenteeism, behavioural problems, and lower academic success, including an increased risk of school dropout (Asscheman et al., 2019). Over time, chronic peer exclusion fosters hypervigilance to social cues and heightened sensitivity to peer exclusion, creating a self-perpetuating cycle of emotional distress and cognitive disruption (Buelow et al., 2015; Tobia et al., 2017). Adolescents are especially vulnerable to these long-term effects due to heightened peer sensitivity and neurodevelopmental changes in the brain, including regions involved in social evaluation and emotion regulation (Blakemore & Mills, 2014; Sebastian et al., 2010; Will et al., 2016).

From a neuroscientific perspective, peer exclusion engages brain systems implicated in both social pain and cognitive regulation. Neuroimaging research indicates that social exclusion activates the anterior cingulate cortex (ACC) and insula, which are involved in processing social distress, as well as the dorsolateral and ventrolateral prefrontal cortex (dlPFC, vlPFC), which underlie cognitive control and emotion regulation (Eisenberger et al., 2003; Sebastian et al., 2010; Bolling et al., 2011; Tang et al., 2018). More recent work provides converging neurological evidence for what is observed behaviourally, showing that peer exclusion diverts prefrontal resources toward emotion regulation at the expense of concurrent cognitive functioning (e.g., Masten & Eisenberger, 2021). These findings thus highlight that the brain diverts cognitive resources to cope with the emotional demands of peer exclusion, thereby limiting the availability of these cognitive resources for concurrent cognitive tasks.

Several moderators can buffer or intensify the aforementioned effects. Friendship and social support are consistently highlighted as protective factors (Arslan, 2018). Supportive relationships with peers, parents, and teachers can mitigate the negative consequences of peer exclusion by promoting resilience and encouraging re-engagement (van der Meulen et al., 2018). Parental warmth and teacher support, for example, foster better emotion regulation and school engagement following peer exclusion (Roorda et al., 2011), while high-quality friendships provide adolescents with a sense of belonging that reduces the pain of peer exclusion (Masten et al., 2010). Peer support further moderates the negative effect of peer exclusion on self-esteem and school well-being, and teacher support predicts resilience after peer exclusion episodes (Nezlek et al., 2015; Butler et al., 2022).

Research has also identified gender-specific patterns in peer exclusion behaviours and their consequences. Boys are more likely to engage in overt, physical, and direct forms of exclusion, whereas girls tend to rely on covert, emotional, and indirect strategies (Underwood et al., 2004). Girls also appear more emotionally affected by peer exclusion, perceiving it as more unethical and distressing than boys (Sandstrom et al., 2017). These gender differences suggest that the experience

and impact of peer exclusion may vary across subgroups, further underlining the complexity of the phenomenon.

Despite growing recognition of peer exclusion as a salient negative experience in school settings, the phenomenon remains under-researched compared to peer rejection and victimisation. Whereas peer rejection typically reflects social status and peer victimisation focuses on overt aggressive behaviours, peer exclusion provides unique insight into the subjective and immediate effects of being ignored or left out. Investigating specific episodes of peer exclusion during single peer interactions can reveal how these experiences directly affect students' day-to-day functioning in school, particularly regarding cognitive performance and academic achievement. Nevertheless, research on peer exclusion remains limited in terms of its operationalisation, experimental manipulation, and its impact on key educational outcomes.

Taken together, the evidence mentioned above shows that peer exclusion not only undermines mood and psychological needs but may also compromise cognitive functioning, particularly EFs, which play a major predictive role not only for academic achievement but also for socio-emotional learning. Most research to date has emphasised socioemotional outcomes, while neglecting how peer exclusion disrupts EFs, which traditionally consist of working memory, inhibitory control, and cognitive flexibility; these core processes are crucial for both learning and goal-directed behaviour (Diamond, 2013). Given the clear involvement of prefrontal control systems during peer exclusion, this gap is striking. The lack of systematic investigation has also contributed to an underestimation of its cognitive implications, paving the way for the subsequent sections of this dissertation, which will first specifically examine the overlooked role of peer exclusion on EFs and then address the methodological gap.

In sum, peer exclusion exerts immediate, chronic, and neurocognitive effects that undermine both socioemotional well-being and cognitive functioning. Therefore, the next section will focus specifically on EFs as a core mechanism linking peer exclusion to academic achievement.

Executive Functions

EFs are a multifaceted set of cognitive processes that enable individuals to formulate goals, guide behaviour toward those goals, monitor performance, and adjust actions as needed (Zelazo & Carlson, 2012). The core components of EFs typically include inhibition, cognitive flexibility (or shifting), and working memory (or updating). Inhibition refers to the ability to suppress automatic responses and filter out irrelevant stimuli or thoughts, while cognitive flexibility enables individuals to shift between mental sets, tasks, or strategies in response to changing goals or environmental demands, such as adapting to new classroom rules or changing problem-solving strategies (Miyake et al., 2000). Working memory (WM) is the capacity to temporarily hold, manipulate, and use information to guide goal-directed behaviour—for example, remembering instructions while completing a task (Diamond, 2013).

The development of EFs follows a non-linear trajectory from early childhood through late adolescence, marked by alternating periods of rapid growth and more gradual refinement (Tervo-Clemmens et al., 2023). Inhibition tends to show the earliest developmental gains during the preschool years (ages 3–6), while WM and cognitive flexibility improve more gradually during this period (Zelazo & Carlson, 2012). Throughout middle childhood and early adolescence, both WM and cognitive flexibility undergo significant increases in efficiency, followed by further refinement during adolescence, when higher-order cognitive processes like planning, decision-making, and problem-solving become more sophisticated (Prencipe et al., 2011). These behavioural changes are closely linked to structural and functional maturation in key brain areas, especially the prefrontal cortex (PFC) and other cortical and subcortical regions. Recent reviews and empirical work indicate that neurodevelopmental processes such as synaptic pruning, myelination, and the progressive reorganisation and specialisation of prefrontal circuits continue into adolescence, supporting increasingly efficient EF-related networks (Pöpplau et al., 2024; Hagler Jr et al., 2022). As the brain matures, behaviour also changes—improvements in structural and functional connectivity between

brain regions (e.g., prefrontal and subcortical areas) support more coordinated and efficient EF performance across age (Luna et al., 2015). Connectivity here refers to both the anatomical pathways (e.g., white matter tracts) and the functional synchrony between brain regions that enable the coordinated control of cognition (van den Heuvel & Hulshoff Pol, 2010).

Importantly, individual differences in EFs' development are not only shaped by age but also by environmental experiences, particularly within proximal contexts such as the family and the classroom. Research consistently shows that the quality of the home learning environment and parenting practices—meaning higher-quality, supportive, and responsive parent–child interactions—predict better EF development (Valcan et al., 2018; Cook et al., 2024; Segundo-Marcos et al., 2022). Similarly, positive teacher–student relationships and supportive classroom climates have been linked to specific improvements in children's EF performance (for reviews, cfr Sankalaite et al., 2021; Vandenbroucke et al., 2018; Xu et al., 2024). Distal environmental factors such as socioeconomic status (SES) also exert significant influence, with lower SES associated with poorer EF outcomes and changes in family income corresponding to changes in WM (Hackman et al., 2015).

Taken together, this body of research highlights that EFs are not fixed traits, but dynamic abilities shaped by neurodevelopmental maturation and contextual influences. They also contribute significantly to children's and adolescents' social functioning and emotional regulation. Cognitive flexibility has been closely linked to social cognition and empathy, while inhibitory control has been associated with behavioural regulation and the prevention of impulsivity and externalising behaviours, particularly in relation to conditions like ADHD (Claire, 2020; Nigg, 2017). In addition, WM plays a central role in emotion regulation, as recent evidence shows that stronger WM abilities predict lower emotion dysregulation in children, even after controlling for other EF components and ADHD symptoms (Groves et al., 2022).

In what follows, the focus will be primarily on WM, as it represents the core executive component most directly involved in maintaining and updating information necessary for goal-

directed behaviour, and thus provides the most informative lens through which to examine cognitive processes in this dissertation. In Miyake et al.'s (2000) influential model of EFs, "WM updating" (WMU) is a specific subcomponent of working memory that refers to the ability to monitor incoming information, discard no-longer-relevant content, and replace it with new, task-relevant data. This executive subfunction plays a critical role in adapting to new information and demands in real time—such as updating problem-solving steps based on feedback or changes in task instructions. Baddeley's model of WM complements this view by proposing a supervisory system—the central executive—that is responsible for this updating process, in coordination with storage systems like the phonological loop, visuospatial sketchpad, and episodic buffer (Baddeley, 2000).

The main focus on WM is justified for several reasons. First, WM stands out as the strongest and most stable predictor of academic achievement, supporting both basic and complex cognitive tasks. Among all EF components, WM has consistently emerged as the most robust predictor of performance in domains such as reading comprehension, mathematical reasoning, and spelling (Oberer et al., 2018; Vandenbroucke et al., 2017). Longitudinal studies demonstrate that WM abilities at the beginning of preschool or primary school reliably predict later academic success (Welsh et al., 2010; Judd et al., 2021; Segundo-Marcos et al., 2022), underscoring its foundational role as a mechanism underpinning learning and educational outcomes. Second, although WM is considered the most stable EF construct to measure (Garon et al., 2008), this stability reflects its reliability as an index of cognitive control rather than its invariance over time. In fact, WM is also highly sensitive to environmental and contextual influences, showing meaningful within-person fluctuations that mirror everyday social experiences. Ambulatory assessment studies reveal that WM varies considerably across days and situations, and that greater within-person variability is associated with lower academic achievement and fluid intelligence (Dirk & Schmiedek, 2016; Galeano-Keiner et al., 2022). Thus, WM combines relative stability at the trait level with flexibility at the state level, making it particularly suitable for studying the interplay between individual differences and situational effects.

Third, WM appears to be the EF component most susceptible to environmental influences. Recent longitudinal and cross-sectional studies show that parenting practices such as autonomy support, scaffolding, and sensitivity have strong associations with WM growth, above and beyond their effects on inhibitory control or cognitive flexibility (Valcan et al., 2018; Cook et al., 2024). Similarly, classroom practices and teacher–student interactions, particularly instructional and organisational support, have been linked to selective improvements in WM (Xu et al., 2024). Compared to these domains, peer influences on WM remain less extensively studied, but emerging evidence indicates that experiences of peer acceptance or exclusion can directly shape WM performance both in the short term and across developmental trajectories (Vandenbroucke et al., 2018a; Fuhrmann et al., 2019). Taken together, this body of work positions WM as a central and highly sensitive construct that is at once stable enough to predict long-term academic success and dynamic enough to capture meaningful within-person changes in response to everyday social experiences.

EFs and WM have proven to be vulnerable to the effects of peer exclusion, providing a clear bridge between social experience and cognitive functioning (Williams et al., 2000). For example, experimental studies have shown reduced WM performance in children and adolescents following peer exclusion episodes (Hawes et al., 2012; Vandenbroucke et al., 2018a; Fuhrmann et al., 2019). Neuroimaging studies further suggest that peer exclusion activates brain regions responsible for emotional regulation and executive control—such as the dlPFC and ACC—even when EF performance is not directly measured, underscoring the latent cognitive impact of such experiences (Will et al., 2016). In addition to these experimental findings, a few longitudinal (within-subject) studies have explored how peer relationships shape the developmental trajectories of EFs. Using sociometric and self-report measures, two studies focusing on childhood found that prior peer acceptance positively predicted later WM performance, whereas prior peer rejection predicted lower subsequent WM performance (de Wilde et al., 2016; Lecce et al., 2020). Another longitudinal study, conceptualising negative peer relationships in terms of peer problems, linked these problems to

subsequent declines in WM during childhood; however, this association was only observed in childhood and no longer in adolescence (Holmes et al., 2016). Together, these findings highlight that peer exclusion and broader peer relationship dynamics can influence EFs and WM both immediately, in experimental paradigms, and chronically, over time.

Few studies to date have simultaneously examined children across the transition from childhood to adolescence while also employing ecologically valid peer exclusion manipulations or assessing within-person daily or momentary variation in WM performance. Within-person daily effects can capture the accumulation of peer exclusion experiences or peer relationship quality across days in naturalistic school settings (cf. Dirk & Schmiedek, 2016; Galeano-Keiner et al., 2022). While Dirk and Schmiedek (2016) document within-person WM fluctuations in school sessions, these studies did not capture the transitional phase from childhood to adolescence, nor did they combine this developmental focus with peer exclusion manipulations that realistically mirror everyday school dynamics. As a result, the current evidence base has yet to integrate ecological validity, developmental transition, and intraindividual change into one coherent framework. This is the central gap addressed in this dissertation. In this respect, it is important to differentiate between immediate and daily effects of peer exclusion on WM and subsequent academic achievement.

The next section introduces the methodological approach to peer exclusion used in this dissertation. It outlines limitations of traditional paradigms, proposes immersive virtual reality (VR) to improve ecological validity, and describes how intensive longitudinal designs can capture both immediate responses and daily variability in WM in relation to peer exclusion at school.

Manipulation of Peer Exclusion

Previous literature has pointed out that peer exclusion can be manipulated through the Cyberball paradigm (Williams et al., 2000). Cyberball is an experimental paradigm consisting of an online ball-tossing game: here, children and adolescents believe they are playing with other real peers

who are, in fact, only standardised computer players. Usually, the classic version of this online game involves three players passing a ball among each other, one of which being the participant in the experiment. Before the start, researchers give some information about the other two players in the game by providing meaningful, but made-up, brief biographies in order to make them more realistic within the participants' perceptions. In the exclusion condition, children and adolescents never or rarely receive the ball, as compared to the neutral or inclusion condition, in which they often receive it. The number of tosses the participant gets out of the overall amount of tosses reflects the degree of inclusion or exclusion.

The Cyberball paradigm seems to be a better manipulation of peer exclusion experiences than sociometric measures (e.g., peer network, peer nomination; Coie et al., 1982). Sociometric measures operationalise peer relationships in terms of a social status, assessing peer rejection by means of other people's point of view, thereby ignoring the rejected children and adolescents' point of view and their perception of being rejected by peers. As such, reasons for which some children are liked more than others remain unclear, while at the same time, there is no information about the correspondence between belonging to a rejected status and feeling effectively rejected (Riva & Eck, 2016). Moreover, sociometric measures are only based on pre-existing relationships among classmates. Compared to the sociometric measures, Cyberball allows individual effects of peer exclusion experiences to be examined without the need to consider pre-existing relationships.

Cyberball is effective in dissatisfying the psychological needs for belonging, control, certainty, meaningful existence, and self-esteem, (Williams, 2001). It has been used successfully both within adult samples (Williams & Sommer, 1997) and children and adolescents in school contexts (Abrams et al., 2011). Cyberball reflects an operationalisation of Williams' ostracism and Need-Threat Model. According to William's model participants feel either frustrated after the experience of not getting the ball from other players because they are not being part of the group (need for belonging), or get a sense of hopeless and helpless because of the impossibility in changing the

treatment received by other players (need for control), or experience a lack of social competence within the group interaction during the game time (need for certainty). Moreover, participants, as victims, feel invisible to others and socially devalued (need for meaningful existence), consequently thinking that something about them is wrong (need for self-esteem).

Although Cyberball seems to be an effective paradigm to manipulate peer exclusion and assess the immediate impact of peer exclusion on children and adolescents' mood and psychological needs (Abrams et al., 2011), it presents some limitations.

First, although the Cyberball paradigm has revealed to be powerful in assessing peer exclusion, as a 2D paradigm, it presents limited ecological validity (i.e., the ability to reproduce the same effects in real-world life), whereas a 3D paradigm can work better in order to replicate reality, achieving a higher ecological validity (Parsons, 2015). In this regard, among the ecological validity issues pertaining to the Cyberball paradigm, it lacks real interaction among players, as participants and avatars are not actually interacting with each other but are only passing a ball. Therefore, participants cannot interact with each other or react to the exclusion experience, as it would happen in common real-life exclusion situations (Tuijnman et al., 2021).

Second, related to the ecological validity of the Cyberball paradigm, the graphic quality and the overall basic and light design represent additional limitations. Children and adolescents may experience boredom when interacting with such an online environment. Indeed, most children and adolescents are accustomed to playing better-quality video games, which may offer a more realistic representation of real life (e.g., 3D and Immersive VR games and environments; Tuijnman et al., 2021). Although an attempt to transfer the Cyberball paradigm into a 3D dimension by Immersive VR has been made (Kassner et al., 2012), findings have shown no significant differences between the 2D and the 3D version of the paradigm, probably due to the poorness of the interactive activity (as players are only passing a ball), which remains the same in both dimensions and can be perceived by participants as different from everyday-life exclusion situations (Tuijnman et al., 2021).

Third, currently, there is insufficient consistent literature examining Cyberball's ability to operationalise peer exclusion in terms of immediate effects (on mood and psychological needs) in children and adolescents by comparing it to alternative experimental paradigms. To the best of our knowledge, only one attempt has been made to compare the use of Cyberball in adolescents with another experimental paradigm. This was achieved by building an online chatroom interactive environment in which each participant was excluded by two other fake peers (Latina et al., 2023). This alternative paradigm has demonstrated superior efficacy in mitigating negative moods in comparison to Cyberball. Moreover, it effectively addressed and rectified the aforementioned interaction issues by employing a conversational context. Nevertheless, it has been constructed ad hoc to be used exclusively with a clinical sample of adolescents afflicted with multiple mood disorders (Latina et al., 2023). Consequently, its implementation within a school setting is challenging. Furthermore, when alternative paradigms rely on human-administered interactions (such as trained research assistants simulating peer exclusion in a chatroom), they may introduce subjective variability and threaten internal validity (Chester et al., 2021). Because the responses or exclusion behaviours by human operators can vary over time—due to fatigue, shifting interpretations, or inconsistent application of protocol—this introduces additional, uncontrolled variance (Agee et al., 2025). This variability may compromise standardisation (i.e., ensuring each participant receives exactly the same exclusion experience) and repeatability across participants. Indeed, human-mediated dialogues may differ subtly in tone, timing, or response style, and these unpredictable differences may confound results (e.g., the affective impact may be confounded with variations in the operator's behaviour; see Matthay et al., 2020). Therefore, because the chatroom exchange was mediated by trained assistants rather than fully automated scripts, the issues of subjective variation and inconsistent interaction remain relevant.

In conclusion, the aforementioned limitations indicate the need for a new paradigm reflecting the same methodological and powerful features of the Cyberball paradigm, but with higher ecological

validity in terms of graphic design, interactions among players and an overall better real-life transfer. A 3D paradigm like VR is a powerful candidate to meet these requirements (Mavromihelaki et al., 2014).

3D VR Paradigms

As mentioned before, ecological validity refers to all research aspects that allow generalising research outcomes from an experimental study to the real world (Parsons, 2015). With respect to insights on peer exclusion, higher ecological validity may amplify or refine the current findings (predominantly found through the Cyberball paradigm). Providing real-life environments and situations allows researchers to better understand the mechanisms through which peer exclusion exerts its effect on children and adolescents by simulating real-life exclusion experiences. Using a virtual environment, participants can perceive the situation as more realistic and, consequently, their feelings and emotions can be closer to those they would have felt in a real, everyday exclusion situation. This assumption has proved to be valid for 3D virtual reality paradigms on social and learning skills used in school contexts (Villena-Taranilla et al., 2022). Research on the effect of higher ecological validity on the manipulation of peer exclusion remains uncharted territory.

VR is a 3D immersive advanced technology that has become increasingly applied in research and education over the years. The increasing use of VR, especially in the educational context, is mainly due to its higher ecological validity (Parsons, 2015). Compared to other technologies used in educational contexts (e.g., video games, online paradigms, and other 2D resources), VR allows researchers to build experimental paradigms and lab situations closer to what people would experience in everyday life, allowing participants to experience a more realistic situation as well. Moreover, within recent years, VR has become more accessible, low-cost, and easy to combine with other electronic devices (like all kinds of smartphones and laptops; Brown et al., 2020).

Research on educational psychology has demonstrated that providing learning content by VR leads students to elicit and amplify positive emotions because of the higher level of active participation and engagement, developing a general positive attitude towards the learning content (Chirico et al., 2018). The positive implications of VR can be attributed primarily to the profound level of presence and immersion offered by its experience. In the context of VR, "presence" refers to the subjective sensation of being fully involved and present within a particular situation or environment, while "immersion" pertains to the perceived realism and authenticity of the virtual experience. By harnessing these two inherent characteristics, students are able to cultivate a heightened sense of self-engagement that surpasses what can typically be achieved through traditional school activities (Di Natale et al., 2020). Therefore, the immersive nature of VR, combined with presence and immersion, facilitates deep engagement in tasks and activities, focusing attention and intensifying emotional responses within the virtual environment (Villena-Taranilla et al., 2022; Riva et al., 2004).

Despite the aforementioned advantages, previous investigations have also revealed certain constraints and issues associated with VR use in educational settings (Southgate et al., 2019). An ethical constraint arises from the potential physical and psychological discomfort experienced by individuals, particularly children, after engaging with VR, such as feelings of nausea and headaches. In particular, disorientation (including dizziness, vertigo and difficulty focusing), oculomotor (like eyestrain, headache and blurred vision), and nausea (including stomach awareness and increased salivation) are the most reported symptoms (Arshad et al., 2021). In most instances, they can be attributed to subpar VR content quality or improper usage of these technologies. More specifically, the three major causes of cybersickness reported have been attributed to hardware factors (device-related features such as display types and modes), content factors (associated with the VR scene, such as optical flow, graphic realism, and task-related features), and demographic features (Chang et al., 2020). Among the latter features, children who are susceptible to motion sickness (Rebenitsch &

Owen, 2014) and girls compared to boys (Kim et al., 2020) are more likely to experience cybersickness. The aforementioned problems may be easily fixed by high-quality VR contents (reducing stimulation realism) and a proper usage of VR technologies (including image manipulation techniques such as depth of field, modified scene transitions, and central vision blockers; Ang & Quarles, 2023).

VR can play an important role in the school context to train and develop specific skills, especially social skills. Existing literature highlights several social skills that can be augmented through the utilisation of VR training programs, encompassing peer interactions, collaborative learning, synchronous participation, shared educational activities, as well as interpersonal communication and discourse among peers (Zhou & Kalota, 2020). Moreover, according to the Social Presence Theory (Triberti et al., 2018), VR environments aimed to improve social skills through interactions among peers, allow students to feel the sense of being in the company of others, enhancing feelings of belongingness, relatedness and companionship because of the real-life social interactions performed by VR as a facilitator. Therefore, VR contains all the requirements to become a very useful tool and resource within the educational context for building specific content related to peer relationships. Nonetheless, it is noteworthy that all these skills have hitherto been honed exclusively within VR environments wherein students engage with their authentic peers.

Bridging the aforementioned theoretical advantages to empirical peer exclusion paradigms is still a challenge. So far, VR programs that aim to simulate social dynamics have always relied on the involvement of actual individuals. Additionally, previous attempts to adapt Cyberball into a 3D VR environment have not demonstrated increased effectiveness over the traditional 2D version. This could have happened because the activity itself (passing a ball) does not sufficiently generate a realistic perception of social interaction, reducing participants' sense of being in the company of others (Kassner et al., 2012). However, VR paradigms have been developed for simulating social exclusion, albeit with adults or in work contexts where adult participants are being excluded by their

colleagues (computerised avatars) during a group conversation (e.g., Prendergast & Schubert, 2020). Study findings show that such 3D group conversation can be a powerful scenario for simulating peer exclusion situations, able to raise a better perception of social interaction as well. Therefore, a VR paradigm based on the same assumption but able to assess peer exclusion within the school context is still missing.

Taken together, the aforementioned findings underscore both the potential and the current limitations of VR for studying peer exclusion and highlight the need for a school-based paradigm that combines realism with methodological rigour. In order to address this gap, the next section turns to the use of intensive longitudinal designs. These methods provide a way to move beyond the assessment of immediate reactions, allowing researchers to capture daily fluctuations and intraindividual changes in mood, psychological needs, and cognitive functioning, and thereby link immersive VR manipulations to real-world developmental outcomes.

Intensive Longitudinal Designs

As highlighted in the previous section, WM has often been conceptualised as a stable, between-person construct, assessed at a single time point and linked to academic and socioemotional outcomes. However, such approaches overlook the moment-to-moment fluctuations in WM performance, particularly in response to social experiences such as peer exclusion. Intensive longitudinal designs (ILDs) are ideally suited to address this gap, as they represent a class of research methodologies in which participants are assessed repeatedly across short time intervals, often multiple times per day or across consecutive days and weeks (Bolger & Laurenceau, 2013). These designs capture the temporal dynamics of human behaviour, allowing researchers to model within-person variability and uncover patterns that are masked in traditional between-person approaches. In educational psychology, ILDs have become increasingly valuable for understanding how students' cognitive, emotional, and social experiences fluctuate in real time, providing insights into processes

that are highly context-dependent and sensitive to daily environmental influences (Hamaker et al., 2015; McNeish & Hamaker, 2020).

For research on peer exclusion and its potential impact on WM, ILDs would offer a unique advantage. While classic cross-sectional, experimental, or even traditional longitudinal studies focus primarily on stable, between-person differences in WM or social status, ILDs would be expected to reveal the moment-to-moment impact of social experiences on WM. Such designs would be especially useful for capturing how acute episodes of peer exclusion could transiently disrupt WM, and how these disruptions might accumulate to influence academic performance over time (cf. Bolger & Laurenceau, 2013; Schmidt et al., 2019). For example, a student might show temporarily reduced WM performance immediately after being excluded by peers, while another child with similar between-person WM ability might not exhibit the same decline. Traditional between-person analyses, which rely on averages across participants, obscure these intraindividual effects. In contrast, ILDs would capture the within-level variation (e.g., mean, standard deviation, temporal patterns) that links situational experiences—as well as the lingering influence of previous exclusion episodes—to WM performance in real time. This approach aligns with the theoretical shift in developmental and educational psychology toward recognising the dynamic interplay between situational experiences and long-term developmental trajectories. This dynamic interplay can be conceptualised within the framework of Dynamic Systems Theory, which posits that stable abilities emerge from repeated interactions between the individual and the environment over time (Thelen & Smith, 1994; van Geert, 1994). Applying this framework to WM highlights how repeated peer exclusion episodes may shape longer-term WM trajectories.

As far as scientific evidence has demonstrated the importance of developmental contexts in ensuring the maturation of stable aspects of EFs, situational manifestations of WM in relation to their contexts have been underexplored (Best & Miller, 2010; Luna et al., 2015; Michel et al., 2025). Starting from the assumption that stable WM skills emerge from repeated situational expressions over

time, the operationalisation of these situational manifestations—and their fluctuations within developmental contexts—requires methodologies sensitive to the within-person level (Bolger & Laurenceau, 2013; Hamaker et al., 2015; Xu et al., 2018). This within-person level has been largely overlooked in prior research on peer exclusion, despite its centrality for understanding the immediate cognitive and emotional consequences of this social experience (Hartgerink et al., 2015; Hawes et al., 2012; Fuhrmann et al., 2019). In the absence of intraindividual data, it is impossible to trace how children and adolescents respond to exclusion in real time, or to identify how repeated and specific episodes of peer exclusion during single peer interactions shape long-term cognitive and socioemotional trajectories (Dirk & Schmiedek, 2016; Blume et al., 2022; Ma & Pang, 2023). Evidence about the intraindividual effects of peer exclusion on WM and, consequently, academic achievement across the school years is therefore still missing.

Recent studies on peer relationships have begun to adopt within-person approaches to investigate these dynamic processes. For example, intraindividual variation has been examined in the context of peer relationships and mood (Schmidt et al., 2019), self-esteem (Schmidt et al., 2021), need satisfaction, frustration, and overall school well-being (Schmidt et al., 2020). Similarly, intensive longitudinal research has started to explore how daily school contexts influence EFs and learning outcomes (e.g., Blume et al., 2022). These studies collectively underscore the importance of capturing intraindividual fluctuations to understand how peer-related experiences shape both immediate and cumulative outcomes. However, these studies remain limited in their capacity to provide a comprehensive picture of the real-time effects of peer exclusion on EFs—particularly the nuanced ways in which these effects unfold across short and long timescales. Thus, the present work aims to fill this gap by combining a 3D VR manipulation of peer exclusion with an ILD approach, tracking both immediate and daily WM fluctuations in children and adolescents. This design allows us to examine how immediate peer exclusion events affect WM in real time and how repeated

experiences shape learning-relevant cognitive outcomes over time, providing a direct link to the research questions presented in the following section.

Research Questions

This chapter has thus far emphasised three key points. First, ample evidence indicates that peer exclusion is a significant negative dynamic within peer relationships. Second, the role of peer exclusion in the context of EFs and WM within schools remains underestimated, as evidenced by previous research. Third, the necessity for a more profound and ecological investigation into the immediate and daily effects of peer exclusion on children and adolescents within school environments becomes evident. This investigation is crucial to enhance our understanding of the role of peer exclusion in affecting students' mood and WM. Capturing both immediate and daily effects of peer exclusion requires methodological designs that can disentangle within-person variability from between-person differences, allowing researchers to trace the specific episodes of peer exclusion during single peer interactions that ultimately contribute to emotional and cognitive outcomes.

The overarching goal of this dissertation is to advance our understanding of how peer exclusion can be experimentally assessed and how it affects cognitive and academic achievement in children and adolescents. Because peer-related processes have been neglected at this level, the present work aims to integrate both within- and between-person perspectives to advance our understanding of how peer exclusion impacts EFs and academic achievement. To achieve this goal, the dissertation is structured in a theoretical chapter and four empirical chapters, each addressing a specific research question. Together, these chapters employ a multimethod approach, integrating literature review and qualitative, quantitative, and experimental designs to capture both the immediate and developmentally nuanced consequences of peer exclusion in school contexts. Across three empirical studies, the thesis aims to demonstrate that peer exclusion—whether simulated in a controlled experimental setting or experienced in real-life school interactions—exerts immediate and daily effects on mood, psychological needs, WM, and perceived academic success.

Research Question 1: *How can peer exclusion be best assessed in an experimental design?*

To address the first research question, the thesis begins with a literature review on *Immersive Virtual Reality as an Educational Resource* (**Chapter 2**). This chapter provides the necessary theoretical and applied foundation for considering VR as a methodological innovation in the study of peer exclusion. Building on current literature in educational and school psychology, it reviews the technical features of immersive VR, its pedagogical potential, and its integration with established learning theories. This background is essential for understanding how immersive VR can serve as a novel paradigm to operationalise peer exclusion, reviewing its technical features, pedagogical potential, and integration with established learning theories to justify the adoption of immersive virtual environments in the current research and to frame the subsequent empirical investigations.

The first empirical study, presented in **Chapter 3**, focuses on the methodological challenge of capturing realistic experiences of peer exclusion in children and adolescents. Traditional paradigms, such as Cyberball, have proven effective in eliciting peer exclusion-related distress but lack ecological validity. To address this, a 3D immersive VR classroom paradigm simulating naturalistic peer conversations has been developed. This study qualitatively compares participants' subjective experiences of peer exclusion in the VR paradigm versus the classic Cyberball task, evaluating realism, social presence, and emotional impact. The findings inform the development of ecologically valid tools to study peer exclusion in educational settings.

The second empirical study, presented in **Chapter 4,** quantitatively compares the effects of the traditional 2D Cyberball paradigm and our novel 3D VR paradigm simulating peer exclusion during a classroom conversation. The study measures mood and psychological needs—using validated questionnaires—before and after peer exclusion episodes simulated by the two paradigms to capture immediate effects and to compare their ecological validity. The design also allows for an investigation of developmental differences and individual moderators, such as social support and previous rejection experiences.

Research Question 2: *What are the immediate effects of peer exclusion on working memory?*

The third empirical study, presented in **Chapter 5**, examines the emotional and cognitive consequences of experiencing peer exclusion in an ecological experimental context. Peer exclusion is experimentally manipulated by using the validated 3D VR paradigm, and participants' mood and WM are assessed pre- and post-exclusion. This study adopts a within-subject experimental design to capture the immediate cognitive cost of peer exclusion and to explore developmental differences between children and adolescents, as well as the mediating role of mood, the moderating role of social support, and individual characteristics. By linking peer exclusion to WM, this study bridges social-emotional experiences with educational performance.

Research Question 3: *How does daily peer relatedness (satisfaction and frustration) influence working memory updating and perceived academic success?*

The fourth empirical study, presented in **Chapter 6**, explores the daily impact of peer relatedness frustration through two ILD studies conducted across 28 school days with fourth and fifth graders (aged 9–11). The design aims to disentangle within-person fluctuations from stable, between-person differences and to explore how repeated daily experiences of peer relatedness frustration accumulate to shape WMU and perceived academic success.

Chapter 7 integrates the methodological, experimental, and intensive longitudinal findings. This general discussion synthesises the theoretical implications, methodological innovations, and practical applications of the research, focusing on the role of peer exclusion in shaping children and adolescents' WM and academic achievement. The chapter also provides a framework to interpret the findings of the empirical chapters in the context of developmental and educational psychology.

References

Abrams, D., Weick, M., Thomas, D., Colbe, H., & Franklin, K. M. (2011). On-line ostracism affects children differently from adolescents and adults. *British Journal of Developmental Psychology*, 29(1), 110–123.

Agee, L. A., Fourtassi, A., & Monfils, M. H. (2025). Social context as a source of variability in the psychological sciences. *Frontiers in Human Neuroscience*, 18, 1507010.

Ahmed, S. F., Tang, S., Waters, N. E., & Davis-Kean, P. E. (2019). Executive function and academic achievement: Longitudinal relations from early childhood to adolescence. *Journal of Educational Psychology*, 111(3), 446–458.

Ainsworth, M. D. S., Blehar, M. C., Waters, E., & Wall, S. (1978). Patterns of attachment: A psychological study of the strange situation. Hillsdale, NJ: Lawrence Erlbaum

Allen, J. P., & Tan, J. (2016). The multiple facets of attachment in adolescence In Cassidy J & Shaver P (Eds.), Handbook of Attachment, (pp. 399–415). *New York NY: Guilford*.

Ang, S., & Quarles, J. (2023). Reduction of cybersickness in head mounted displays use: A systematic review and taxonomy of current strategies. In *Frontiers in Virtual Reality* (Vol. 4).

Arshad, I., de Mello, P., Ender, M., McEwen, J. D., & Ferré, E. R. (2021). Reducing Cybersickness in 360-Degree Virtual Reality. *Multisensory Research*.

Arslan, G. (2018). Social Exclusion, Social Support and Psychological Wellbeing at School: A Study of Mediation and Moderation Effect. *Child Indicators Research*, 11(3).

Asscheman, S. J., Koot, S., Ma, I., Marieke Buil, J., Krabbendam, L., Cillessen, A. H. N., & van Lier, P. A. C. (2020). Erratum: Heightened neural sensitivity to social exclusion in boys with a history of low peer preference during primary school (Developmental Cognitive Neuroscience (2019) 38, (S1878929318302676), (10.1016/j.dcn.2019.100673)). In *Developmental Cognitive Neuroscience* (Vol. 44).

Baddeley, A. D. (2000). The episodic buffer: A new component of working memory? *Trends in Cognitive Sciences*, 4(11), 417–423

Bartholomew, K. J., Ntoumanis, N., Ryan, R. M., Bosch, J. A., & Thøgersen-Ntoumani, C. (2011). Self-determination theory and diminished functioning: The role of interpersonal control and psychological need thwarting. *Personality and Social Psychology Bulletin, 37*(11), 1459–1473.

Best, J.R., & Miller, P.H. (2010). A developmental perspective on executive function. *Child Development*, 81, 1641-1660.

Blakemore, S. J., & Mills, K. L. (2014). Is adolescence a sensitive period for sociocultural processing? *Annual Review of Psychology*, 65, 187–207

Blume, F., Irmer, A., Dirk, J., & Schmiedek, F. (2022). Day-to-day variation in students' academic success: The role of self-regulation, working memory, and achievement goals. *Developmental Science*, 13301.

Bolger, N., & Laurenceau, J. P. (2013). Intensive longitudinal methods: An introduction to diary and experience sampling research. Guilford press.

Bolling, D. Z., Pitskel, N. B., Deen, B., Crowley, M. J., Mayes, L. C., & Pelphrey, K. A. (2011). Development of neural systems for processing social exclusion from childhood to adolescence. *Developmental Cognitive Neuroscience*, 1–2, 72–88.

Bowlby, J. (1969). Attachment and loss, Vol. 1. *Attachment*. New York, NY: Basic

Bowlby, J. (1982). Attachment and loss: Retrospect and prospect. *American Journal of Orthopsychiatry*, 52(4), 664–678.

Bretherton, I., & Munholland, K. A. (2008). Internal working models in attachment relationships: Elaborating a central construct in attachment theory. In J. Cassidy & P. R. Shaver (Eds.), *Handbook of attachment: Theory, research, and clinical applications* (2nd ed., pp. 102–127). The Guilford Press.

Bronfenbrenner, U. (1992). Ecological systems theory. In R. Vasta (Ed.), *Six theories of child development: Revised formulations and current issues* (pp. 187–249). Jessica Kingsley

Bronfenbrenner, U. (2005). Making human beings human: Bioecological perspectives on human development. Sage.

Bronfenbrenner, U., & Morris, P. A. (2006). The Bioecological Model of Human Development. In R. M. Lerner & W. Damon (Eds.), *Handbook of child psychology: Theoretical models of human development* (6th ed., pp. 793–828). John Wiley & Sons, Inc.

Bronfenbrenner, U. (2006). The bioecological model of human development. In R. M. Lerner (Ed.), *Handbook of child psychology: Vol. 1. Theoretical models of human development* (6th ed., pp. 793–828). Wiley.

Brown, M., McCormack, M., Reeves, J., Brooks, C., & Grajek, S. (2020). 2023 EDUCAUSE Horizon Report. Teaching and Learning Edition. In *EDUCAUSE Horizon Report Review* (Vol. 55, Issue 1)

Buelow, M. T., Okdie, B. M., Brunell, A. B., & Trost, Z. (2015). Stuck in a moment and you cannot get out of it: The lingering effects of ostracism on cognition and satisfaction of basic needs. *Personality and Individual Differences,* 76, 63–67.

Butler, N., Quigg, Z., Bates, R., Jones, L., Ashworth, E., Gowland, S., & Jones, M. (2022). The contributing role of family, school, and peer supportive relationships in protecting the mental wellbeing of children and adolescents. *School Mental Health*, 14(3), 776-788.

Büttner, C. M., Ren, D., Stavrova, O., Rudert, S. C., Williams, K. D., & Greifeneder, R. (2024). Ostracism in everyday life: A framework of threat and behavioral responses in real life. *Journal of personality and social psychology*.

Caemmerer, J. M., & Keith, T. Z. (2015). Longitudinal, reciprocal effects of social skills and achievement from kindergarten to eighth grade. *Journal of school psychology*, 53(4), 265-281Casey et al., 2005

Chang, E., Kim, H. T., & Yoo, B. (2020). Virtual Reality Sickness: A Review of Causes and Measurements. *International Journal of Human-Computer Interaction*.

Chester, D. S., & Lasko, E. N. (2021). Construct validation of experimental manipulations in social psychology: Current practices and recommendations for the future. *Perspectives on Psychological Science*, 16(2), 377-395.

Chirico, A., Ferrise, F., Cordella, L., & Gaggioli, A. (2018). Designing awe in virtual reality: An experimental study. *Frontiers in Psychology*, 8(JAN).

Claire, H. (2020). Executive function: development, individual differences and clinical insights. In *Neural Circuit and Cognitive Development* (pp. 539-559). Academic Press.

Coie, J. D., & Dodge, K. A. (1983). Continuities and changes in children's social status: A five-year longitudinal study. *Merrill-Palmer Quarterly*, 29(3), 261–282.

Coie, J. D., Dodge, K. A., & Coppotelli, H. (1982). Dimensions and types of social status: A cross-age perspective. *Developmental Psychology*, 18(4).

Cook, C. J., Howard, S. J., Makaula, H., Merkley, R., Mshudulu, M., Tshetu, N., ... & Draper, C. E. (2024). Risk and protective factors for executive function in vulnerable South African preschool-age children. *Journal of Cognition*, 7(1), 58.

Cortés-Pascual, A., Moyano-Muñoz, N., & Quílez-Robres, A. (2019). The relationship between executive functions and academic performance in primary education: Review and meta-analysis. *Frontiers in Psychology*, 10, 1582.

Deci, E. L., & Ryan, R. M. (1985). Intrinsic Motivation and Self-Determination in Human Behavior. Springer US.

de Wilde, A., Koot, H. M., & van Lier, P. A. (2016). Developmental links between children's working memory and their social relations with teachers and peers in the early school years. *Journal of abnormal child psychology*, 44(1), 19-30.

de Water, E., Mies, G. W., Ma, I., Mennes, M., Cillessen, A. H., & Scheres, A. (2017). Neural responses to social exclusion in adolescents: Effects of peer status. *Cortex*, 92, 32-43.

Diamond, A. (2013). Executive functions. *Annual review of psychology*, *64*(1), 135-168.

Di Natale, A. F., Repetto, C., Riva, G., & Villani, D. (2020). Immersive virtual reality in K-12 and higher education: A 10-year systematic review of empirical research. In *British Journal of Educational Technology* (Vol. 51, Issue 6).

Dirk, J., & Schmiedek, F. (2016). Fluctuations in elementary school children's working memory performance in the school context. *Journal of Educational Psychology*, 108(5), 722.

Du, X., Xu, H., & Cheng, X. (2025). The mediating effect of basic psychological needs between peer relationships and learning engagement in primary school students in Tibet. BMC *Pediatrics*, 25, 42

Eccles, J. S., & Roeser, R. W. (2011). Schools as developmental contexts during adolescence. *Journal of Research on Adolescence*, 21(1), 225–241.

Eisenberger, N. I., Lieberman, M. D., & Williams, K. D. (2003). Does rejection hurt? An fMRI study of social exclusion. *Science*, 302(5643), 290–292.

Fuhrmann, D., Casey, C. S., Speekenbrink, M., & Blakemore, S. J. (2019). Social exclusion affects working memory performance in young adolescent girls. *Developmental Cognitive Neuroscience*, 40.

Galeano-Keiner, E. M., Neubauer, A. B., Irmer, A., & Schmiedek, F. (2022). Daily fluctuations in children's working memory accuracy and precision: Variability at multiple time scales and links to daily sleep behavior and fluid intelligence. *Cognitive Development*, 64, 101260.

Garon, N., Bryson, S. E., & Smith, I. M. (2008). Executive function in preschoolers: a review using an integrative framework. *Psychological bulletin*, 134(1), 31.

Gempp, R., & González-Carrasco, M. (2021). Peer relatedness, school satisfaction, and life satisfaction in early adolescence: a non-recursive model. *Frontiers in Psychology*, 12, 641714.

Greenberg, M. T. (1999). Attachment and psychopathology in childhood. In J. Cassidy and P. R. Shaver (Eds.), *Handbook of attachment: Theory, research, and clinical applications* (pp. 469-496). New York: Guilford Press.

Groves, N. B., Wells, E. L., Soto, E. F., Marsh, C. L., Jaisle, E. M., & Kofler, M. J. (2022). Executive Functioning and Emotion Regulation in Children with and without ADHD. *Research on Child and Adolescent Psychopathology*, 50(6), 721-735.

Guyer, A. E., Jarcho, J. M., Bukowski, W. M., Laursen, B., & Rubin, K. H. (2018). Neuroscience and peer relations. *Handbook of peer interactions, relationships, and groups*, 177-199.

Hackman, D. A., Gallop, R., Evans, G. W., & Farah, M. J. (2015). Socioeconomic status and executive function: developmental trajectories and mediation. *Developmental Science*, 18, 686-702.

Hagler Jr, D. J., Thompson, W. K., Chen, C. H., Reuter, C., Akshoomoff, N., & Brown, T. T. (2022). Do aggregate, multimodal structural neuroimaging measures replicate regional developmental differences observed in highly cited cellular histological studies?. *Developmental Cognitive Neuroscience*, 54, 101086.

Hamaker, E. L., Ceulemans, E., Grasman, R. P., & Tuerlinckx, F. (2015). Modeling affect dynamics: State of the art and future challenges. *Emotion Review*, 7(4), 316-322.

Hartgerink, C. H. J., van Beest, I., Wicherts, J. M., & Williams, K. D. (2015). The ordinal effects of ostracism: Meta analysis of 120 Cyberball studies. *PLOS ONE*, 10(5), e0127002.

Hawes, D. J., Zadro, L., Fink, E., Richardson, R., O'Moore, K., Griffiths, B., Williams, K. D. (2012). The effects of peer ostracism on children's cognitive processes. *European Journal of Developmental Psychology*, 9, 599–613

Hawker, D. S. J., & Boulton, M. J. (2000). Twenty years' research on peer victimization and psychosocial maladjustment: A meta-analytic review of cross-sectional studies. *Journal of Child Psychology and Psychiatry*, 41(4), 441–455.

Holmes, C. J., Kim-Spoon, J., & Deater-Deckard, K. (2016). Linking executive function and peer problems from early childhood through middle adolescence. *Journal of abnormal child psychology*, 44(1), 31-42.

Jang, H., Kim, E. J., & Reeve, J. (2016). Why students become more engaged or more disengaged during the semester: A self-determination theory dual-process model. *Learning and Instruction, 43*, 27–38.

Judd, N., Klingberg, T., & Sjöwall, D. (2021). Working memory capacity, variability, and response to intervention at age 6 and its association to inattention and mathematics age 9. *Cognitive Development*, 58, 101013.

Juvonen, J., Wang, Y., & Espinoza, G. (2011). Bullying experiences and compromised academic performance across middle school grades. *Journal of Early Adolescence*, 31(1), 152–173.

Kassner, M. P., Wesselmann, E. D., Law, A. T., & Williams, K. D. (2012). Virtually ostracized: Studying ostracism in immersive virtual environments. *Cyberpsychology, Behavior, and Social Networking*, 15(8).

Killen, M., Mulvey, K. L., & Hitti, A. (2013). Social exclusion in childhood: A developmental intergroup perspective. *Child Development*, 84(3), 772–790.

Kim, J., Luu, W., & Palmisano, S. (2020). Multisensory integration and the experience of scene instability, presence and cybersickness in virtual environments. *Computers in Human Behavior*, 113.

Ladd, G. W., Ettekal, I., & Kochenderfer-Ladd, B. (2017). Peer victimization trajectories from kindergarten through high school: Differential pathways for children's school engagement and achievement? *Journal of Educational Psychology*, 109(6), 826.

La Guardia, J. G., Ryan, R. M., Couchman, C. E., & Deci, E. L. (2000). Within-person variation in security of attachment: A self-determination theory perspective on attachment, need fulfillment, and well-being. *Journal of Personality and Social Psychology, 79*(3), 367–384.

Latina, D., Goreis, A., Sajko, P., & Kothgassner, O. D. (2023). Does Being Ignored on WhatsApp Hurt? A Pilot Study on the Effect of a Newly Developed Ostracism Task for Adolescents. *Journal of Clinical Medicine*, 12(5).

Lecce, S., Bianco, F., & Ronchi, L. (2020). Executive function in the school context: The role of peer relationships. *Infant and Child Development*, 29(1), e2151.

Lei, Y., Li, M., Lin, C., Zhang, C., & Yu, Z. (2024). The effect of ostracism on social withdrawal behavior: the mediating role of self-esteem and the moderating role of rejection sensitivity. *Frontiers in Psychology*, *15*, 1411697.

Li, Y., Kang, S., Lu, Q., et al. (2024). How peer relationships affect academic achievement among junior high school students: The chain mediating roles of learning motivation and learning engagement. *BMC Psychology*, 12, Article 278.

Lila, M., van Aken, M., Musitu, G., & Buelga, S. (2020). Families and adolescents. In *Handbook of adolescent development* (pp. 154-174). Psychology Press.

Luna, B., Marek, S., Larsen, B., Tervo Clemmens, B., & Chahal, R. (2015). An integrative model of the maturation of cognitive control. *Annual Review of Neuroscience*, 38, 151–170.

Ma, Q., & Pang, Y. (2023). The emotional mechanism underlying the adverse effect of social exclusion on working memory performance: A tDCS study. *PLOS ONE*, 18(4).

Martin, R. P., & Lease, A. M. (2022). Influential children in middle childhood peer culture: Effects of temperament and community culture. *Frontiers in Psychology*, *13*, 923469.

Masten, C. L., Eisenberger, N. I., Pfeifer, J. H., & Dapretto, M. (2013). Neural responses to witnessing peer rejection after being socially excluded: fMRI as a window into adolescents' emotional processing. *Developmental science*, 16(5), 743-759.

Masten, C. L., Telzer, E. H., Fuligni, A. J., Lieberman, M. D., & Eisenberger, N. I. (2010). Time spent with friends in adolescence relates to less neural sensitivity to later peer rejection. *Social Cognitive and Affective Neuroscience*, 5(2 3), 215–222.

Matthay, E. C., & Glymour, M. M. (2020). A graphical catalog of threats to validity: Linking social science with epidemiology. *Epidemiology*, 31(3), 376-384.

Mavromihelaki, E., Eccles, J., Harrison, N., Grice-Jackson, T., Ward, J., Critchley, H., & Mania, K. (2014). Cyberball3D+: A 3D serious game for fMRI investigating social exclusion and empathy. In *2014 6th International Conference on Games and Virtual Worlds for Serious Applications (VS-GAMES)* (pp. 1-8). IEEE

McNeish, D., & Hamaker, E. L. (2020). A primer on two-level dynamic structural equation models for intensive longitudinal data in Mplus. *Psychological methods*, 25(5), 610.

Michel, E., Knopf, M., & Daum, M. M. (2025). Stability of individual differences in executive functions in kindergarten children – a microgenetic study. *Cognitive Processing*, 26(1), 35–48.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex “frontal lobe” tasks: A latent variable analysis. *Cognitive psychology*, 41(1), 49-100.

Nezlek, J. B., Wesselmann, E. D., Wheeler, L., & Williams, K. D. (2015). Ostracism in everyday life: The effects of ostracism on those who ostracize. *The Journal of social psychology*, *155*(5), 432-451.

Nigg, J.T. (2017). Annual Research Review: On the relations among self-regulation, self-control, executive functioning, effortful control, cognitive control, impulsivity, risk-taking, and inhibition for developmental psychopathology. *The Journal of Child Psychology and Psychiatry*

Oberer, N., Gashaj, V., & Roebers, C. M. (2018). Executive functions, visual-motor coordination, physical fitness and academic achievement: Longitudinal relations in typically developing children. *Human Movement Science,* 58, 69–79

Parsons T.D. (2015) Virtual Reality for Enhanced Ecological Validity and Experimental Control in the Clinical, Affective and Social Neurosciences. *Front. Hum. Neurosci*. 9:660

Piaget, J. (1972). The psychology of the child. New York, NY: Basic Books.

Platt, B., Cohen Kadosh, K., & Lau, J. Y. F. (2013). The role of peer rejection in adolescent depression. *Depression and Anxiety*, 30(9), 809–821

Pöpplau, J. A., Schwarze, T., Dorofeikova, M., Pochinok, I., Günther, A., Marquardt, A., & Hanganu-Opatz, I. L. (2024). Reorganization of adolescent prefrontal cortex circuitry is required for mouse cognitive maturation. *Neuron*, 112(3), 421-440.

Prencipe, A., Kesek, A., Cohen, J., Lamm, C., Lewis, M. D., & Zelazo, P. D. (2011). Development of hot and cool executive function during the transition to adolescence. *Journal of Experimental Child Psychology*, 108, 621-637.

Prendergast, C.N., and Schubert, T. (2020) Investigating Reflexive Responses to Explicit and Implicit Forms of Social Exclusion Using Immersive Virtual Environment Technology. *Front. Psychol*. 11:575783

Raufelder, D., Neumann, N., Domin, M., Lorenz, R. C., Gleich, T., Golde, S., ... & Hoferichter, F. (2021). Do belonging and social exclusion at school affect structural brain development during adolescence?. *Child development*, 92(6), 2213-2223.

Rebenitsch, L., & Owen, C. (2014). Individual variation in susceptibility to cybersickness. *UIST 2014 - Proceedings of the 27th Annual ACM Symposium on User Interface Software and Technology.*

Riva, P., & Eck, J. (2016). The many faces of social exclusion. In P. Riva & J. Eck (Eds.), *Social exclusion: Psychological approaches to understanding and reducing its impact* (pp. 1–5). Springer.

Riva, G., Mantovani, F., & Gaggioli, A. (2004). Presence and rehabilitation: Toward second-generation virtual reality applications in neuropsychology. In *Journal of NeuroEngineering and Rehabilitation* (Vol. 1).

Roorda, D. L., Koomen, H. M., Spilt, J. L., & Oort, F. J. (2011). The influence of affective teacher–student relationships on students' school engagement and achievement: A meta-analytic approach. *Review of Educational Research*, 81(4), 493–529.

Rudolph, K. D. (2021). Understanding peer relationships during childhood and adolescence through the lens of social motivation. In *Advances in motivation science* (Vol. 8, pp. 105-151). Elsevier.

Rubin, K. H., Bukowski, W. M., & Laursen, B. (2011). Handbook of peer interactions, relationships, and groups. Guilford Press.

Ryan, R. M., & Deci, E. L. (2000). Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. *American Psychologist*, 55(1), 68–78.

Ryan, R. M., & Deci, E. L. (2017). Self-determination theory: Basic psychological needs in motivation, development, and wellness. *Guilford Press*.

Rytioja, M., Lappalainen, K., & Savolainen, H. (2019). Behavioural and emotional strengths of sociometrically popular, rejected, controversial, neglected, and average children. *European Journal of Special Needs Education*, 34(5), 557-571.

Sandilos, L. E., Rimm-Kaufman, S. E., & Cohen, J. J. (2017). Warmth and demand: The relation between students' perceptions of the classroom environment and achievement growth. *Child development*, *88*(4), 1321-1337.

Sankalaite, S., Huizinga, M., Dewandeleer, J., Xu, C., De Vries, N., Hens, E., & Baeyens, D. (2021). Strenghtening Executive Function and Self-Regulation Through Teacher Student Interaction in Preschool and Primary School Children: A Systematic Review. *Frontiers in Psychology*, 12.

Sandstrom, M. J., Deutz, M. H., Lansu, T. A., Van Noorden, T. H., Karremans, J. C., & Cillessen, A. H. (2017). Unanimous versus partial rejection: How the number of excluders influences the impact of ostracism in children. *Aggressive Behavior*, 43(2), 190-203.

Schmidt, A., Dirk, J., & Schmiedek, F. (2019). The importance of peer relatedness at school for affective well-being in children: Between-and within-person associations. *Social Development*, 28(4), 873-892.

Schmidt, A., Neubauer, A. B., Dirk, J., & Schmiedek, F. (2020). The bright and the dark side of peer relationships: Differential effects of relatedness satisfaction and frustration at school on affective well-being in children's daily lives. *Developmental psychology*, 56(8), 1532.

Schmidt, A., Dirk, J., Neubauer, A. B., & Schmiedek, F. (2021). Evaluating sociometer theory in children's everyday lives: Inclusion, but not exclusion by peers at school is related to within-day change in self-esteem. *European Journal of Personality*, 35(5), 736-753.

Sebastian, C. L., Viding, E., Williams, K. D., & Blakemore, S. J. (2010). Social brain development and the affective consequences of ostracism in adolescence. *Brain and Cognition*, 72(1), 134–145.

Segundo-Marcos, R., Carrillo, A. M., Fernández, V. L., & González, M. T. D. (2022). Development of executive functions in late childhood and the mediating role of cooperative learning: A longitudinal study. *Cognitive Development*, 63, 101219.

Sentse, M., Prinzie, P., & Salmivalli, C. (2017). Testing the direction of longitudinal paths between victimization, peer rejection, and different types of internalizing problems in adolescence. *Journal of Abnormal Child Psychology,* 45(5), 1013–1023.

Southgate, E., Smith, S. P., Cividino, C., Saxby, S., Kilham, J., Eather, G., Scevak, J., Summerville, D., Buchanan, R., & Bergin, C. (2019). Embedding immersive virtual reality in classrooms: Ethical, organisational and educational lessons in bridging research and practice. *International Journal of Child-Computer Interaction*, 19.

Spiegel, J. A., Goodrich, J. M., Morris, B. M., Osborne, C. M., & Lonigan, C. J. (2021). Relations between executive functions and academic outcomes in elementary school children: A meta-analysis. *Psychological Bulletin*, 147(4), 329–351.

Tang, A., Lahat, A., Crowley, M. J., Wu, J., & Schmidt, L. A. (2018). Neurodevelopmental differences in response to social exclusion: An event related neural oscillation study of children, adolescents, and adults. *Emotion*, 19(3), 520–532.

Telzer, E. H., Fuligni, A. J., Lieberman, M. D., Miernicki, M. E., & Galván, A. (2015). The quality of adolescents' peer relationships modulates neural sensitivity to risk taking. *Social cognitive and affective neuroscience*, 10(3), 389-398.

Tervo-Clemmens, B., Calabro, F. J., Parr, A. C., Fedor, J., Foran, W., & Luna, B. (2023). A canonical trajectory of executive function maturation from adolescence to adulthood. *Nature communications*, 14(1), 6922.

Thapa, A., Cohen, J., Guffey, S., & Higgins-D'Alessandro, A. (2013). A review of school climate research. *Review of Educational Research*, 83(3), 357–385.

Thelen, E., & Smith, L. B. (1994). A dynamic systems approach to the development of cognition and action. MIT Press.

Tobia, V., Riva, P., & Caprin, C. (2017). Who are the children most vulnerable to social exclusion? The moderating role of self-esteem, popularity, and nonverbal intelligence on cognitive performance following social exclusion. *Journal of abnormal child psychology*, 45, 789-801

Triberti, S., Brivio, E., & Galimberti, C. (2018). On social presence: theories, methodologies, and guidelines for the innovative contexts of computer-mediated learning. In *Enhancing social presence in online learning environments* (pp. 20-41). IGI Global Scientific Publishing.

Tuijnman, A., Kleinjan, M., Chen, S., Engels, R. C. M. E., & Granic, I. (2021). A Game-based Assessment of the Effects of Rejection on Young Adults. *Proceedings of the ACM on Human-Computer Interaction, 5(CHIPLAY).*

Underwood , M. K. , Scott , B. L. , Galperin , M. B. , Bjornstad , G. J. and Sexton , A. M. 2004 . An observational study of social exclusion under varied conditions: Gender and developmental differences . *Child Development* , 75 (5) : 1538 – 1555.

Valcan, D. S., Davis, H., & Pino-Pasternak, D. (2018). Parental Behaviours Predicting Early Childhood Executive Functions: a Meta-Analysis. *Educational Psychology Review*, 30(3).

van den Heuvel, M. P., & Hulshoff Pol, H. E. (2010). Exploring the brain network: A review on resting-state fMRI functional connectivity. *European Neuropsychopharmacology*, 20(8), 519-534

Van der Meulen, M., Steinbeis, N., Achterberg, M., van IJzendoorn, M. H., & Crone, E. A. (2018). Heritability of neural reactions to social exclusion and prosocial compensation in middle childhood. *Developmental Cognitive Neuroscience*, 34, 42–52.

Vandenbroucke, L., Verschueren, K., & Baeyens, D. (2017). The development of executive functioning across the transition to first grade and its predictive value for academic achievement. *Learning and Instruction*, 49, 103-112.

Vandenbroucke, L., Spilt, J. L., Verschueren, K., & Baeyens, D. (2018). The effects of peer rejection, parent and teacher support on working memory performance: An experimental approach in middle childhood. *Learning and Individual Differences*, 67, 12-21

Vandenbroucke, L., Spilt, J., Verschueren, K., Piccinin, C., & Baeyens, D. (2018). The classroom as a developmental context for cognitive development: A meta-analysis on the importance of teacher–student interactions for children's executive functions. *Review of Educational Research*, 88(1).

van Geert, P. (1994). Dynamic systems of development: Change between complexity and chaos. Harvester Wheatsheaf.

Vansteenkiste, M., Ryan, R. M., & Soenens, B. (2020). Basic psychological need theory: Advancements, critical themes, and future directions. *Motivation and Emotion, 44*(1), 1–31.

Vasquez, A. C., Patall, E. A., Fong, C. J., Corrigan, A. S., & Pine, L. (2016). Parent autonomy support, academic achievement, and psychosocial functioning: A meta-analysis of research. *Educational Psychology Review, 28*(3), 605–644.

Villena-Taranilla, R., Tirado-Olivares, S., Cózar-Gutiérrez, R., & González-Calero, J. A. (2022). Effects of virtual reality on learning outcomes in K-6 education: A meta-analysis. *Educational Research Review*, 100434.

Wang, L., Jiang, S., Tan, S., Wan, Y., & Fei, W. (2024). Ostracism, school engagement, and academic achievement: Examining a mediation model among senior high school students. *School Psychology International*, *45*(6), 641-658.

Welsh, J. A., Nix, R. L., Blair, C., Bierman, K. L., & Nelson, K. E. (2010). The development of cognitive skills and gains in academic school readiness for children from low-income families. *Journal of Educational Psychology*, 102(1), 43.

Wentzel, K. R., & Muenks, K. (2016). Peer influence on students' motivation, academic achievement, and social behavior. In *Handbook of social influences in school contexts* (pp. 13-30). Routledge.

Wentzel, K., Russell, S., & Baker, S. (2014). Peer relationships and positive adjustment at school. In *Handbook of positive psychology in schools* (pp. 260-277). Routledge.

Weyns, T., Colpin, H., De Laet, S., Engels, M., & Verschueren, K. (2018). Teacher support, peer acceptance, and engagement in the classroom: A three-wave longitudinal study in late childhood. *Journal of youth and adolescence*, 47(6), 1139-1150.

Will, G. J., van Lier, P. A. C., Crone, E. A., & Güroğlu, B. (2016). Chronic Childhood Peer Rejection is Associated with Heightened Neural Responses to Social Exclusion During Adolescence. *Journal of Abnormal Child Psychology*, 44(1).

Williams, K. D. (2001). Ostracism: the power of silence. (*Emotions and social behavior*). Guilford.

Williams, K. D. (2007). Ostracism: The kiss of social death. *Social and Personality Psychology Compass*, 1(1), 236–252.

Williams, K. D. (2009). Ostracism: A temporal need-threat model. In M. P. Zanna (Ed.), *Advances in Experimental Social Psychology* (Vol. 41, pp. 275–314). Academic Press

Williams, K. D., Cheung, C. K. T., & Choi, W. (2000). Cyberostracism: Effects of being ignored over the internet. *Journal of Personality and Social Psychology*, 79(5).

Williams, K. D., Forgas, J. P., Hippel, W. von, & Zadro, L. (2005). The Social Outcast: An Overview. In K. D. Williams, J. P. Forgas, & W. von Hippel (Eds.), *The social outcast*

Ostracism, social exclusion, rejection, and bullying. The Sydney Symposium of Social Psychology, Volume 7. New York: Psychology Press.

Williams, K. D., & Nida, S. A. (2022). Ostracism and social exclusion: Implications for separation, social isolation, and loss. *Current Opinion in Psychology*, *47*, 101353.

Williams, K. D., & Nida, S. A. (2011). Ostracism: Consequences and coping. *Current Directions in Psychological Science*, 20(2), 71–75.

Williams, K. D., & Sommer, K. L. (1997). Social Ostracism by Coworkers: Does Rejection Lead to Loafing or Compensation? *Personality and Social Psychology Bulletin*, 23, 693–706. Retrieved December 20, 2009.

Williams, K. D., & Zadro, L. (2005). Ostracism: The indiscriminate early detection system. In M. R. Leary (Ed.), *Interpersonal rejection* (pp. 19–44). Oxford University Press

Xu, C., Huizinga, M., Tekelia Ekubagewargies, D., Soetaert, J., Van Den Noortgate, W., & Baeyens, D. (2024). The relation between teacher–student interaction and executive function performance in children: A cross-cultural meta-analysis. *Educational Psychologist*, *59*(3).

Xu, M., Qiao, L., & Yang, D. (2018). Social exclusion weakens storage capacity and attentional filtering ability in visual working memory. *Social Cognitive and Affective Neuroscience*, 13(1), 92–102.

Yang, M. Y., Chen, Z., Rhodes, J. L., & Orooji, M. (2018). A longitudinal study on risk factors of grade retention among elementary school students using a multilevel analysis: Focusing on material hardship and lack of school engagement. *Children and Youth Services Review*, 88, 25-32.

Yu, X., Wang, X., Zheng, H., Zhen, X., Shao, M., Wang, H., & Zhou, X. (2023). Academic achievement is more closely associated with student-peer relationships than with student-parent relationships or student-teacher relationships. *Frontiers in psychology*, *14*, 1012701.

Zelazo, P. D., & Carlson, S. M. (2012). Hot and cool executive function in childhood and adolescence: Development and plasticity. *Child Development Perspectives*, 6, 354-360.

Zhou, M., & Kalota, F. (2020). Promoting collaborative learning through VR technologies in the era of COVID-19. *2020 7th International Conference on Information Technology Trends*, ITT 2020.

Zimmermann, P. (2004). Attachment representations and characteristics of friendship relations during adolescence. *Journal of Experimental Child Psychology, 88*(1), 83–101.

CHAPTER 2

Immersive Virtual Reality as Educational Resource

Giuseppe De Luca[1,2], Martina Benvenuti[1], Friederike Blume[3,4], Dieter Baeyens[2], Gerrit Meixner[5], Tung Khau[5], Elvis Mazzoni[1]

[1] University of Bologna, Department of Psychology, Italy
[2] KU Leuven, Parenting and Special Education Research Unit, Belgium
[3] DIPF | Leibniz Institute for Research and Information in Education, Germany
[4] IDeA, Center for Research on Individual Development and Adaptive Education of Children at Risk, Germany
[5] Heilbronn University, Usability and Interaction Technology Laboratory, Germany

Bibliographical reference:
De Luca, G., Benvenuti, M., Blume, F., Baeyens, D., Meixner, G., Khau, T., & Mazzoni, E. (2025). Immersive Virtual Reality as educational resource. In *Research Handbook on Cyberpsychology* (pp. 221-251). Edward Elgar Publishing.

Introduction

In the dynamic landscape of education, technological advancements have continually shaped the way we approach learning and teaching. Among these innovations, immersive Virtual Reality stands out as a transformative force, offering unprecedented opportunities to enhance the educational experience. This chapter delves into the fascinating realm of immersive Virtual Reality and its profound impact on today's education. From its inception as a tool for simulation and entertainment, immersive Virtual Reality has evolved into a powerful educational asset, providing students with immersive, interactive, and experiential learning environments. As we explore the applications, benefits, and challenges of integrating immersive Virtual Reality into education, we will investigate its potential to revolutionise traditional teaching methods and foster a new era of engaging, inclusive, and effective learning. More specifically, we will start by defining and differentiating immersive Virtual Reality from the other types of Virtual and Augmented Reality, focusing on the key and technical features, qualities, limitations and problems of this innovative tool within educational contexts. We will continue by showing how immersive Virtual Reality can practically be applied to educational contexts according to several educational theoretical frameworks. We will thereby demonstrate the benefits and challenges of its application at school over the years, and the opinions of students and teachers about the use of learning environments developed using immersive Virtual Reality. Lastly, we will focus on the use of immersive Virtual Reality to improve teachers' and students' skills at school, concluding by presenting our proposal for a novel immersive virtual environment.

Immersive Virtual Reality: Keyword Concepts

Virtual Reality (VR) refers to the experience of being completely embedded within a virtual and artificial environment employing advanced technologies, which include specific hardware and devices (Radianti et al., 2020). Thereby, the first distinction we need to point out is the one between Virtual Reality and Augmented Reality (AR): the former refers to a 3D environment separated from the real-world environment, within which users interact while they only experience the virtual

environment and do not perceive the real-world one; the second one refers to a technology which allows users to augment the real-world environment with virtual elements by using everyday-life devices like smartphones and tablets (for instance, by using AR with smartphone or tablet cameras, people can visualize and perceive in their device screen additional elements which are not present in the real environment; Bazavan et al., 2021). VR, moreover, can be distinguished in turn as immersive Virtual Reality (IVR) and non-immersive or desktop VR (D-VR): as it can be inferred by the terminology, the first one aims to completely immerse the user within the virtual environment. As immersion is a feature placed within a continuum (i.e., it goes from the total absence of immersion to the completed immersion, users can feel or not immersed at several different levels) and not an obvious feature of VR, how well the user is immersed depends on factors the VR developers need to control. To this end, it requires the use of specific and advanced devices like headsets, which allow for visual and auditory inputs using particular lenses and earphones and which increase the user's proprioception through tracking sensors and controllers (Murcia-López & Steed, 2016). In contrast, the D-VR environment can be more easily displayed on a usual computer screen utilising usual technological devices like keyboards and mouse hardware (Ai-Lim Lee et al., 2010).

IVR, as the most advanced VR technique, due to its potential to create and replicate real images, sounds and interactions with objects, allows users to be involved in computer-generated 3D experiences in which they feel as if they were physically present in that environment (Bodzin et al., 2021). Users embedded in IVR perceive the environment more realistically as they have the opportunity to perform physical actions and interact with all the elements situated in the virtual environment (Smith, 2015). Therefore, IVR, compared to other types of VR, is a visual, multisensory, computer-stimulated environment in which users can feel their field of view as being fully taken over by another reality different from the real one, granting them the chance to experience interactions with the generated world as real (Blascovich et al., 2002).

As IVR technology can create new and differentiated stimuli and keep a high experimental control and a high quality of realism, it has become a useful tool within several contexts over the

years, also the educational one (Persky & McBride, 2009). The application of IVR in education covers a wide range of various areas and subjects. IVR is most commonly used in STEM subjects (i.e., science, technology, engineering, and mathematics) according to the literature (Pellas et al., 2021). In these subjects, IVR can be a valuable complement to conventional instructional methods. It provides improved opportunities for visualisation and interaction, such as intricate three-dimensional representations of molecular structures (Bakar et al., 2019).

In the following sections, several additional benefits will be consistently highlighted, including improving the learning experience for students with identified special needs (Innocenti et al., 2019), preparing students for real-life educational environments and improving the understanding of academic methods (Bolkas et al., 2020), facilitating a more natural learning approach (Parmar et al., 2016), high didactic utility (Becerra et al., 2017), generating new knowledge (Southgate et al., 2019), enhancing presentation skills and improving oral presentation competence (Boetje & van Ginkel, 2021). Moreover, IVR features and educational implications will be emphasised, and preliminary works already conducted by employing IVR in educational contexts will highlight its role as a promising tool for educational contexts.

Immersive Virtual Reality's main technical features

The main features that make IVR particularly suitable for educational contexts are its design elements, including immersion, presence, perception of realism and engagement, which allow students to be embedded in an artificial world moving and looking around it without distractions coming from the actual classroom (Jensen & Konradsen, 2018). Indeed, by implementing these features within educational contexts, students can be placed in a different and artificial environment characterised by a higher realism compared to other educational resources like textbooks, lectures and any 2D media. Moreover, IVR allows to exclude specific elements that could hinder students' learning in the real environment (Blascovich et al., 2002). IVR creates active environments in which students can learn through several possibilities such as active participation, collaboration, and exploration, having fun while learning and increasing the engagement and attention fundamental for

the learning process: for instance, students can actively be engaged in a school activity provided by an IVR environment (active participation), the activity specifically created to be performed in group and aimed to achieve a collective solution (collaboration), within the IVR environment students can go around investigating its elements (exploration), and, lastly, they can experience it as an enjoyable game (Connolly, 2005). Moreover, through IVR students can be immersed in countless settings and time periods (Pérez Martínez, 2011) and thus achieve a higher experiential learning by breaking space-time barriers (Cuesta Cambra & Mañas Viniegra, 2016). Therefore, we can consider IVR as a high-potential pedagogical tool and an immersive learning space, offering learners an authentic context to expand their learning horizons and visualise situations and concepts that are challenging to represent through alternative mediums.

The literature mainly focuses on two features: immersion and presence. Immersion refers to the level of sensory fidelity provided by a VR system, and it characterises the impact of IVR technology (Slater, 2003). Immersion sets IVR apart from other technological resources in education, making it more powerful (Webster, 2016). It operates through the substitution of sensory inputs from reality with digitally generated counterparts, encompassing visual and auditory elements (Freina & Ott, 2015). Spatial immersion, a concept prevalent in IVR gaming, occurs when a player perceives the simulated environment as convincingly authentic, providing it with a sense of actuality and presence (Jennett et al., 2008). Presence, in the context of a VR system, encapsulates a user's subjective psychological response, wherein the user reacts to the virtual environment with a perceived reality similar to actuality (Sanchez-Vives & Slater, 2005). By enhancing the feeling of presence, students can achieve a substantial degree of agency and autonomy, manifested through embodied manipulation, interactive engagement, navigational control, verbal and non-verbal communication, creative pursuits, and unrestricted play (Slater & Sanchez-Vives, 2016).

The features of immersion and presence have undergone evolution concomitant with advancements in VR technology. Immersion is contingent upon the technological attributes inherent in the system providing the experiential interface. Furthermore, it constitutes an objectively

measurable characteristic of technology, displaying variation across different systems, each offering distinct levels of immersive engagement. Presence, instead, has been elucidated as the user's perception of "being there" with findings indicating that the individual's level of experiential involvement differs, even when employing identical systems and conditions (Bowman & McMahan, 2007). Taken together, these features may develop a perception of realism by encompassing realistic and secure depictions of surroundings, captivating portrayals of real-world scenarios and interactions, as well as independent management of the user experience. These elements contribute to simulating the feeling of being physically present in distinct environments (Jennett et al., 2008). Consequently, such features enhance user engagement and facilitate learning. Deeper and more detailed information about students' individual feelings of presence, immersion, engagement, and perception of realism will be further introduced and specified within the following sections.

As a feature that combines immersion, presence and perception of realism, engagement is the most significant characteristic that makes IVR a powerful pedagogical tool. Engagement can be defined as an individual's concentration, involvement, and persistence in a task, which is linked to adaptive or self-regulated learning (Dorph et al., 2016). It also denotes the experiential intensity of a relationship or interaction, along with one's temporal investment in or interactions with activities within an immediate environment (Shernoff, 2011). The term encompasses the dynamic interplay between learners and the inherent characteristics of both the task and the supportive environment. Three dimensions of engagement can be differentiated: (1) *behavioural engagement*, which assesses active participation or off-task behaviours; (2) *cognitive engagement*, which focuses on thought processes and attention directed at processing and understanding task content; and (3) *affective engagement*, which encompasses emotions experienced during a science activity (Dorph et al., 2016). Research indicates that a combination of these engagement aspects supports students' learning (Fredricks et al., 2004), and IVR has the potential to enhance all three of them. For example, providing learning contents by employing IVR increase students' curiosity for the novel and digital approach. This curiosity enhances students' cognitive engagement, as they are fully captured by the tool, but

also their affective engagement, as this makes students excited by thinking to use a so advanced tool at school. This process, in turn, will consequentially enhance students' behavioural engagement, as they will feel actively involved in the cool activity presented by using IVR. Furthermore, a more recent facet of learning engagement, termed agentic engagement, pertains to students' constructive contributions and proactive behaviours within the received instructional flow (Reeve, 2013). In an IVR learning environment, learners may exercise autonomous control as they intentionally choose pathways that personalise their learning and accomplish the given task.

To achieve optimal isolation of users from the real world and enhance feelings of immersion, presence, perception of realism and engagement, a head-mounted display (HMD) is the most effective device. Other traditional media-based alternatives (like smartphones, laptops, and multimedia boards) cannot create the same sense of being fully immersed in the virtual environment (Witmer & Singer, 1998). Over the years, the integration of smartphone devices into systems commonly referred to as "Cardboard VR headsets", exemplified by Google Cardboard, has emerged as the predominant method for VR simulations. This prevalence can be attributed to the method's convenience in assimilating into instructional approaches at the classroom scale and its cost-effectiveness. A substantial majority of students possess personal smartphone devices (Amin et al., 2016). In contrast, hardware devices like HMD incur higher costs due to the necessity of acquiring a new device for each student. Among these, the HTC Vive ranks as the second most frequently employed device with 20% of all implemented systems.

Another type of IVR simulation is the Cave Automatic Virtual Environment (CAVE system). CAVE VR technology presents a feasible choice for groups of individuals seeking interaction, collaboration, and shared participation in both physical and virtual spaces (de Back et al., 2020). The CAVE system can range from three-sided to six-sided installations (Miller et al., 2017). However, in comparison to contemporary HMDs, one drawback of the CAVE system is that it requires a separate physical room with three or six projection surfaces. Additionally, users have to wear 3D stereoscopic glasses to recreate a three-dimensional environment, making its installation more intricate and

expensive. Applied to the educational contexts, CAVE can be used to create collaborative and cooperative activities that allow more students to spend time together in the same immersive virtual environment, learning by socialising and collaborating among them and improving, in turn, also their social skills. Although the CAVE system delivers an immersive experience (K. Kim et al., 2012), it has limitations on embodiment. Users cannot see their hands represented within the virtual world, a feature common in VR applications supported by modern HMDs. Instead, they see their hands in the real-world context while utilising the CAVE's controllers and stereoscopic glasses, consequentially impacting their feeling of being immersed, as they feel the virtual world and their body as two separated entities. Unlike the CAVE system, which is not widely supported, modern development platforms provide users with a diverse set of features for HMDs, enabling them to create innovative applications (de Vasconcelos et al., 2019). Consequently, the CAVE system leans more towards a Mixed Reality approach, integrating the real environment with projections on flat displays using stereoscopic viewing methodology, rather than offering a VR experience like HMDs.

Among the HMDs, Oculus devices follow in popularity, presenting a range of several versions, among which come out the Oculus Rift and the Oculus Go. Meta's Oculus Quest 2 is also a featured HMD device notable for its distinctive characteristics, such as haptic control and stand-alone functionality without requiring a connection to a computer. Haptic control, providing tactile sensations to the user, holds the potential to enhance the immersive experience and contribute to improved knowledge acquisition and recall among students. More specifically, haptic control provided by Oculus Quest allows students to perceive that they are actually touching physical elements, and this can be useful both in scientific subjects to investigate physical phenomena, but also in more humanistic ones to better interact with the historical or geographical environment (Jochecová et al., 2022). The Oculus has redefined the landscape of HMDs. This transformation has been facilitated by advancements in hardware, including improvements in screen resolution, refresh rate, colour range, and sophisticated control hardware with gesture recognition capabilities. Notably, manufacturers such as Oculus have played a pivotal role in giving new significance to HMDs and

VR. The progress has been further fuelled by the support of software developers who offer cross-platform 3D engines like Unreal Engine and Unity3D. Online stores that provide rich content in various applications have also played a crucial role in the breakthrough of VR. These aspects, combined with the collaboration of developers and researchers, have created an environment conducive to producing high-quality content. This, in turn, has contributed to the widespread adoption of VR and introduced diverse solutions for developing applications for educational contexts. Developing high-quality contents by using 3D platforms, it is possible, for instance, to perfectly replicate a historical situation, a geographical location, or a chemical or biological structure, but also create virtual games used to improve cognitive functioning and develop useful life skills (Marougkas et al., 2023a).

Despite all the mentioned useful resources, while developing applications for educational contexts, designers, researchers and all school users need to take into account several limitations related to students' health and the general school asset.

Immersive Virtual Reality: physical and organizational limitations for educational contexts

Although the features and qualities make IVR suitable within educational contexts, it is important to consider several limitations, both physical (i.e., related to students' health) and organisational (i.e., related to school assets).

Firstly, as for the physical limitations, they are fundamental to be taken properly into consideration, especially in primary school contexts, because younger students are the most vulnerable to the possible negative effects of IVR. According to a marketing survey (Castaneda et al., 2017), only a minority of students reports experiencing physical discomfort due to the IVR environment being excessively intense. Manufacturers of IVR systems include health and safety warnings, specifying that their technology is unsuitable for children under 12–13 years of age. They also recommend that young people restrict their time using HMDs and take regular breaks under adult supervision (Southgate et al., 2019). Although age restrictions are recommended, manufacturers of

VR technology have not offered a justification or presented supporting findings for their disclaimers (Araiza-Alba et al., 2022).

The adverse effects of using HMDs with children can be classified as short-term and long-term. Common short-term side effects include motion sickness, eyestrain, headaches, and discomfort (which may be more pronounced in children due to the substantial weight of the glasses; Jensen & Konradsen, 2018). VR exposure can be dangerous even for people affected by photosensitive epilepsy, as VR headsets, being positioned close to the eyes, would consequently impact a broader expanse of the visual cortex in comparison to witnessing an identical flashing sequence on a television or mobile device (Binnie et al., 2002). Some individuals may experience issues such as loss of balance or feelings of nausea due to disruptions caused by the virtual environment. These adverse effects, commonly known as cybersickness or simulator sickness, can arise from a mismatch between the visual, vestibular, and proprioceptive sensory systems (Chang et al., 2020). The prevalence and severity of these symptoms can vary among users, affecting their comfort, well-being, and overall acceptance of VR technology. However, these phenomena are typically less concerning among younger students, given their correlation with the maturation process of the prefrontal cortex. Moreover, users commonly discern any discomfort within the initial minute(s) of engagement, thereby affording an advantageous aspect for consideration (Arshad et al., 2021).

Concerning long-term effects, there is a general public concern about the health of children's eyes when using VR headsets for extended periods (Araiza-Alba et al., 2022). Indeed, a notable limitation of many contemporary VR devices is their proximity to the user's eyes, with screens positioned within 10 cm. This configuration gives rise to two significant concerns that impact both the user experience and overall health. Firstly, unlike real-life vision, which allows dynamic focus adjustment at various distances, VR devices typically necessitate a fixed focus at a specific distance. This disparity can lead to a noticeable difference between the natural visual experience and the virtual environment, potentially affecting the level of immersion and realism perceived by users (Yoon et al., 2020). Additionally, the long-term effects of liquid crystal display (LCD) or Organic light-

emitting diode (OLED) screen emissions on eye health are not thoroughly explored. Given the direct exposure of the eyes to emitted light during extended VR sessions, it is crucial to consider potential implications for eye health. However, eye issues can probably be associated with exposure duration as well; therefore, the employment of VR for school aims by not exposing students to extended times might help to mitigate eye issues (Ang & Quarles, 2023).

Recognising and addressing these negative aspects is crucial when proposing methodologies for the use of VR. Researchers and practitioners need to account for potential health risks and develop suitable strategies to mitigate them. This may involve designing VR experiences that minimise eye strain, incorporating regular breaks, or utilising technologies aimed at reducing the risk of cybersickness. Furthermore, providing adequate training and acclimatisation to VR environments can help users overcome issues related to balance and motion sickness (Marougkas et al., 2023b).

Secondly, regarding organisational limitations, the current discussion about the use, suitability, and integration of IVR in schools and other fields mainly focuses on technical, practical, and budgetary challenges. From a technical standpoint, the use of high-quality IVR necessitates specific system requirements, which depend not only on a powerful computer but also on regular software updates. Additionally, current IVR equipment is mainly designed for entertainment purposes rather than educational use, and it often lacks compatibility with classroom settings. This can be challenging for teachers, as it demands a level of technical proficiency that may be daunting (Vesisenaho et al., 2019). Incorporating IVR into school classrooms has a significant drawback due to the substantial costs associated with both hardware and content. While mainstream technology companies have introduced more affordable IVR equipment in recent years, the creation of high-quality IVR content remains expensive. The development of new and tailored educational content is limited by financial barriers. Furthermore, the deployment of IVR in any specific field requires greater programming or technical expertise compared to traditional 2D tools. Therefore, any school aiming to adopt this technology not only incurs the expense of the equipment but also needs to invest in training for its teachers to fully harness the capabilities of this technology (Huang et al., 2010).

Another concern related to school assets is the issue of space, as the level of immersion and interactivity in a VR environment is directly linked to the physical space required for equipment use. Most IVR headsets require substantial space around the user to allow for unrestricted engagement with the virtual experience and surroundings. Traditional school structures, with typical classroom settings, often lack the necessary facilities for the safe implementation of this technology. In confined spaces, such as classrooms, there is a risk of physical injuries as students may inadvertently bump into each other or walls. Another often overlooked aspect involves the cables connecting the headset to the computer, posing risks such as tripping hazards or strangulation. Therefore, all IVR manufacturers emphasise the necessity of adult supervision for students using wired IVR equipment to ensure safe usage (D'Argenioe, 2016). Furthermore, in addition to considering physical and organisational limitations of IVR in education, IVR manufacturers and designers must incorporate a theoretical background as the primary element for providing an effective learning experience to students, rather than just an enjoyable one. To achieve this, IVR contents should be based on specific learning theories, which will be explained in detail below.

Immersive Virtual Reality in Education: Theoretical Background

Designing impactful IVR learning experiences, as the ones briefly introduced at the beginning of this chapter and the more specific ones which will follow further, is contingent on integrating learning theories. The integration of these theories into IVR enables educators to create immersive and interactive learning experiences that promote students' engagement with the learning content and thus promote more efficient and effective learning. As VR technology advances, it is becoming increasingly important for educators to understand how to apply learning theories to design effective VR-based learning experiences (Marougkas et al., 2023b).

Learning theories provide a framework for understanding how students learn, that is, how they absorb, process, and retain information (Pritchard, 2017). In the context of the educational use of IVR, these theories should offer guidance on how to design optimal learning situations (Hamilton et al., 2021).

Many researchers view the constructivist paradigm as the theoretical foundation for learning in IVR (Aiello et al., 2012). This is because numerous features and learning capabilities of IVR align with constructivist learning principles, which facilitate the VR integration and implementation (Bailenson et al., 2008). Constructivism, a theory associating learning with the creation of meaning from experience, emphasises interactive teaching strategies and the establishment of a meaningful context that should engage, motivate, and activate students' knowledge construction (Piaget, 1971). IVR possesses the capacity to adhere to these principles. It allows students to exercise control over content, sequence, and learning strategies, enabling their construction of knowledge. Additionally, they provide authentic, contextual, and discovery activities that stimulate diverse thinking patterns, which should foster intrinsic motivation. Furthermore, the manipulation of objects, interactivity, and active engagement emerge as pivotal facets in the learning process through media technology (Huber et al., 2016). These aspects align with key characteristics of IVR systems. Moreover, learning can be achieved through play and exploration, which IVR provides a unique opportunity for. Finally, IVR can stimulate their senses through auditory, visual, and haptic cues, thus enriching the learning experience.

The feasibility of these possibilities is due to the sense of presence provided in the computer-generated environment as mentioned above. This presence allows participants to interact with the VR world more naturally, ultimately contributing to improved learning outcomes (Lee et al., 2010). In particular, IVR elevates immersion levels by enhancing stimulus realism and involving the user as an active participant. Immersion places students inside the simulation, creating a virtual environment that feels fully enveloping and authentic (Persky & Eccleston, 2011). The heightened realism in immersive VR improves spatial cues and aids the formation of an accurate mental map. This mental map, in turn, serves as a memory aid for learning complex procedures (Sowndararajan et al., 2008).

One constraint associated with integrating the constructivist framework with VR learning environments is the students' reliance on the instructor, hindering their ability to operate autonomously. Learners frequently lean on the instructor for guidance and support, which restricts

their capacity for independent exploration and self-directed learning. Therefore, students cannot be totally engaged in the environment as they need external help, and either exploit the opportunity to develop by themselves a unique experience. Furthermore, the learning process in IVR is shaped by the students' existing knowledge, which can either facilitate or impede the acquisition of new information, as students need to know enough about the learning content before being immersed in a content-related experience; otherwise, they can risk to no take advantage of the experience. To mitigate these limitations, it is essential to design IVR experiences that encourage learner autonomy and offer opportunities for independent exploration. For instance, IVR experiences can be implemented by digital platforms within which students can find learning contents to be applied further in the IVR environment, and teachers can act as scaffolders by explaining and guiding the entire process instead of the single IVR experience (Huang & Liaw, 2018). Indeed, by employing effective scaffolding techniques, teachers can allow students to build the necessary prior knowledge, providing them with enough resources to explore independently the IVR environment and personalise the experience. This approach aims to strike a balance, fostering independent learning while providing necessary support to optimise the educational outcomes in VR environments (Marougkas et al., 2023b).

Another theoretical approach underlying the use of IVR for education is Gamification (Bernecker & Ninaus, 2021). To enhance motivation and engagement, VR learning experiences can incorporate gamification elements (Chen, 2020). Features such as points, badges, and leaderboards create a sense of competition, motivating students to achieve their objectives. Game-like environments also offer a secure and enjoyable space for students to practice skills, receive feedback, and overcome challenges. The use of IVR with gamification offers several benefits to students. It provides a safe environment for exploring challenging or hazardous problems, delivers a more interesting and dynamic learning experience, and offers personalised learning tailored to individual preferences (Zhang et al., 2017). This personalised approach stimulates students' interest, fostering engaging and exciting experiences (Chen et al., 2005). However, challenges and limitations exist in

integrating IVR into education with gamification. The cost of developing and implementing IVR technology may be prohibitively expensive, limiting access for some students and organisations. Educators might require special training to effectively integrate VR into their teaching methods, and IVR experiences may not be suitable for all learners, particularly those prone to motion sickness or sensory disorders (Martin et al., 2020). Despite these challenges, IVR with gamification has the potential to revolutionise education by providing immersive and engaging learning experiences (Marougkas et al., 2023a).

The cognitive load theory is another significant theoretical approach used to justify the use of IVR in education and create IVR applications suitable for this framework (Mayer & Moreno, 2003). The cognitive load theory posits that students' working memory experiences cognitive load when processing new domain-specific concepts and skills (Sweller, 1994). This intrinsic cognitive load is combined with extraneous cognitive load, which comes from the instructional environment. Since working memory has a maximum cognitive load capacity (Xu & Franconeri, 2015), instructional design should aim to minimise extraneous cognitive load (Sweller, 2016). To optimise cognitive load in IVR learning environments, designers must consider all the types of cognitive load. One approach is to reduce intrinsic cognitive load by breaking down complex concepts into smaller, more manageable chunks of information. This helps students better grasp and process the material without overwhelming their working memory (Anmarkrud et al., 2019). Additionally, designers can minimise extraneous cognitive load by eliminating distractions and unnecessary information within the IVR environment. Simplifying the learning space and focusing on relevant content aids in directing students' attention to key concepts, preventing cognitive overload (Wong et al., 2012). Furthermore, to reduce cognitive load, designers should craft IVR learning experiences that actively engage learners (Kirschner et al., 2009). Encouraging active participation and interaction with the material helps to build connections between new information and existing knowledge stored in long-term memory, as the learning is co-built and processed by more than one student, allowing the single student to reduce the cognitive load by dividing it with the peers (Kirschner et al., 2018). This

approach promotes a deeper understanding of the subject matter and facilitates the transfer of knowledge from the virtual environment to real-world applications (Marougkas et al., 2023b).

In the realm of IVR educational contexts, applying cognitive load theory poses challenges, primarily stemming from the immersive nature of VR and the demand for meticulously designed instructional approaches. The inherent qualities of IVR can potentially increase cognitive load, necessitating careful consideration in instructional design to optimise learning outcomes. Enhancing cognitive load management in VR education requires a deeper understanding of the interplay between immersive technologies and effective instructional strategies, emphasising the importance of ongoing research and the establishment of best practices in this evolving field (Marougkas et al., 2023b).

Moving to another theoretical approach, student engagement, based on flow theory, is phenomenologically conceptualised as a simultaneous experience of heightened concentration, enjoyment, and interest (Shernoff et al., 2003). These components are closely related to the learning experience (Shernoff & Csikszentmihalyi, 2009). Flow is an optimal psychological state in which an individual engaging in an activity becomes fully immersed, experiencing concentrated focus and enjoyment throughout the process (Csikszentmihalyi, 1998). This state of flow occurs when the activity is appropriately challenging for the individual's skill level. In the context of IVR learning environments, optimal design can incorporate elements such as perceptions of value, relatedness, agency, control, and autonomy. These factors, combined with other conditions for flow experiences, including a suitable match of challenges to users' skill levels, goals, and feedback, contribute to creating an environment conducive to the flow state during the learning process. This approach aims to enhance the overall learning experience by aligning the challenges presented with the learners' capabilities and fostering a sense of engagement and enjoyment (Bodzin et al., 2021).

A notable limitation of flow theory lies in its predominant emphasis on individual experiences, often neglecting the impact of social and cultural contexts that can significantly shape and influence the flow experiences of individuals. This drawback becomes particularly salient within the realm of IVR educational contexts, where IVR has the potential to immerse learners in collaborative

educational experiences. In these settings, the individualistic focus of flow theory may not fully capture the complexity and richness of the social and cultural dynamics that play a crucial role in shaping the learning experience within virtual environments. Recognising and addressing this limitation is essential for a more comprehensive understanding of the dynamics involved in VR educational settings (Marougkas et al., 2023b).

A further fundamental theoretical framework that school users and educators need to consider when using IVR within an educational context is the Technological Pedagogical Content Knowledge Framework (TPACK; Mishra & Koehler, 2006). The TPACK model emphasises the critical importance of understanding the interplay between content, pedagogy, and technology for successful technology integration in education. In the realm of IVR education, this means that learning experiences need to combine subjects' content, pedagogical methods, and IVR technology. However, applying the TPACK in IVR educational contexts has its limitations. One challenge involves the demand for educators to be proficient in both IVR technology and pedagogical strategies specific to IVR, which requires additional training and professional development. The effective incorporation of IVR into the curriculum requires a profound comprehension of the subjects' content and its alignment with IVR experiences. Moreover, the evolving nature of IVR technology poses difficulties in ensuring educators have access to current resources and tools. Furthermore, issues such as the cost and accessibility of IVR equipment and resources may impede widespread implementation in educational settings. These issues impact teachers' skills and willingness to apply pedagogical and learning contents to IVR environments. To overcome these challenges, continuous support and training for educators are essential to enhance their TPACK within the context of VR (Marougkas et al., 2023b).

Assuming one of the previously mentioned learning theories as the theoretical framework for developing an IVR learning environment, education has benefited from IVR over the years in terms of better learning outcomes and an overall better understanding of the school contents, as will become evident in the following paragraph.

Immersive Virtual Reality in Education: Learning Outcomes and Educational Limitations

IVR learning environments can significantly enhance students' overall learning, with one of the most commonly cited benefits being the improved content knowledge compared to traditional school methods (Wu et al., 2020). The didactic features associated with IVR contribute to better educational outcomes and increased academic achievement, as evidenced by findings from several studies (Villena-Taranilla et al., 2022).

When applied to cognitive learning tasks that require a significant degree of spatial understanding and visualisation (Maresky et al., 2019), students gain insights that are difficult to replicate in reality. IVR has the potential to generate immersive and captivating learning experiences, whereby it promotes active learning and enhances information retention. Additionally, numerous studies have highlighted the positive impacts of immersive learning experiences on cognitive outcomes, such as knowledge transfer (Lucas, 2018), knowledge retention (Meyer et al., 2019), and task engagement (Bhargava et al., 2018). Although enhancing cognitive outcomes is crucial in learning with IVR, research also highlights the importance of affective outcomes in the learning process. Outcomes such as engagement, presence, experienced realism, and eliciting emotion can facilitate learning (Cheng & Tsai, 2019). Several studies have explored IVR's capacity to better elicit emotions and increase engagement compared to other forms of media, such as video or printed material (Chirico et al., 2018). Affective mediation is recognised for increasing cognitive engagement through motivational factors (Plass et al., 2014). The affective aspects of educational experiences stimulate the necessary cognitive processes for learning.

The popularity of IVR at school, especially in STEM subjects, can be attributed to the ability for students to manipulate and interact with objects. When students attempt to grasp content presented through any 2D media, objects and images not only exist in a different dimension (2D) than real objects (3D), but are also degraded in comparison to real objects (e.g., lacking depth cues, shadows, colour, and gradients). This degradation makes it more difficult for the child to comprehend and learn

the material (Wilson & Soranzo, 2015). In contrast, the objects and images in an IVR environment are three-dimensional, eliminating the need for students to use cognitive resources to translate them into real-world objects. This allows them to utilise their mental resources more effectively to comprehend and learn the content (Araiza-Alba et al., 2022).

However, the usefulness of IVR has also been noticed among all subjects within which linear narratives predominate as pedagogical frameworks (such as history and literature). As IVR increases its popularity in the field of education, there is a growing interest in understanding how it transforms storytelling within classrooms. In a conventional history class, a linear narrative is typically presented to the listener, reader, or viewer, unfolding the story in the order the events occurred. This conventional method adheres to a logical structure with a distinct introduction, body, and conclusion. However, in the realm of IVR, students are no longer mere observers of the narrative. Instead, they can adopt different perspectives, immerse themselves in the story, and interact with people and objects within the virtual world. This dynamic engagement in the narrative provides a more interactive and participatory learning experience for students (Calvert & Abadia, 2020). Various studies have explored linear narratives in IVR and have found that they provide users with an embodied experience (Shin, 2017), induce emotional reactions (Chirico et al., 2018), increase presence (Ferguson et al., 2020), enhance immersion (Shin, 2017), and improve the retention of learned concepts (Buttussi & Chittaro, 2018).

IVR has been shown to be effective even in socio-culturally disadvantaged school settings. These classrooms often have distractions such as off-task conversations, cell phone use, and gaming on laptops. As a result, many students in these settings may lack motivation and be content with just “getting by”, putting them at risk of dropping out of school (Protheroe, 2004). Digital learning technologies, in particular IVR, have been shown to effectively enhance motivation among students from non-dominant racial, ethnic, and economic cultural backgrounds (Acquah & Katz, 2020). The use of IVR artefacts as tools to mediate learning and facilitate desired performance in specific contexts and locations represents a “practice turn” in theoretical perspectives on human learning,

development, and performance (Rogoff, 2003). According to this perspective, virtual learning materials and objects, including visual representations of data and locations, serve as foundational resources for individuals to engage in learning activities, both independently and collectively.

According to the literature analysing the effects of IVR used as a pedagogical tool on students' learning outcomes, researchers suggest that increased levels of immersive content, promoting multisensory engagement, have the potential to lead to more effective learning outcomes (Webster, 2016). Furthermore, IVR has the potential to increase student motivation, creating opportunities for authentic and immersive learning experiences (Luo et al., 2021). Additionally, it can enhance learning by facilitating active and experiential learning opportunities (Di Natale et al., 2020). IVR has been associated with several learning affordances, including enhancing learners' understanding of spatial concepts, enabling the execution of tasks that would be impractical or impossible in the real world, and fostering opportunities for meaningful collaborations (Dalgarno & Lee, 2010). Furthermore, it is recommended that elements that contribute to effective learning include features like free navigation and first-person perspective, the ability to manipulate size, transduction and reification, and autonomy (Southgate et al., 2019).

Despite these advantages, significant challenges have been emphasised (Radianti et al., 2020). Teachers face limitations in relying solely on materials created by IVR designers, which may not always align with their own or their students' specific requirements or the desired learning outcomes (Jensen & Konradsen, 2018). Producing entirely virtual environments for HMD remains challenging, even with the availability of affordable IVR creation sites. To create novel IVR experiences tailored for teaching any subject, one must either have a suitable IVR tool or possess the technical expertise to create one. To tackle the shortage of tailored material, one possible solution could be to investigate the educational efficacy of HMD 360° videos in the classroom as a substitute for computer-generated environments. Generating such content is comparably simpler with suitable video equipment and enables customisation to cater for the particular requirements of teachers and students. The broader research on the potential of IVR across diverse disciplines and learning domains is currently

constrained by the limited availability of necessary materials. The advancement of further research in this field may be contingent upon the increased accessibility of novel and individually tailored IVR environments (Hamilton et al., 2021).

IVR may have limitations as an educational tool that could impact its effectiveness with students. One such limitation is that IVR predominantly offers an individual experience, and certain learning skills or concepts may require social interaction for effective learning and practice (Kreijns et al., 2003). Furthermore, the visual elements within the 3D IVR environment that capture the students' interest and appear distinctive could potentially attract their attention, also known as "visual dominance". This is a well-established psychological phenomenon, which suggests that individuals are more likely to perceive and respond to visual stimuli compared to stimuli from other senses (Webb et al., 2022). Research suggested that the visual dominance effect could be counteracted through a process known as "user priming". This approach establishes expectations to guide users in compensating for the less pronounced aspects of the system's multisensory feedback by engaging their imagination (Pusch & Lécuyer, 2011). Attention-related challenges may pose an additional potential limitation. There are contrasting viewpoints on the use of HMDs to present information in the classroom. One perspective suggests that students may be easily distracted when presented with various options within their field of view, hindering concentration (Bell et al., 1995). However, researchers argued that HMDs can also aid concentration by eliminating classroom distractions, allowing students to focus on specific and relevant information presented within their specialised field of view (Southgate et al., 2019).

All the outcomes presented in this section have been found by using mixed approaches (e.g. qualitative approaches by interviewing students and teachers, quantitative approaches by assessing learning outcomes and IVR perception after an IVR experience employing questionnaires and tests; comparisons of IVR experiences and other digital or traditional methods), leading to a still exploratory attitude toward the matter. More specifically, the most common methodological approach in IVR educational research consists of quantitative designs in which core VR-related constructs—

such as presence, immersion, engagement, realism, and usability—are assessed through self-report questionnaires administered immediately after the IVR experience (Radianti et al., 2020; Makransky & Petersen, 2019). In parallel, motivational variables (e.g., interest, intrinsic motivation, perceived competence) and school-related outcomes are typically measured using validated educational questionnaires grounded in learning and motivation theories (Makransky & Petersen, 2021; Cheng & Tsai, 2019). Learning outcomes and content mastery are usually evaluated through objective, domain-specific knowledge tests or performance-based assessments administered pre- and post-intervention, allowing researchers to determine learning gains attributable to the IVR experience (Di Natale et al., 2020; Wu et al., 2020). In many studies, these quantitative assessments are complemented by follow-up qualitative methods—such as focus groups or semi-structured interviews with students, teachers, or both—to capture users' subjective experiences, perceived educational value, and practical classroom implications of IVR use (Jensen & Konradsen, 2018; Hamilton et al., 2021). Therefore, it is fundamental to interpret the aforementioned outcomes carefully and take into account that IVR use in education is becoming promising and popular, but still not widely accepted and investigated within all its aspects. Moreover, in addition to investigating the effects of IVR on students' learning at school, it is also essential to research the usability of IVR learning environments as perceived by school users. This will help to increase the development and usage of this learning tool.

Immersive Virtual Reality in education: Teachers and students' perception of usability

Investigating the perception of IVR usability from the perspectives of teachers and students has become fundamental due to the increasing value of IVR within school and educational contexts, although its use is still evolving over the years. Usability is defined as "the extent to which a system, product, or service can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use" (ISO, 2018). In educational IVR research, usability is most commonly investigated through qualitative methodologies, such as semi-structured interviews, focus groups, classroom observations, and think-aloud protocols, which allow researchers to capture users' subjective experiences, perceived challenges, and contextual constraints in authentic

learning settings (Jensen & Konradsen, 2018; Radianti et al., 2020). These qualitative approaches are often complemented by quantitative self-report instruments assessing specific usability-related dimensions, including ease of use, perceived usefulness, satisfaction, and system acceptability, as well as standardised questionnaires targeting simulator sickness and physical discomfort (e.g., nausea, dizziness, eye strain) associated with head-mounted displays (Kennedy et al., 1993; Rebenitsch & Owen, 2016). The integration of qualitative and quantitative methods is considered particularly appropriate for usability research in IVR, as it enables a comprehensive evaluation of both functional performance and experiential aspects of system use in educational contexts (Tullis & Albert, 2013; Hamilton et al., 2021). Usability testing primarily assesses users' capability to complete tasks. Therefore, designers and developers of IVR and Virtual Learning Environments must ensure that both teachers and students can effectively use these environments. Usability examines the entire interaction of users with the system, including their thoughts, feelings, and perceptions resulting from that interaction (Tullis & Albert, 2013). Usability studies can reveal potential discomfort, health issues, and other concerns that may affect the acceptance of such environments. Furthermore, usability testing and research provide opportunities for developers and educators to explore alternative solutions if these environments prove tobe unsuitable under specific conditions.

Overall, research has shown that teachers perceive IVR as promoting explorative behaviours, perceived usefulness and developing positive attitudes among students (Alalwan et al., 2020). IVR has also been found to make teaching and learning more interesting, effectively engaging, enjoyable, diverse, and experience-based. Additionally, HMD IVR has been recognised as a tool that enhances the ability to visualise complex processes and elevates the importance of teaching and teachers' work (Fransson et al., 2020). Teachers believe that the use of IVR in schools can have a significant impact on students' psychology, particularly their cognitive processes, and can potentially enhance or diminish abstract thinking and spatial orientation (Mukasheva et al., 2023). They expect that the use of IVR in schools will result in more benefits than harm to human psychology, provided that all norms are observed. Regarding teaching methodology, teachers suggested that IVR could improve the

autonomy and initiative of students (Marín-Díaz & Sampedro-Requena, 2023). Additionally, they indicated that the classroom and the learning process would become more active, resulting in a more participatory educational environment (Sousa et al., 2022).

However, teachers generally perceive more challenges than benefits when using IVR in schools. The challenges identified in the use of IVR in education include a lack of competency, limited instructional design, insufficient focused attention, time constraints, limited environmental resources, absence of guidelines, inadequate practice, potential health concerns, and insufficient parental support (Mukasheva et al., 2023). In particular, the teachers have emphasised the importance of new technologies to be user-friendly, easily maintainable, and upgradable without causing complications. They highlighted the need for rapid technical support and intervention to address any issues arising during teaching practices. Some teachers have expressed concerns about potential backlash if VR technology proves too complex or faces technological challenges, drawing from past experiences with digital technologies. Concerning the technical implementation of HMD VR, teachers have identified the challenge of developing accurate digital competence to navigate related hardware and applications. They have expressed the need for technical support, professional development, and time to learn and familiarise themselves with HMD VR equipment and suitable IVR applications (Fransson et al., 2020).

Additionally, teachers have discussed the technological learning barriers, specifically the challenge of helping students effectively use HMDs and applications as intended. Understanding the logic of various IVR hardware and software is complex, as similar tools could have different user interfaces (Stojšić et al., 2018). Once mastered, the teachers have observed that students might focus more on the general IVR app experience rather than the specific subject intended by the teachers. Managing this shift in focus has been viewed as a challenge by some, while others have emphasised the teacher's responsibility in guiding students on what to concentrate on during VR experiences (Mukasheva et al., 2023). All teachers have faced organisational challenges in implementing HMDs for teaching and learning, including aspects such as class size, the number of available HMD devices,

staffing, group rooms, and flexibility in locations and schedules (Fransson et al., 2020). Sharing a limited number of HMDs often has been noted to lead to discussions about organising station systems, where smaller groups of students rotate through different activities or technologies, with dedicated HMD VR applications assigned to specific stations. The significance of aligning curricular goals, intended learning outcomes, content, tasks, and assessment methods has been emphasised, showcasing teachers' pedagogical skills (Medland, 2019). However, teachers found specific alignment details challenging due to their limited knowledge and experience with specific IVR applications.

Regarding students' perception of the positive effects of IVR on their learning, data have revealed that students benefited from IVR in their learning process. They described it as an enjoyable method of learning and expressed interest in incorporating IVR into their future learning experiences (Bodzin et al., 2021). Students have perceived the use of IVR in schools positively and have not found learning to use IVR to be challenging. They identified various curriculum topics where they believed IVR could enhance their learning. Additionally, they noted that IVR increases their interest in learning. Moreover, students expressed satisfaction with IVR applications, finding them engaging and intriguing as IVR sparked their curiosity (Parmar et al., 2016). Introducing IVR in the classroom, therefore, has the potential to amplify their enjoyment of the learning process (Pande et al., 2021).

However, despite potential negative effects, few students have expressed concerns about the adverse health effects of IVR, such as nausea and dizziness (Mukasheva et al., 2023). More specifically, younger children are susceptible to motion sickness (Rebenitsch & Owen, 2014), and girls compared to boys (Kim et al., 2020) are more likely to experience cybersickness. Moreover, when exposed to IVR, students have reported a profound sense of presence, driven by both place illusion (i.e., expectations of how objects or people should behave in context-specific ways) and plausibility illusion (i.e., belief that the events are genuinely happening; Slater & Sanchez-Vives, 2016). This enhanced presence could be overwhelming for novices, requiring time to acclimate to the novelty and understand the possibilities within the virtual environment. Unfortunately, the time

available for this adjustment is limited due to a crowded curriculum (Southgate & Smith, 2017). Researchers' observations and recorded sessions confirmed that some students became more engrossed in the virtual environment than in the assigned learning task. Although some students remained focused and produced work reflecting deep knowledge and understanding, others seemed absorbed in the experience itself. This novelty effect may influence engagement and the learning process (Southgate et al., 2019). While IVR may lead to greater engagement and in-depth knowledge for some students, it could have a different effect on others. The novelty effect of new learning technologies has been acknowledged by students, but it is important to note that some students have reported feeling dissociated during VR experiences, describing it as "not you in there" or "feeling like someone else". This highlights a need for careful consideration of the affective and cognitive responses of students in IVR, as these responses may affect their attention to tasks and information processing (Hew & Cheung, 2010).

Finally, it is worth noting that while only a small number of girls initially expressed reluctance to try IVR, this phenomenon has not been observed among boys (Southgate et al., 2019). This imbalance may be attributed to factors such as the male gaze, peer relationships, and societal norms around gendered behaviour, especially during adolescence. Wearing a large and seemingly unattractive HMD without the ability to monitor classmates' reactions may make some girls feel uncomfortable and self-conscious, even if no one is observing them. Limited prior exposure to VR with an HMD among girls compared to boys highlights the necessity for early and sustained opportunities for girls to interact with such technology. This will help demystify VR and transform it from being perceived as 'embarrassing' to 'cool' (Currie et al., 2006).

Although we have presented evidence on the effects and perception of usability of overall learning environments developed by IVR, it would also be interesting to investigate the use of IVR for developing environments aimed at improving teachers' and students' skills, which in turn could enhance the overall learning environment.

Immersive Virtual Reality in Education: Enhancing teachers' and students' skills

IVR has been demonstrated to be a powerful and effective tool for enhancing teachers' and students' skills at school, particularly social skills. In addition to the features and qualities of IVR applied to educational contexts, its ability to improve teachers' and students' social skills through Social Presence makes it useful for everyday school activities. Social presence is the extent to which a user recognises another person in a virtual environment. It indirectly enhances satisfaction when using IVR (Shin, 2017). The concept of social presence reflects the perception of being connected to other social users in the realm of IVR (Biocca et al., 2003). Initially, this concept was understood as a sense of togetherness between individuals interacting through technical drama. However, since the advent of IVR, it has evolved as a connection to other social users since (Shin & Biocca, 2017). IVR interactions among social users ultimately foster a feeling of coexistence (i.e., the sense of togetherness). In a mediated world, this sense of coexistence is considered a factor that enables users to immerse themselves in the service, consequently enhancing enjoyment.

Teachers' Training in Immersive Virtual Reality

Classroom management has been the primary skill trained by VR so far. It refers to a set of strategies enacted by teachers to establish an efficient learning environment. Among these, effective classroom management involves establishing transparent expectations for desired behaviour, actively monitoring students, and crafting an optimal physical environment that promotes learning, including selecting appropriate materials and arranging the classroom layout (Hamre & Pianta, 2007). By achieving a higher level of classroom management, disruptions are consequently reduced to a minimum (Emmer & Stough, 2001). The effectiveness of classroom management depends on the teacher's ability to anticipate, understand, and interpret events that may conflict with these goals in real-time situations. Training in classroom management could therefore involve implementing training programs to improve teachers' communication skills and equip them with conflict resolution skills that commonly arise in school classrooms (Alonso et al., 2021). IVR environments offer numerous advantages for investigating and improving teacher expertise in classroom management,

surpassing the limitations of real-world classrooms. First, IVR enables the manipulation of experimental conditions by programming virtual avatars and configuring virtual classroom settings, resulting in a realistic and immersive educational environment (Bozki et al., 2021). Furthermore, conducting studies in IVR addresses significant privacy concerns, as no actual videos of students are recorded. Recording synchronised sensor data, such as eye- and controller-tracking data, can be easily and accurately achieved with advanced off-the-shelf VR devices, requiring minimal effort. IVR simulations have been used in previous studies to support teaching practices (Gao et al., 2023), and IVR classrooms have even been developed to aid novice teachers in enhancing their expertise in classroom management, utilising IVR as a valuable research tool (Seufert et al., 2022).

Among the IVR environments developed for classroom management training (Billingsley et al., 2019), *ClassroomVR-MotionCapture* (CVR-MC) is a tool aimed at refining teaching skills through practical application (Bocos-Corredor et al., 2020). The authors created an environment that enables teachers to immerse themselves in the authentic climate and emotional dynamics of a classroom. Several extensions were introduced to enhance the functionality of CVR-MC. These extensions include features such as the generation of conflict situations and their corresponding management options, allowing for the escalation and easy generation of situations. The system also incorporates tone of voice analysis, detecting changes during pivotal moments in the simulation. Additionally, it analyses the proximity between interlocutors, specifically the distance between students and teachers, influencing the simulation response. Keyword detection is used in conflict management to classify keywords and to determine an appropriate simulation response based on the user's emotions. The system also utilises the Perception Neuron and EmoPose system (García-Magariño et al., 2019) to capture and analyse the teacher's body language, associating it with specific emotions. During the simulation, important parameters are stored for later analysis. Teachers receive feedback on their behaviours and perceived intentions at the end of the simulation.

The empirical evaluation of the CVR-MC has typically employed a mixed-methods research design, focusing on usability and acceptance (Alonso et al., 2021). Participants were equipped with

immersive VR hardware and provided with a briefing on the virtual classroom context. During the simulation, teachers were asked to respond to a series of progressively disruptive classroom scenarios by enacting one of several possible management strategies in a naturalistic manner. The system dynamically recognised the selected behavioural path and generated automated feedback at the end of each scenario, including the appropriateness of the chosen action, dominant emotional states inferred from multimodal signals, and variations in vocal tone across the interaction. Upon completion of the simulation, participants completed standardised self-report measures grounded in the Technology Acceptance Model (Davis, 1989), assessing perceived usefulness, perceived ease of use, attitudes toward system use, and behavioural intentions. These quantitative data were complemented by semi-structured post-simulation interviews, which explored participants' subjective evaluations of the experience, the perceived relevance of the emotional feedback, and suggestions for improving the system's pedagogical and technical features.

The aforementioned tool exhibits significant potential as a learning system that could greatly contribute to teacher training. Teachers have strongly endorsed CVR-MC, stating that it is an invaluable support tool for trainee teachers, enabling them to safely practice essential techniques for handling conflictive situations. As a result, it serves as a platform for substantial development in their conflict resolution skills (Alonso et al., 2021). The feedback provided by CVR-MC, as highlighted in expert comments from teachers, is particularly beneficial for trainee teachers. Additionally, engaging in joint discussions during teacher training is seen as constructive and interesting for future educators. However, some teachers have faced learning challenges with the tool, primarily related to manageability issues. Incorporating training sessions before practical use could be advantageous in ensuring optimal utilisation and effectiveness of the tool.

Recent development in low-cost consumer-grade IVR systems have facilitated their integration into teaching environments. The *Breaking Bad Behaviors* (BBB) system takes advantage of this technology by utilising consumer-grade VR hardware and implementing collaborative and immersive VR teacher training (Lugrin et al., 2016). This system specifically simulates classrooms

with multiple virtual pupils, typically up to 25, without requiring additional actors or infrastructure. These virtual pupils are semi-autonomous agents that can be controlled by the instructor (a human operator) during a classroom simulation via a connected computer. The trainee, whether a pre-service or in-service teacher, becomes fully immersed in the virtual classroom using an HMD and 3D controllers. Instructors, who are experts in classroom management, can initiate conflict situations and evaluate a trainee's reaction and their classroom management competencies within this virtual setting. This approach offers a practical and interactive training environment, utilising the immersive nature of VR technology for effective teacher training.

The BBB system's evaluation has employed controlled pre-test–post-test designs combining behavioural assessment, self-report questionnaires, and instructor ratings (Seufert et al., 2022). Prior to both testing sessions, participants received structured familiarisation with the VR system and task requirements, including classroom rules and lesson content, to reduce novelty effects. Each experimental session followed a standardised sequence comprising informed consent, baseline questionnaires, system preparation, and an immersive classroom simulation in which participants conducted a short instructional activity while responding to instructor-triggered classroom disturbances. The type and intensity of these disturbances were adaptively adjusted based on participants' observed classroom management competencies. Following the simulation, participants completed a comprehensive battery of questionnaires assessing classroom management skills, presence, social presence, believability, perceived utility, and overall training experience, while instructors independently rated participants' classroom management performance using standardised observation instruments. This multi-informant and multi-method approach allowed for a fine-grained evaluation of both perceived and observed training outcomes within the IVR environment.

Findings in relation to the BBB system indicate that it is effective in improving classroom management competencies (Seufert et al., 2022). It has been found to enhance and develop teachers' theoretical knowledge and classroom management competencies more effectively than video and role-play. These findings are supported by teachers' self-assessments. They highlight the benefits of

applying theoretical knowledge within the BBB environment. BBB offers high-quality learning opportunities by allowing students to practice scenarios in a virtual environment. Teachers found BBB to be useful for reflecting on their actions and evaluating their strengths and weaknesses. Immediate reflection by teachers on the IVR learning situation, along with instructor feedback, provides qualitative support for ongoing individual progress. The IVR environment was positively rated by teachers for their future careers and professional practice. BBB thus emerges as a potential solution to address the lack of preparation felt by young teachers in their early years. It serves as a supportive tool for the development of classroom management competencies and self-efficacy. BBB is a fully immersive simulation system that provides a high sense of presence in realistic surroundings. Teachers reported feeling present in the simulation, particularly in the classroom environment, virtual student interactions, and disturbances, all of which were deemed believable. To enhance authenticity in future versions, advancements in agents and disturbances have been suggested, along with improved interaction possibilities between students and agents.

Noteworthy ongoing research is developing novel tools for training teachers' instructional support as well (Kugurakova et al., 2021). The integration of IVR facilitates an authentic reconstruction of the pedagogical process, allowing teachers to engage with various pedagogical scenarios they are likely to encounter in future teaching practice. Within this virtual environment, mistakes and errors are not perceived as severe setbacks but rather as opportunities for refining behavioural strategies that can effectively address issues within real educational settings. In contrast to traditional methodologies, where participants often confront psychological barriers during the acquisition of communication skills, virtual training offers a distinct advantage. Research highlights that participants experience heightened relaxation and ease within the virtual realm, alleviating psychological pressure while maintaining educational efficacy (Kickmeier-Rust et al., 2020).

In summary, the incorporation of a VR simulator into educators' training endeavors is anticipated to yield several benefits: provision of firsthand experience in navigating virtual conflict scenarios based on real-world cases; cultivation of diagnostic and reflexive skills essential for

organizing productive collaborative activities; enhancement of conflict resolution skills within educational contexts; fostering the capacity to design, model, and anticipate one's own behavior and actions, with due consideration of educational objectives amidst complex conflict scenarios; promotion of a communicative culture foundational for fostering interpersonal relationships; development of rapid decision-making and response capabilities in real-world conflict situations encountered in professional pedagogical practice.

Student' skills enhancement by Immersive Virtual Reality

To improve students' skills, IVR environments are developed based on the assumption of social constructivism. This means that learning is enriched when students share meanings in social contexts (Vygotsky et al., 1979). Collaborative learning, where learners co-construct knowledge and enhance understanding through the exchange of ideas, requires interdependency. In collaborative learning, group members work together to create plans, organise activities, and solve problems collectively (National Academies of Sciences, 2018). This process requires students to express their positions and interpretations, which can lead to conflicts when divergent opinions arise during collaborative work. Resolving conflicts in learning requires learners to defend and justify their stances, often prompting reflection on their understanding (Piaget, 1929). To arrive at the most convincing interpretations, learners need to engage with multiple perspectives, emphasising the essential role of peer interaction in the learning process. This becomes particularly crucial when grappling with ambiguous and complex concepts (Greenwald et al., 2017). In summary, peer interaction is a vital element in the learning process as it fosters reflection, debate, and a deeper understanding of intricate subjects.

Recent literature has emphasised the role of collaboration in schools, highlighting the use of IVR as a communication and collaborative tool to facilitate lively discussions among students who are synchronously present in the same virtual space (Jensen, 2017). In the IVR system, students actively contribute to developing rules of engagement, fostering a user-driven approach aimed at promoting collaboration. This approach aligns with the concept of collaborative scripts (Zhao et al.,

2015), which emphasises the use of predefined structures to encourage active participation and collaboration. The collaborative script approach suggests that task design should establish interdependence among team members, as this type of relationship fosters active engagement and productive collaboration. The effectiveness of participants in IVR activities is intricately linked to the thoughtful and mature design of tasks. More deliberate and sophisticated tasks are likely to yield better performance outcomes. Therefore, it is necessary to carefully consider task design to influence participants' engagement and performance in IVR collaborative environments (Zhou & Kalota, 2020).

Another approach used to enhance collaborative learning in schools is "pair programming". This approach emphasises the importance of role assignment and has been shown to have a significant effect in promoting collaborative interaction (Chen et al., 2018). Pair programming enhances students' responsibility for group work, increases awareness of collaboration, and improves overall learning outcomes. In the field of programming education, a paired learning process involving role assignment has proven to be effective, particularly in the challenging domain of programming, demonstrating notable benefits in both school and higher education settings (Umapathy & Ritzhaupt, 2017). The "pair programming" model, where one student (i.e., the pilot) writes the program while the other (i.e., the navigator) provides guidance, has been successfully utilised in IVR. The literature emphasises the importance of student dialogue and expressing uncertainty during pair programming, which leads to further clarification and enhanced ideas (Rodríguez et al., 2017). To enable collaborative learning in IVR environments, the challenge is to mitigate the isolation caused by individual students wearing VR headsets. In this framework, a pilot/co-pilot model has facilitated collaborative learning, making the immersed student feel grounded in the real world. The pilot/co-pilot model is considered a promising approach for collaborative learning in VR environments, drawing inspiration from the paired learning process. Although initial observations have suggested potential drawbacks in role assignment (pilot/navigator) due to the navigational focus, the pilot/co-pilot model has emerged as more conducive to problem-solving collaboration.

Webb et al. (2022) designed a study with 64 students, aged 12-13, who participated in a collaborative learning activity in a haptic-enabled 3D VR environment focused on cell membrane biology. Students worked in pairs using a pilot/co-pilot model, where one student directly manipulated the VR environment while the other provided guidance. The study tested two conditions: one with haptic feedback, where students could feel virtual forces such as molecular movements, and one without haptic feedback. The study found that students reported an enhanced understanding of the material, particularly the ability to visualise complex biological structures like the cell membrane. Findings also indicate that the value of sharing ideas and problems is recognised by students. Although there were no significant differences in post-test knowledge gains between the haptic and non-haptic groups, students in both conditions acknowledged the benefit of collaborative learning. This was particularly evident in the pilot/co-pilot model, where students engaged in active discussion and problem-solving. This model encouraged the sharing of ideas, which facilitated learning. Additionally, the study employed a controlled design, where the students were randomly assigned to the two conditions, and a knowledge test was administered before and after the VR activities, as well as after a retention period of eight months. This rigorous methodology allowed not only the assessment of the effectiveness of haptic feedback but also the role of collaboration in enhancing conceptual understanding.

The approaches and environments mentioned above have been developed with the co-presence of real students within IVR environments in mind. In the case of “pair programming”, IVR technologies are used collaboratively, emphasising the importance of improving social skills such as collaboration and cooperation through interaction and the use of IVR as a medium for better learning outcomes. However, to our knowledge, no IVR environment has been developed yet that is suitable for both assessing and improving pure peer interactions and social skills at school, as the literature only reports on IVR learning environments built to enhance social skills aimed at achieving higher learning outcomes. Furthermore, it was previously mentioned that IVR approaches and environments require the presence of multiple students. Therefore, the need for finding an IVR learning

environment that is appropriate for improving social skills in individual students is still emerging. Additionally, there is potential for IVR to extend beyond skill development in the classroom to the realm of school counselling, where clinical professionals can collaborate with teachers to identify and improve classroom-relevant processes. Based on these assumptions, and due to the lack of literature in the field of school psychology, we developed a new IVR environment focused on peer dynamics and interaction. This environment aims to simulate and investigate the effects of peer exclusion and inclusion as an assessment tool. It may also be used as an intervention tool to improve students' social skills.

A proposal for a novel Immersive Virtual Reality paradigm

Our focus has been on applying IVR to recreate social dynamics such as peer exclusion and peer inclusion within school contexts as widely operationalised by means of the Cyberball paradigm, a well-established tool for investigating social dynamics (Williams, 2001), driven by the pursuit of heightened experimental control and realism. The Cyberball paradigm has been widely used in educational psychology to simulate scenarios such as peer exclusion and inclusion, and to assess their impacts on K-12 students (Abrams et al., 2011). However, the conventional 2D implementation of the Cyberball paradigm suffers from low ecological validity (Parsons, 2015). The paradigm involves participants tossing a ball in a controlled setting. It has undergone a significant transformation as it enters into the realm of IVR. The motivation for this innovative leap is to overcome the limitations of traditional implementations and create a conversational simulation that allows for a more sophisticated exploration of social behaviours and psychological phenomena (Prendergast & Schubert, 2020). In this preliminary version, students will interact with two same-aged peers represented by two avatars in an immersive virtual classroom while sharing a school activity. The objective of introducing this novel version of the Cyberball paradigm in IVR is to replicate the same feeling of exclusion by virtual peers, mirroring the experiences in the original situation. This shift to IVR has the potential to offer a more immersive and ecologically valid platform for studying social dynamics and psychological responses.

The Unity platform, which is a robust foundation engine for VR application development, was used to develop the virtual environment. To create immersive experiences, we utilised the Oculus Quest 2 VR headset, which is known for its 90 Hz refresh rate, 1832×1920 display resolution per eye, integrated speakers, and microphone. This headset includes hand-tracking functionality, which allows participants to use their own hands in the virtual environment, enhancing the overall IVR experience. Our paradigm examines psychological and emotional effects of peer interactions in three distinct age groups: Children (8 to 10 years old), preadolescents (11 to 13 years old), and adolescents (14 to 16 years old).

For the virtual environment, we have created a realistic classroom setting that includes a blackboard, 40 pairs of single desks, and tables. To increase reliability, we have introduced three sets of virtual avatars, each representing male and female characters that resemble the age groups of the participants. Participants and virtual avatars assumed a seated position within the virtual classroom, strategically positioned at the centre. To enable conversations, six sets of conversation scripts have been created for virtual avatars. These scripts address topics that align with specific interests for each age group. Text-to-speech tools with AI enhancements have been used to transform the scripts into auditory stimuli. This ensures age-appropriate auditory experiences for students.

In relation to the animation of virtual avatars, the focus has been on coordinating upper-body movements. This is crucial for participants who engage in upper-body gestures facilitated by the hand tracking feature of the Oculus Quest 2. Two categories of animations were used: idle and emotional animations. These were designed to replicate neutral behaviour and a range of emotional states during verbal interactions. To enhance the authenticity of virtual interactions, two strategies were implemented. The first involved a dynamic question-asking mechanism. Virtual avatars adopted a focused orientation towards participants, creating an appearance of genuine engagement. The second included a mechanism to respond to ambient participant noise during the conversation. This enhanced visual realism and reinforced the illusion of heightened attentiveness on the part of the avatars. These

strategies aimed to create an immersive virtual environment that closely approximates authentic human interaction.

Following the guidelines for developing novel IVR paradigms in educational contexts (Pantelidis, 2010), we aim to implement the preliminary version of the IVR paradigm with the necessary changes identified in the first studies to enhance its quality and usability. This will prepare for future assessments and interventions aimed at improving peer relationships and social skills in schools.

Conclusions

We can conclude that IVR is a powerful tool within education for school activities and experiences, both intra- and extra-curricular. Learning environments developed using IVR provide better quality, usability, and outcomes compared to non-immersive, semi-immersive, or D-VR environments, as well as AR ones. IVR is superior to other technologies due to its advanced features that provide a sense of immersion, presence, perception of realism, and engagement. This allows users to feel fully immersed in a new environment, perceiving it as a real one and resulting in a more enjoyable experience. To achieve these outcomes, IVR requires a specific headset that allows users to enter the virtual environment. The most commonly used and updated headset currently is Meta's Oculus Quest.

However, while several qualities have been discussed, several limitations have been addressed as well, particularly regarding health and school assets. Specifically, the use of IVR with students under the age of 13 has been known to cause cybersickness, which is characterised by symptoms such as nausea, diarrhoea, headache, and a certain degree of discomfort due to the imbalance between the real world and the virtual one. Another physical limitation is posed by the headset lens, which has been found to be too close to users' eyes, potentially affecting students' field of view. Nevertheless, research has shown that these issues can be easily resolved by developing high-quality virtual environments, thus minimising any risk for younger students. The financial challenges associated with implementing technology in schools are primarily related to the costs of devices, hardware and

software, and the physical space required. Often, schools cannot afford to purchase devices for all the students or hire a developer to create custom virtual learning environments. Additionally, traditional structures may not facilitate the effective organisation of technology use among teachers and students.

Despite the issues, the popularity of IVR as a tool for school programs has been increasing over the years. This is due to several theoretical frameworks that explain and justify its usability and effectiveness within the educational environment. The most important theories that build this background refer to *constructivism*, *gamification learning*, *cognitive load*, *flow* and the *technological pedagogical content knowledge framework (TPACK).* In summary, IVR may serve as a robust operationalisation of the underlying principles and potential inherent in the aforementioned theories. It provides a learning environment that allows students to create their own knowledge through practical interaction with the environment, making learning enjoyable and reducing the cognitive load. The simplified elements within the learning environment aid in knowledge representation, and students can better assimilate learning content and knowledge. By developing IVR learning environments built on the theoretical frameworks mentioned above, IVR has become an effective and useful tool for school purposes, as literature on the use of IVR in schools has reported numerous positive outcomes in terms of learning, expertise, cognitive, and affective improvements. This is particularly evident in STEM subjects, where immersive learning environments enable students to directly manipulate scientific elements, and in linear narrative subjects, where students can experience historical situations as if they were present. However, it is important to address and overcome educational limitations, such as the risk of losing students' attention due to novelty effects of a new environment, which may distract from the actual learning content. Therefore, it is crucial to ensure a balanced approach to the use of technology in education.

Usability studies with teachers and students have shown that they perceive IVR as a useful learning tool and appreciate its qualities. They emphasise that it provides a better learning experience for students and improves the overall perception of learning. However, several challenges have also

been reported. As for teachers, the main challenges relate to their technological skills in using this type of technology and developing suitable learning programs. Additionally, they need pedagogical skills to apply learning content to this type of learning environment, keep students engaged, and manage general organisational issues such as the school spaces and timeframes. However, students reported that the main challenge they faced was cybersickness, which can occur while experiencing an immersive virtual environment. The occurrence of cybersickness stems from a discrepancy between vestibular input regarding head movements and visual feedback provided by VR displays, wherein the observed imagery in VR exhibits a perceptible lag in response to head movements. Additionally, female students may feel uncomfortable wearing a headset and participating in learning activities within a virtual environment due to the stereotype of gaming being a male-dominant activity. In the final section of the chapter, we emphasised the significance of utilising IVR as a training tool in addition to a learning tool at school. We demonstrated how immersive virtual environments can be used to improve classroom management skills in teachers and social skills in students, such as cooperation and collaboration. Furthermore, within the aforementioned framework, it is important to note that existing tools assume that improving students' social skills will subsequently enhance their learning outcomes and require the presence of multiple students. In contrast, our purpose is to develop a novel, single-student immersive virtual environment that focuses firstly on investigating and intervening in students' social dynamics related to peer relationships and interactions, including peer exclusion and inclusion, and then also as an effective and useful tool for school services such as school counselling in order to be helpful of taking care of students' wellbeing by using more advanced and powerful tools. After testing and validating the aforementioned paradigm, our goal is to refine, implement, and use it to investigate the effects of peer relationships on variables in school contexts, such as students' cognitive functioning and learning outcomes. Based on the results we achieve, we plan to validate and test the paradigm as an intervention tool for students who tend to feel a high level of rejection and exclusion by their peers.

References

Abrams, D., Weick, M., Thomas, D., Colbe, H., & Franklin, K. M. (2011). On-line ostracism affects children differently from adolescents and adults. *British Journal of Developmental Psychology*, *29*(1). https://doi.org/10.1348/026151010X494089

Acquah, E. O., & Katz, H. T. (2020). Digital game-based L2 learning outcomes for primary through high-school students: A systematic literature review. *Computers & Education*, *143*, 103667. https://doi.org/10.1016/j.compedu.2019.103667

Aiello, P., D'Elia, F., Di Tore, S., & Sibilio, M. (2012). A constructivist approach to virtual reality for experiential learning. *E-Learning and Digital Media*, *9*(3). https://doi.org/10.2304/elea.2012.9.3.317

Ai-Lim Lee, E., Wong, K. W., & Fung, C. C. (2010). How does desktop virtual reality enhance learning outcomes? A structural equation modeling approach. *Computers and Education*, *55*(4). https://doi.org/10.1016/j.compedu.2010.06.006

Alalwan, N., Cheng, L., Al-Samarraie, H., Yousef, R., Ibrahim Alzahrani, A., & Sarsam, S. M. (2020). Challenges and Prospects of Virtual Reality and Augmented Reality Utilization among Primary School Teachers: A Developing Country Perspective. *Studies in Educational Evaluation*, *66*. https://doi.org/10.1016/j.stueduc.2020.100876

Alonso, S., López, D., Puente, A., Romero, A., Álvarez, I. M., & Manero, B. (2021). *Evaluation of a Motion Capture and Virtual Reality Classroom for Secondary School Teacher Training*.

Amin, A., Gromal, D., Tong, X., & Shaw, C. (2016). Immersion in cardboard VR compared to a traditional head-mounted display. *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, *9740*. https://doi.org/10.1007/978-3-319-39907-2_25

Ang, S., & Quarles, J. (2023). Reduction of cybersickness in head mounted displays use: A systematic review and taxonomy of current strategies. In *Frontiers in Virtual Reality* (Vol. 4). https://doi.org/10.3389/frvir.2023.1027552

Anmarkrud, Ø., Andresen, A., & Bråten, I. (2019). Cognitive Load and Working Memory in Multimedia Learning: Conceptual and Measurement Issues. *Educational Psychologist*, *54*(2). https://doi.org/10.1080/00461520.2018.1554484

Araiza-Alba, P., Keane, T., & Kaufman, J. (2022). *Title: Are we ready for virtual reality in K-12 classrooms?*

Arshad, I., de Mello, P., Ender, M., McEwen, J. D., & Ferré, E. R. (2021). Reducing Cybersickness in 360-Degree Virtual Reality. *Multisensory Research*. https://doi.org/10.1163/22134808-bja10066

Bailenson, J. N., Yee, N., Blascovich, J., Beall, A. C., Lundblad, N., & Jin, M. (2008). The use of immersive virtual reality in the learning sciences: Digital transformations of teachers, students, and social context. In *Journal of the Learning Sciences* (Vol. 17, Issue 1). https://doi.org/10.1080/10508400701793141

Bakar, I. S. A., Sugiyarto, K. H., & Ikhsan, J. (2019). Effects of use 3D visualization virtual reality to increase scientific attitudes and cognitive learning achievement. *Journal of Physics: Conference Series*, *1397*(1). https://doi.org/10.1088/1742-6596/1397/1/012040

Bazavan, L. C., Roibu, H., Petcu, F. B., Cismaru, S. I., & George, B. N. (2021, September 1). Virtual Reality and Augmented Reality in Education. *Proceedings of the 2021 30th Annual Conference of the European Association for Education in Electrical and Information Engineering, EAEEIE 2021*. https://doi.org/10.1109/EAEEIE50507.2021.9531005

Becerra, D. A. I., Quispe, J. A. H., Aceituno, R. G. A., Vargas, G. M. P., Zamora, F. G. F., Mango, J. L. H., Paulina, G., Figueroa, A., Vizcarra, A. A. P., & Chana, J. W. T. (2017). Evaluation of a gamified 3D virtual reality system to enhance the understanding of movement in physics. *CSEDU 2017 - Proceedings of the 9th International Conference on Computer Supported Education*, *1*. https://doi.org/10.5220/0006328003950401

Bell, J. T., Fogler, H. S., & Arbor, A. (1995). The Investigation and Application of Virtual Reality as an Educational Tool. *Proceedings of the American Society for Engineering Education*, *2513*.

Bernecker, K., & Ninaus, M. (2021). No Pain, no Gain? Investigating motivational mechanisms of game elements in cognitive tasks. *Computers in Human Behavior*, *114*. https://doi.org/10.1016/j.chb.2020.106542

Bhargava, A., Bertrand, J. W., Gramopadhye, A. K., Madathil, K. C., & Babu, S. V. (2018). Evaluating multiple levels of an interaction fidelity continuum on performance and learning in near-field training simulations. *IEEE Transactions on Visualization and Computer Graphics*, *24*(4). https://doi.org/10.1109/TVCG.2018.2794639

Billingsley, G., Smith, S., Smith, S., & Meritt, J. (2019). A systematic literature review of using immersive virtual reality technology in teacher education. *Journal of Interactive Learning Research*, *30*(1).

Binnie, C. D., Emmett, J., Gardiner, P., Harding, G. F. A., Harrison, D., & Wilkins, A. J. (2002). Characterizing the flashing television images that precipitate seizures. *SMPTE Journal*, *111*(7–8). https://doi.org/10.5594/j15330

Biocca, F., Harms, C., & Burgoon, J. K. (2003). Toward a More Robust Theory and Measure of Social Presence: Review and Suggested Criteria. *Presence: Teleoperators and Virtual Environments*, *12*(5). https://doi.org/10.1162/105474603322761270

Blascovich, J., Loomis, J., Beall, A. C., Swinth, K. R., Hoyt, C. L., & Bailenson, J. N. (2002). Immersive virtual environment technology as a methodological tool for social psychology. *Psychological Inquiry*, *13*(2). https://doi.org/10.1207/S15327965PLI1302_01

Bocos-Corredor, M., Diaz-Nieto, A., Lopez-Garcia, A., Romero-Hernandez, A., Alvarez, I., & Manero, B. (2020). A VR GAME TO IMPROVE COMMUNICATION SKILLS IN SECONDARY-SCHOOL TEACHERS. *EDULEARN20 Proceedings*, *1*. https://doi.org/10.21125/edulearn.2020.2148

Bodzin, A., Araujo Junior, R., Hammond, T., & Anastasio, D. (2021). *Investigating Engagement and Flow With A Placed-based Immersive Virtual Reality Game*.

Boetje, J., & van Ginkel, S. (2021). The added benefit of an extra practice session in virtual reality on the development of presentation skills: A randomized control trial. *Journal of Computer Assisted Learning*, *37*(1). https://doi.org/10.1111/jcal.12484

Bolkas, D., Chiampi, J., Chapman, J., Fioti, J., & Pavill, V. F. (2020). Creating Immersive and Interactive Surveying laboratories in virtual reality: A differential leveling example. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *5*(5). https://doi.org/10.5194/isprs-annals-V-5-2020-9-2020

Bowman, D. A., & McMahan, R. P. (2007). Virtual reality: How much immersion is enough? *Computer*, *40*(7). https://doi.org/10.1109/MC.2007.257

Bozki, E., Stark, P., Gao, H., Hasenbein, L., Hahn, J. U., Kasneci, E., & Gollner, R. (2021). Exploiting object-of-interest information to understand attention in VR classrooms. *Proceedings - 2021 IEEE Conference on Virtual Reality and 3D User Interfaces, VR 2021*. https://doi.org/10.1109/VR50410.2021.00085

Buttussi, F., & Chittaro, L. (2018). Effects of Different Types of Virtual Reality Display on Presence and Learning in a Safety Training Scenario. *IEEE Transactions on Visualization and Computer Graphics*, *24*(2). https://doi.org/10.1109/TVCG.2017.2653117

Calvert, J., & Abadia, R. (2020). Impact of immersing university and high school students in educational linear narratives using virtual reality technology. *Computers and Education*, *159*. https://doi.org/10.1016/j.compedu.2020.104005

Castaneda, L., Cechonu, A., & Bautista, A. (2017). *All-school aggregated findings 2016-2017 - VR, Report, Foundary 10*.

Chang, E., Kim, H. T., & Yoo, B. (2020). Virtual Reality Sickness: A Review of Causes and Measurements. International Journal of Human-Computer Interaction. https://doi.org/10.1080/10447318.2020.1778351

Chen, C. M., Lee, H. M., & Chen, Y. H. (2005). Personalized e-learning system using Item Response Theory. *Computers and Education*, *44*(3). https://doi.org/10.1016/j.compedu.2004.01.006

Cheng, K. H., & Tsai, C. C. (2019). A case study of immersive virtual field trips in an elementary classroom: Students' learning experience and teacher-student interaction behaviors. *Computers and Education*, *140*. https://doi.org/10.1016/j.compedu.2019.103600

Chen, J., Wang, M., Kirschner, P. A., & Tsai, C. C. (2018). The Role of Collaboration, Computer Use, Learning Environments, and Supporting Strategies in CSCL: A Meta-Analysis. *Review of Educational Research*, *88*(6). https://doi.org/10.3102/0034654318791584

Chen, P. H. (2020). The design of applying gamification in an immersive virtual reality virtual laboratory for powder-bed binder jetting 3dp training. *Education Sciences*, *10*(7). https://doi.org/10.3390/educsci10070172

Chirico, A., Ferrise, F., Cordella, L., & Gaggioli, A. (2018). Designing awe in virtual reality: An experimental study. *Frontiers in Psychology*, *8*(JAN). https://doi.org/10.3389/fpsyg.2017.02351

Connolly, P. E. (2005). Virtual Reality & Immersive Technology in Education. *International Journal of Information and Communication Technology Education (IJICTE)*, *1*(1). https://doi.org/10.4018/jicte.2005010102

Csikszentmihalyi, M. (1998). *Creativity: Flow and the Psychology of Discovery and Invention - ProQuest*. Personnel Psycology.

Cuesta Cambra, Dr. U., & Mañas Viniegra, L. (2016). Integración de la realidad virtual inmersiva en los Grados de Comunicación. *Revista ICONO14. Revista Científica de Comunicación y Tecnologías Emergentes*, *14*(2). https://doi.org/10.7195/ri14.v14i2.953

Currie, D. H., Kelly, D. M., & Pomerantz, S. (2006). "The geeks shall inherit the earth": Girls' Agency, Subjectivity and Empowerment. *Journal of Youth Studies*, *9*(4). https://doi.org/10.1080/13676260600914416

Dalgarno, B., & Lee, M. J. W. (2010). What are the learning affordances of 3-D virtual environments? *British Journal of Educational Technology*, *41*(1). https://doi.org/10.1111/j.1467-8535.2009.01038.x

D'Argenioe, A. M. (2016). *VR SAFE FOR CHILDREN?* . GAMECREATE.

Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly*, *13*(3), 319–340. https://doi.org/10.2307/249008

D., C. P., Vygotsky, L. S., Cole, M., John-Steiner, V., Scribner, S., Souberman, E., & Wertsch, J. V. (1979). L. S. Vygotsky: Mind in Society. The Development of Higher Psychological Processes. *The American Journal of Psychology*, *92*(1). https://doi.org/10.2307/1421493

de Back, T. T., Tinga, A. M., Nguyen, P., & Louwerse, M. M. (2020). Benefits of immersive collaborative learning in CAVE-based virtual reality. *International Journal of Educational Technology in Higher Education*, *17*(1). https://doi.org/10.1186/s41239-020-00228-9

de Vasconcelos, G. N., Malard, M. L., van Stralen, M., Campomori, M., de Abreu, S. C., Lobosco, T., Gomes, I. F., & Lima, L. D. C. (2019). Do we still need CAVEs? *Proceedings of the International Conference on Education and Research in Computer Aided Architectural Design in Europe*, *3*. https://doi.org/10.5151/proceedings-ecaadesigradi2019_474

Di Natale, A. F., Repetto, C., Riva, G., & Villani, D. (2020). Immersive virtual reality in K-12 and higher education: A 10-year systematic review of empirical research. In *British Journal of Educational Technology* (Vol. 51, Issue 6). https://doi.org/10.1111/bjet.13030

Dorph, R., Cannady, M. A., & Schunn, C. D. (2016). How science Learning activation enables Success for youth in science learning. *Electronic Journal of Science Education*, *20*(8).

Emmer, E. T., & Stough, L. M. (2001). Classroom management: A critical part of educational psychology, with implications for teacher education. *Educational Psychologist*, *36*(2). https://doi.org/10.1207/S15326985EP3602_5

Ferguson, C., van den Broek, E. L., & van Oostendorp, H. (2020). On the role of interaction mode and story structure in virtual reality serious games. *Computers and Education*, *143*. https://doi.org/10.1016/j.compedu.2019.103671

Fransson, G., Holmberg, J., & Westelius, C. (2020). The challenges of using head mounted virtual reality in K-12 schools from a teacher perspective. *Education and Information Technologies*, *25*(4), 3383–3404. https://doi.org/10.1007/s10639-020-10119-1

Fredricks, J. A., Blumenfeld, P. C., & Paris, A. H. (2004). School engagement: Potential of the concept, state of the evidence. In *Review of Educational Research* (Vol. 74, Issue 1). https://doi.org/10.3102/00346543074001059

Freina, L., & Ott, M. (2015). A LITERATURE REVIEW ON IMMERSIVE VIRTUAL REALITY IN EDUCATION: STATE OF THE ART AND PERSPECTIVES. *11th International Conference ELearning and Software for Education*, *1*. https://doi.org/10.12753/2066-026x-15-020

Gao, H., Bozkir, E., Stark, P., Goldberg, P., Meixner, G., Kasneci, E., & Göllner, R. (2023, October). Detecting Teacher Expertise in an Immersive VR Classroom: Leveraging Fused Sensor Data with Explainable Machine Learning Models. In 2023 IEEE International Symposium on Mixed and Augmented Reality (ISMAR) (pp. 683-692). IEEE.

García-Magariño, I., Cerezo, E., Plaza, I., & Chittaro, L. (2019). A mobile application to report and detect 3D body emotional poses. *Expert Systems with Applications*, *122*. https://doi.org/10.1016/j.eswa.2019.01.021

Greenwald, S. W., Kulik, A., Kunert, A., Beck, S., Fröhlich, B., Cobb, S., Parsons, S., Newbutt, N., Gouveia, C., Cook, C., Snyder, A., Payne, S., Holland, J., Buessing, S., Corning, W., Lee, V., Xia, L., & Maes, P. (2017). Technology and applications for collaborative learning in virtual reality. *Computer-Supported Collaborative Learning Conference, CSCL*, *2*.

Hamilton, D., McKechnie, J., Edgerton, E., & Wilson, C. (2021). Immersive virtual reality as a pedagogical tool in education: a systematic literature review of quantitative learning outcomes and experimental design. *Journal of Computers in Education*, *8*(1), 1–32. https://doi.org/10.1007/s40692-020-00169-2

Hamre, B. K., & Pianta, R. C. (2007). Learning opportunities in preschool and early elementary classrooms. In *School readiness and the transition to kindergarten in the era of accountability*.

Hew, K. F., & Cheung, W. S. (2010). Use of three-dimensional (3-D) immersive virtual worlds in K-12 and higher education settings: A review of the research. *British Journal of Educational Technology*, *41*(1). https://doi.org/10.1111/j.1467-8535.2008.00900.x

Huang, H. M., & Liaw, S. S. (2018). An analysis of learners' intentions toward virtual reality learning based on constructivist and technology acceptance approaches. *International Review of Research in Open and Distance Learning*, *19*(1). https://doi.org/10.19173/irrodl.v19i1.2503

Huang, H. M., Rauch, U., & Liaw, S. S. (2010). Investigating learners' attitudes toward virtual reality learning environments: Based on a constructivist approach. *Computers and Education*, *55*(3). https://doi.org/10.1016/j.compedu.2010.05.014

Huber, B., Tarasuik, J., Antoniou, M. N., Garrett, C., Bowe, S. J., & Kaufman, J. (2016). Young children's transfer of learning from a touchscreen device. *Computers in Human Behavior*, *56*. https://doi.org/10.1016/j.chb.2015.11.010

Innocenti, E. D., Geronazzo, M., Vescovi, D., Nordahl, R., Serafin, S., Ludovico, L. A., & Avanzini, F. (2019). Mobile virtual reality for musical genre learning in primary education. *Computers and Education*, *139*. https://doi.org/10.1016/j.compedu.2019.04.010

ISO. (2018). Ergonomics of human-system interaction - Part 11: Usability: Definitions and Concepts. *Iso 9241-11:2018(E)*, *November*.

Jean Piaget. (1971). Measurement and Piaget. In *The theory of stages in cognitive development*.

Jennett, C., Cox, A. L., Cairns, P., Dhoparee, S., Epps, A., Tijs, T., & Walton, A. (2008). Measuring and defining the experience of immersion in games. *International Journal of Human Computer Studies*, *66*(9). https://doi.org/10.1016/j.ijhcs.2008.04.004

Jensen, C. G. (2017). Collaboration and Dialogue in Virtual Reality. *Journal of Problem Based Learning in Higher Education*, *5*(1).

Jensen, L., & Konradsen, F. (2018). A review of the use of virtual reality head-mounted displays in education and training. *Education and Information Technologies*, *23*(4). https://doi.org/10.1007/s10639-017-9676-0

Jochecová, K., Černý, M., Stachoň, Z., Švedová, H., Káčová, N., Chmelík, J., Brůža, V., Kvarda, O., Ugwitz, P., Šašinková, A., Fořtová, N. C., & Šašinka, Č. (2022). Geography Education in a Collaborative Virtual Environment: A Qualitative Study on Geography Teachers. *ISPRS International Journal of Geo-Information*, *11*(3). https://doi.org/10.3390/ijgi11030180

Kennedy, R. S., Lane, N. E., Berbaum, K. S., & Lilienthal, M. G. (1993). Simulator Sickness Questionnaire: An enhanced method for quantifying simulator sickness. *The International Journal of Aviation Psychology, 3*(3), 203–220. https://doi.org/10.1207/s15327108ijap0303_3

Kim, J., Luu, W., & Palmisano, S. (2020). Multisensory integration and the experience of scene instability, presence and cybersickness in virtual environments. *Computers in Human Behavior*, *113*. https://doi.org/10.1016/j.chb.2020.106484

Kim, K., Rosenthal, M. Z., Zielinski, D., & Brady, R. (2012). Comparison of desktop, head mounted display, and six wall fully immersive systems using a stressful task. *Proceedings - IEEE Virtual Reality*. https://doi.org/10.1109/VR.2012.6180922

Kirschner, F., Paas, F., & Kirschner, P. A. (2009). A cognitive load approach to collaborative learning: United brains for complex tasks. *Educational Psychology Review*, *21*(1). https://doi.org/10.1007/s10648-008-9095-2

Kirschner, P. A., Sweller, J., Kirschner, F., & Zambrano, J. R. (2018). From Cognitive Load Theory to Collaborative Cognitive Load Theory. *International Journal of Computer-Supported Collaborative Learning*, *13*(2). https://doi.org/10.1007/s11412-018-9277-y

Kreijns, K., Kirschner, P. A., & Jochems, W. (2003). Identifying the pitfalls for social interaction in computer-supported collaborative learning environments: A review of the research. In *Computers in Human Behavior* (Vol. 19, Issue 3). https://doi.org/10.1016/S0747-5632(02)00057-2

Kugurakova, V. V., Golovanova, I. I., Shaidullina, A. R., Khairullina, E. R., & Orekhovskaya, N. A. (2021). Digital Solutions in Educators' Training: Concept for Implementing a Virtual Reality Simulator. *Eurasia Journal of Mathematics, Science and Technology Education*, *17*(9). https://doi.org/10.29333/ejmste/11174

Lucas, J. (2018). Immersive VR in the construction classroom to increase student understanding of sequence, assembly, and space of wood frame construction. *Journal of Information Technology in Construction*, *23*.

Lugrin, J. L., Latoschik, M. E., Habel, M., Roth, D., Seufert, C., & Grafe, S. (2016). Breaking bad behaviors: A new tool for learning classroom management using virtual reality. *Frontiers in ICT*, *3*(NOV). https://doi.org/10.3389/fict.2016.00026

Luo, H., Li, G., Feng, Q., Yang, Y., & Zuo, M. (2021). Virtual reality in K-12 and higher education: A systematic review of the literature from 2000 to 2019. In *Journal of Computer Assisted Learning* (Vol. 37, Issue 3). https://doi.org/10.1111/jcal.12538

Makransky, G., & Petersen, G. B. (2019). Immersive virtual reality and learning: A meta-analysis. *Educational Psychology Review*, *31*(3), 561-589.

Makransky, G., & Petersen, G. B. (2021). The cognitive affective model of immersive learning (CAMIL): A theoretical research-based model of learning in immersive virtual reality. *Educational psychology review*, *33*(3), 937-958.

Maresky, H. S., Oikonomou, A., Ali, I., Ditkofsky, N., Pakkal, M., & Ballyk, B. (2019). Virtual reality and cardiac anatomy: Exploring immersive three-dimensional cardiac imaging, a pilot study in undergraduate medical anatomy education. *Clinical Anatomy*, *32*(2). https://doi.org/10.1002/ca.23292

Marín-Díaz, V., & Sampedro-Requena, B. E. (2023). Views of secondary education teachers on the use of mixed reality. *Frontiers in Education*, *7*. https://doi.org/10.3389/feduc.2022.1035003

Marougkas, A., Troussas, C., Krouska, A., & Sgouropoulou, C. (2023a). How personalized and effective is immersive virtual reality in education? A systematic literature review for the last decade. *Multimedia Tools and Applications*. https://doi.org/10.1007/s11042-023-15986-7

Marougkas, A., Troussas, C., Krouska, A., & Sgouropoulou, C. (2023b). Virtual Reality in Education: A Review of Learning Theories, Approaches and Methodologies for the Last Decade. In *Electronics (Switzerland)* (Vol. 12, Issue 13). Multidisciplinary Digital Publishing Institute (MDPI). https://doi.org/10.3390/electronics12132832

Martin, N., Mathieu, N., Pallamin, N., Ragot, M., & Diverrez, J. M. (2020). Virtual reality sickness detection: An approach based on physiological signals and machine learning. *Proceedings - 2020 IEEE International Symposium on Mixed and Augmented Reality, ISMAR 2020*. https://doi.org/10.1109/ISMAR50242.2020.00065

Mayer, R. E., & Moreno, R. (2003). Nine ways to reduce cognitive load in multimedia learning. *Educational Psychologist*, *38*(1). https://doi.org/10.1207/S15326985EP3801_6

Medland, E. (2019). 'I'm an assessment illiterate': towards a shared discourse of assessment literacy for external examiners. *Assessment and Evaluation in Higher Education*, *44*(4). https://doi.org/10.1080/02602938.2018.1523363

Meyer, O. A., Omdahl, M. K., & Makransky, G. (2019). Investigating the effect of pre-training when learning through immersive virtual reality and video: A media and methods experiment. *Computers and Education*, *140*. https://doi.org/10.1016/j.compedu.2019.103603

Miller, J., Baiotto, H., MacAllister, A., Hoover, M., Evans, G., Schlueter, J., Kalivarapu, V., & Winer, E. (2017). Comparison of a virtual game-day experience on varying devices. *IS and T International Symposium on Electronic Imaging Science and Technology*. https://doi.org/10.2352/ISSN.2470-1173.2017.16.CVAS-346

Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. In *Teachers College Record* (Vol. 108, Issue 6). https://doi.org/10.1111/j.1467-9620.2006.00684.x

Mukasheva, M., Kornilov, I., Beisembayev, G., Soroko, N., Sarsimbayeva, S., & Omirzakova, A. (2023). Contextual structure as an approach to the study of virtual reality learning environment. *Cogent Education*, *10*(1). https://doi.org/10.1080/2331186X.2023.2165788

Murcia-López, M., & Steed, A. (2016). The effect of environmental features, self-avatar, and immersion on object location memory in virtual environments. *Frontiers in ICT*, *3*(NOV). https://doi.org/10.3389/fict.2016.00024

National Academies of Sciences, E. and M. (2018). How people learn II: Learners, contexts, and cultures. In *How People Learn II: Learners, Contexts, and Cultures*. https://doi.org/10.17226/24783

Pande, P., Thit, A., Sørensen, A. E., Mojsoska, B., Moeller, M. E., & Jepsen, P. M. (2021). Long-term effectiveness of immersive vr simulations in undergraduate science learning: Lessons from a media-comparison study. *Research in Learning Technology*, *29*. https://doi.org/10.25304/rlt.v29.2482

Pantelidis, V. S. (2010). Reasons to Use Virtual Reality in Education and Training Courses and a Model to Determine When to Use Virtual Reality. *Themes in Science and Technology Education*, *2*(1–2).

Parmar, D., Bertrand, J., Babu, S. V., Madathil, K., Zelaya, M., Wang, T., Wagner, J., Gramopadhye, A. K., & Frady, K. (2016). A comparative evaluation of viewing metaphors

on psychophysical skills education in an interactive virtual environment. *Virtual Reality*, *20*(3). https://doi.org/10.1007/s10055-016-0287-7

Parsons, T. D. (2015). Virtual reality for enhanced ecological validity and experimental control in the clinical, affective and social neurosciences. *Frontiers in Human Neuroscience*, *9*(DEC). https://doi.org/10.3389/fnhum.2015.00660

Pellas, N., Mystakidis, S., & Kazanidis, I. (2021). Immersive Virtual Reality in K-12 and Higher Education: A systematic review of the last decade scientific literature. *Virtual Reality*, *25*(3). https://doi.org/10.1007/s10055-020-00489-9

Pérez Martínez, F. J. (2011). Presente y Futuro de la Tecnología de la Realidad Virtual. *Creatividad y Sociedad: Revista de La Asociación Para La Creatividad*, *16*.

Persky, S., & Eccleston, C. P. (2011). Impact of genetic causal information on medical students' clinical encounters with an obese virtual patient: Health promotion and social stigma. *Annals of Behavioral Medicine*, *41*(3). https://doi.org/10.1007/s12160-010-9242-0

Persky, S., & McBride, C. M. (2009). Immersive virtual environment technology: a promising tool for future social and behavioral genomics research and practice. *Health Communication*, *24*(8). https://doi.org/10.1080/10410230903263982

Piaget, J. (1929). The child's concept of the world. In *Londres, Routldge & Kegan Paul*.

Plass, J. L., Heidig, S., Hayward, E. O., Homer, B. D., & Um, E. (2014). Emotional design in multimedia learning: Effects of shape and color on affect and learning. *Learning and Instruction*, *29*. https://doi.org/10.1016/j.learninstruc.2013.02.006

Prendergast, C. N., & Schubert, T. (2020). Investigating Reflexive Responses to Explicit and Implicit Forms of Social Exclusion Using Immersive Virtual Environment Technology. *Frontiers in Psychology*, *11*. https://doi.org/10.3389/fpsyg.2020.575783

Pritchard, A. (2017). Ways of learning: Learning theories for the classroom. In *Ways of Learning: Learning Theories for the Classroom*. https://doi.org/10.4324/9781315460611

Protheroe, N. (2004). *Motivating Reluctant Learners*. www.naesp.org

Pusch, A., & Lécuyer, A. (2011). Pseudo-haptics: From the theoretical foundations to practical system design guidelines. *ICMI'11 - Proceedings of the 2011 ACM International Conference on Multimodal Interaction*. https://doi.org/10.1145/2070481.2070494

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

Rebenitsch, L., & Owen, C. (2016). Review on cybersickness in applications and visual displays. *Virtual Reality, 20*(2), 101–125. https://doi.org/10.1007/s10055-016-0285-9

Rebenitsch, L., & Owen, C. (2014). Individual variation in susceptibility to cybersickness. *UIST 2014 - Proceedings of the 27th Annual ACM Symposium on User Interface Software and Technology*. https://doi.org/10.1145/2642918.2647394

Reeve, J. (2013). How students create motivationally supportive learning environments for themselves: The concept of agentic engagement. *Journal of Educational Psychology*, *105*(3). https://doi.org/10.1037/a0032690

Rodríguez, F. J., Price, K. M., & Boyer, K. E. (2017). Exploring the pair programming process: Characteristics of effective collaboration. *Proceedings of the Conference on Integrating Technology into Computer Science Education, ITiCSE*. https://doi.org/10.1145/3017680.3017748

Rogoff, B. (2003). Orienting concepts and ways of understanding the cultural nature of human development. *The Cultural Nature of Human Development*.

Sanchez-Vives, M. V., & Slater, M. (2005). From presence to consciousness through virtual reality. In *Nature Reviews Neuroscience* (Vol. 6, Issue 4). https://doi.org/10.1038/nrn1651

Seufert, C., Oberdörfer, S., Roth, A., Grafe, S., Lugrin, J. L., & Latoschik, M. E. (2022). Classroom management competency enhancement for student teachers using a fully immersive virtual classroom. *Computers and Education*, *179*. https://doi.org/10.1016/j.compedu.2021.104410

Shernoff, D. J. (2011). Engagement and positive youth development: Creating optimal learning environments. In *APA educational psychology handbook, Vol 2: Individual differences and cultural and contextual factors.* https://doi.org/10.1037/13274-008

Shernoff, D. J., & Csikszentmihalyi, M. (2009). Flow in schools: Cultivating engaged learners and optimal learning environments. In *Handbook of Positive Psychology in Schools*. https://doi.org/10.4324/9780203884089-20

Shernoff, D. J., Csikszentmihalyi, M., Schneider, B., & Shernoff, E. S. (2003). Student engagement in high school classrooms from the perspective of flow theory. In *School Psychology Quarterly* (Vol. 18, Issue 2). https://doi.org/10.1521/scpq.18.2.158.21860

Shin, D. H. (2017). The role of affordance in the experience of virtual reality learning: Technological and affective affordances in virtual reality. In *Telematics and Informatics* (Vol. 34, Issue 8). https://doi.org/10.1016/j.tele.2017.05.013

Shin, D. H., & Biocca, F. (2017). Explicating user behavior toward multi-screen adoption and diffusion: User experience in the multi-screen media ecology. *Internet Research*, *27*(2). https://doi.org/10.1108/IntR-12-2015-0334

Slater, M. (2003). *A Note on Presence Terminology*. www.cs.ucl.ac.uk/staff/m.slater

Slater, M., & Sanchez-Vives, M. V. (2016). Enhancing our lives with immersive virtual reality. In *Frontiers Robotics AI* (Vol. 3, Issue DEC). https://doi.org/10.3389/frobt.2016.00074

Smith, J. W. (2015). Immersive virtual environment technology to supplement environmental perception, preference and behavior research: A review with applications. *International Journal of Environmental Research and Public Health*, *12*(9). https://doi.org/10.3390/ijerph120911486

Sousa, C. V., Hwang, J., Cabrera-Perez, R., Fernandez, A., Misawa, A., Newhook, K., & Lu, A. S. (2022). Active video games in fully immersive virtual reality elicit moderate-to-vigorous physical activity and improve cognitive performance in sedentary college students. *Journal of Sport and Health Science*, *11*(2). https://doi.org/10.1016/j.jshs.2021.05.002

Southgate, E., & Smith, S. P. (2017). Designing and conducting research using immersive technologies in schools: Seven observations. *2017 IEEE Virtual Reality Workshop on K-12*

Embodied Learning through Virtual and Augmented Reality, KELVAR 2017. https://doi.org/10.1109/KELVAR.2017.7961564

Southgate, E., Smith, S. P., Cividino, C., Saxby, S., Kilham, J., Eather, G., Scevak, J., Summerville, D., Buchanan, R., & Bergin, C. (2019). Embedding immersive virtual reality in classrooms: Ethical, organisational and educational lessons in bridging research and practice. *International Journal of Child-Computer Interaction*, *19*, 19–29. https://doi.org/10.1016/j.ijcci.2018.10.002

Sowndararajan, A., Wang, R., & Bowman, D. A. (2008). Quantifying the benefits of immersion for procedural training. *IPT/EDT 2008 - Immersive Projection Technologies/Emerging Display Technologies Workshop*. https://doi.org/10.1145/1394669.1394672

Stojšić, I., Ivkov-Džigurski, A., & Maričić, O. (2018). Virtual reality as a learning tool: How and where to start with immersive teaching. In *Didactics of Smart Pedagogy: Smart Pedagogy for Technology Enhanced Learning*. https://doi.org/10.1007/978-3-030-01551-0_18

Sweller, J. (1994). Cognitive load theory, learning difficulty, and instructional design. *Learning and Instruction*, *4*(4). https://doi.org/10.1016/0959-4752(94)90003-5

Sweller, J. (2016). Working Memory, Long-term Memory, and Instructional Design. *Journal of Applied Research in Memory and Cognition*, *5*(4). https://doi.org/10.1016/j.jarmac.2015.12.002

Tullis, T., & Albert, B. (2013). Measuring the User Experience: Collecting, Analyzing, and Presenting Usability Metrics: Second Edition. In *Measuring the User Experience: Collecting, Analyzing, and Presenting Usability Metrics: Second Edition*. https://doi.org/10.1016/C2011-0-00016-9

Umapathy, K., & Ritzhaupt, A. D. (2017). A meta-analysis of pair-programming in computer programming courses: Implications for educational practice. *ACM Transactions on Computing Education*, *17*(4). https://doi.org/10.1145/2996201

Vesisenaho, M., Juntunen, M., Häkkinen, P., Pöysä-Tarhonen, J., Fagerlund, J., Miakush, I., & Parviainen, T. (2019). Virtual Reality in Education: Focus on the Role of Emotions and Physiological Reactivity. *Journal For Virtual Worlds Research*, *12*(1). https://doi.org/10.4101/jvwr.v12i1.7329

Villena-Taranilla, R., Tirado-Olivares, S., Cózar-Gutiérrez, R., & González-Calero, J. A. (2022). Effects of virtual reality on learning outcomes in K-6 education: A meta-analysis. *Educational Research Review*, *35*. https://doi.org/10.1016/j.edurev.2022.100434

Webb, M., Tracey, M., Harwin, W., Tokatli, O., Hwang, F., Johnson, R., Barrett, N., & Jones, C. (2022). Haptic-enabled collaborative learning in virtual reality for schools. *Education and Information Technologies*, *27*(1), 937–960. https://doi.org/10.1007/s10639-021-10639-4

Webster, R. (2016). Declarative knowledge acquisition in immersive virtual learning environments. *Interactive Learning Environments*, *24*(6). https://doi.org/10.1080/10494820.2014.994533

Williams, K. D. (2001). *Ostracism: the power of silence. (Emotions and social behavior)*. Guilford.

Wilson, C. J., & Soranzo, A. (2015). The Use of Virtual Reality in Psychology: A Case Study in Visual Perception. In *Computational and Mathematical Methods in Medicine* (Vol. 2015). https://doi.org/10.1155/2015/151702

Witmer, B. G., & Singer, M. J. (1998). Measuring presence in virtual environments: A presence questionnaire. *Presence: Teleoperators and Virtual Environments*, *7*(3). https://doi.org/10.1162/105474698565686

Wong, A., Leahy, W., Marcus, N., & Sweller, J. (2012). Cognitive load theory, the transient information effect and e-learning. *Learning and Instruction*, *22*(6). https://doi.org/10.1016/j.learninstruc.2012.05.004

Wu, B., Yu, X., & Gu, X. (2020). Effectiveness of immersive virtual reality using head-mounted displays on learning performance: A meta-analysis. In *British Journal of Educational Technology* (Vol. 51, Issue 6). https://doi.org/10.1111/bjet.13023

Xu, Y., & Franconeri, S. L. (2015). Capacity for Visual Features in Mental Rotation. *Psychological Science*, *26*(8). https://doi.org/10.1177/0956797615585002

Yoon, H. J., Kim, J., Park, S. W., & Heo, H. (2020). Influence of virtual reality on visual parameters: Immersive versus non-immersive mode. *BMC Ophthalmology*, *20*(1). https://doi.org/10.1186/s12886-020-01471-4

Zhang, K., Suo, J., Chen, J., Liu, X., & Gao, L. (2017). Design and implementation of fire safety education system on campus based on virtual reality technology. *Proceedings of the 2017 Federated Conference on Computer Science and Information Systems, FedCSIS 2017*. https://doi.org/10.15439/2017F376

Zhao, Q., Chen, G., & Yu, L. (2015). The strategies for designing collaborative scripts. *Lecture Notes in Educational Technology*, *9783662441879*. https://doi.org/10.1007/978-3-662-44188-6_45

Zhou, M., & Kalota, F. (2020). Promoting collaborative learning through vr technologies in the era of COVID-19. *2020 7th International Conference on Information Technology Trends, ITT 2020*, 26–29. https://doi.org/10.1109/ITT51279.2020.9320886

CHAPTER 3

Exploring Social Exclusion Through Immersive Virtual Reality: A Qualitative Comparison with the Cyberball Paradigm in Children and Adolescents

Giuseppe De Luca[1,2], Dieter Baeyens[2], Gerrit Meixner[3], Tung Khau[3], Martina Benvenuti[1], Elvis Mazzoni[1]

[1] University of Bologna, Department of Psychology, Italy
[2] KU Leuven, Parenting and Special Education Research Unit, Belgium
[3] Heilbronn University, Usability and Interaction Technology Laboratory, Germany

Bibliographical reference:
De Luca, G., Baeyens, D., Meixner, G., Khau, T., Benvenuti, M., & Mazzoni, E. (2026). Exploring social exclusion through immersive virtual reality: a qualitative comparison with the Cyberball paradigm in children and adolescents. *European Journal of Psychology of Education*, *41*(1), 20.

Abstract

While the Cyberball paradigm is effective in eliciting exclusion-related distress in studies, it lacks ecological validity and fails to simulate realistic peer interactions. To overcome these limitations, we developed a 3D immersive Virtual Reality (VR) classroom scenario where participants experienced exclusion in peer conversations. This study introduces and validates this novel VR paradigm aimed at assessing social exclusion in children and adolescents within school contexts. A total of 150 students aged 8–16 engaged with both the VR and Cyberball paradigms in a counterbalanced design. Using reflexive thematic analysis of open-ended responses and a follow-up group discussion, we examined participants' emotional reactions to each paradigm. Both paradigms successfully elicited feelings of social exclusion, but the nature and intensity of responses varied developmentally: adolescents showed deeper emotional insight and more critical appraisals of social rejection after the VR paradigm, while children reacted more to graphical and playful features. Compared to Cyberball, the VR paradigm evoked stronger perceptions of realism and social presence, enhancing its effectiveness in replicating real-life exclusion experiences. While the VR paradigm was well-received, feedback from group discussions revealed that improvements in avatar behaviour, voice synthesis, and dialogue realism are needed to strengthen its ecological validity. Future refinements will further enhance the VR paradigm's utility in both educational research and applied psychological practice. Nonetheless, this current VR paradigm offers a developmentally sensitive and ecologically valid tool for examining how social exclusion is perceived across different age groups.

Keywords

Virtual Reality (VR); Social Exclusion; Cyberball Paradigm; Children; Adolescents; Qualitative Research.

Introduction

In response to limitations of ecological validity, experimental studies have seen a gradual shift from conventional methodologies to more sophisticated and technologically driven approaches (Brown et al., 2020). As researchers explored methods to improve the ecological robustness of their results, the advent of Virtual Reality (VR) emerged as a promising avenue. VR provides unparalleled control and realism, transcending the boundaries of physical space so that researchers can manipulate variables with enough precision to maintain a high level of ecological validity (Sanchez-Vives & Slater, 2005). Its immersive nature makes it possible for participants to take part in simulations that reproduce real-world scenarios, offering a better understanding of human behaviour and responses. In this study, we set out to develop a novel 3D VR paradigm to assess social exclusion in children and adolescents. This paradigm will be compared with the most widely used 2D VR paradigm. The fundamental supposition is that a 3D VR simulation of social exclusion would be more potent and efficacious in eliciting adverse outcomes in children and adolescents. This is attributable to its augmented ecological validity in comparison with conventional 2D simulations. Consequently, it could be utilised for research on social exclusion in childhood and adolescence.

Social Exclusion through Cyberball and VR

Social exclusion can be defined as the experience of being kept apart from others, whether physically (e.g. social isolation) or emotionally (e.g. being ignored or told one is not wanted). Social exclusion can be categorised as either explicit or implicit. An explicit communication of disapproval characterises the former, whereas a more subtle form of neglect defines the latter (Riva & Eck, 2016).

Social exclusion has been demonstrated to cause many adverse outcomes across the life course (MacDonald & Jensen-Campbell, 2010). Consequently, its assessment is fundamental in order to investigate previously unexplored immediate negative outcomes (Williams et al., 2000). In order to assess it, it is necessary to operationalise the concept and simulate it in experimental paradigms and scenarios (Kassner et al., 2012). A high level of ecological validity must be achieved in order to

facilitate the development of paradigms and scenarios that accurately represent everyday life situations (Parsons, 2015).

The Cyberball paradigm is a widely recognised tool in psychology for studying social dynamics (Williams & Nida, 2016) and simulating dynamics such as peer exclusion and inclusion (Williams, 2001). Cyberball is an experimental paradigm consisting of an online ball-tossing game in which children and adolescents are made to believe that they are playing with other real peers, but do not know that these peers are only standardised computer players. Typically, the classic version of this online game involves three players passing a ball to each other, one of whom is the participant in the experiment. Before the game starts, the researchers provide some information about the other two players in the game by giving them meaningful, but fictitious, short biographies in order to make them more realistic in the participants' perceptions. In the social exclusion condition, children and adolescents never or rarely receive the ball, compared to the neutral or inclusion condition, in which they often receive it. The number of throws the participant receives out of the total number of throws reflects the degree of inclusion or exclusion. The traditional 2D version of Cyberball is effective in eliciting negative moods and frustration (Williams et al., 2000), yet at the same time is characterised by low ecological validity (Parsons, 2015; Tuijnman et al., 2021). To elaborate further, within the context of a two-dimensional paradigm displayed on a screen, its simplistic graphical design offers low visual realism, and the two-dimensional characteristics do not facilitate a sense of immersion within the paradigm. Moreover, the limited manipulation of variables both inside and outside the interaction reduces experimental control, while the minimal perceived social interaction, due to the absence of authentic social cues, further limits ecological validity. Finally, the act of being excluded through a repetitive ball-tossing game represents an overly abstract simulation of social exclusion, which may not accurately reflect real-life experiences across different age groups. A recent attempt to experience peer exclusion in a 3D VR-adaptation of Cyberball revealed that the 3D version of Cyberball did not differ significantly in eliciting negative moods and frustration from the traditional 2D version (Kassner et al., 2012).

The failure of the 3D VR version of the Cyberball paradigm to elicit more severe outcomes may be attributed to the fact that, despite enhancements in graphics and an increase in immersion and realism, the ball-play activity does not constitute a representative social exclusion situation (Tuijnman et al., 2021). This is due to the absence of social cues from other players. The absence of genuine social interaction with other participants precludes the experience of exclusionary sentiments, due to the omission of the fundamental social dimension inherent in such interactions (Triberti et al., 2018). The necessity for a social exclusion simulation is emerging, within which participants can experience social presence and be situated within a social environment while being socially excluded by another individual. Building on this argument, the following section illustrates how immersive VR has increasingly been positioned as a promising tool within educational research, thereby situating our own paradigm within this broader methodological and pedagogical landscape.

3D VR in educational settings

Recent years have seen a growing interest in using immersive VR technologies within collaborative and educational settings to explore social and emotional phenomena (Lin et al., 2024; Tassinari et al., 2022). For instance, Silseth and colleagues (2024) demonstrated how immersive VR supported collaborative meaning-making among 17–18-year-old students, while Marinucci and Riva (2025) showed that VR simulations could increase empathy and prosocial attitudes among university students in the context of homelessness. Complementing this educational and socioemotional work, experimental research in psychology has demonstrated the effectiveness of both Cyberball and VR for assessing social exclusion, primarily among adults (Williams & Nida, 2016; Prendergast & Schubert, 2020). Yet, when it comes to children and adolescents, only Cyberball has been systematically employed to assess peer exclusion (Abrams et al., 2011), whereas VR-based exclusion paradigms have been used almost exclusively in adult workplace or social-attitude contexts (Prendergast & Schubert, 2020; Marinucci & Riva, 2025). Thus, despite promising applications, empirical evidence on VR-based peer exclusion in school-aged populations—and comparisons with established paradigms like Cyberball—remains absent. The present study directly addresses this

gap.Developmental literature indicates that social connectedness and peer evaluation become progressively more central from childhood into adolescence, shaping self-concept, motivation, and affect regulation (Blakemore & Mills, 2014; Crone & Dahl, 2012; Sebastian et al., 2010). Whereas younger children's reactions to peer exclusion are often concrete and immediate, adolescents integrate cognitive appraisal and self-reflective reasoning, showing heightened emotional resonance and sensitivity to social presence cues (Killen & Rutland, 2011; Somerville, 2013). Because VR paradigms can manipulate immersion and social presence, they provide an ideal platform to examine how developmental changes in social cognition modulate exclusion experiences. The ecological validity and sense of "being there" afforded by immersive VR may thus enhance the authenticity of emotional engagement, particularly among adolescents for whom social feedback is especially salient (Nelson et al., 2016). This developmental grounding strengthens the theoretical rationale for using VR as a tool not only to study but also to simulate and understand peer exclusion processes across age groups.

In this study, we therefore set out to develop a novel 3D VR paradigm to assess social exclusion in children and adolescents. This paradigm will be compared with the most widely used 2D Cyberball paradigm. The overarching rationale of this work lies in the need for an educationally relevant and ecologically valid experimental tool capable of simulating social experiences within the school context (e.g., Badger et al., 2023). In educational psychology, peer exclusion represents a critical risk factor for children's and adolescents' socioemotional adjustment, academic engagement, and overall school wellbeing (Riva & Eck, 2016). According to the Belongingness Hypothesis (Baumeister & Leary, 1995), the fundamental human need to form and maintain positive interpersonal relationships makes experiences of exclusion particularly salient, thereby offering a theoretical grounding for interventions aimed at supporting socioemotional functioning in school contexts. Understanding how peer exclusion experiences are perceived and processed is therefore essential to inform school-based prevention and intervention programmes. By designing an immersive paradigm that mirrors real classroom social interactions, this study aims to bridge the gap between controlled

experimental tasks and authentic school experiences, enabling the assessment of peer exclusion-related emotional and cognitive reactions that directly relate to learning and peer functioning. In the longer term, such VR paradigms could also serve as pedagogical tools to foster empathy and emotion regulation, helping students understand both the experience of being excluded and of excluding others, thereby promoting inclusive school climates.

The fundamental supposition is that a 3D VR simulation of social exclusion would be more potent and efficacious than the traditional 2D Cyberball one in eliciting adverse outcomes in children and adolescents. This is attributable to its augmented ecological validity in comparison with conventional 2D simulations (Parsons, 2015). From a methodological standpoint, this heightened realism enables more accurate assessments of exclusion-related processes in developmental populations. The paradigm also carries theoretical value, as immersive simulations provide a context in which to examine how young people understand, interpret, and emotionally respond to exclusion within social environments. Finally, the paradigm offers applied and pedagogical value: by providing a safe and controlled environment for students to experience and reflect upon social exclusion, it supports educational psychologists and teachers in designing interventions aimed at enhancing socioemotional skills and empathy (Phillips et al., 2025). Consequently, it could be utilised for research on social exclusion in childhood and adolescence.

Immersive VR offers promising applications not only for enhancing educational outcomes but also for school-based psychological interventions, where collaboration between educators and mental health professionals is essential. Given the paucity of research integrating VR into school psychology, we developed a novel immersive VR paradigm focused on peer interaction dynamics—specifically, experiences of social exclusion and inclusion (Fig. 1). This paradigm was conceived as both a research tool and a foundation for future interventions. Guided by established recommendations for educational VR development (Pantelidis, 2010), our objective was to create a modified, ecologically valid version of the Cyberball paradigm (Williams, 2001) adapted for VR environments.

Fig. 1. Screen capture of the virtual environment designed for preadolescents

While the original Cyberball paradigm employs a minimalistic ball-tossing task to simulate social exclusion, our VR adaptation situates participants in a naturalistic conversational setting, thereby enhancing ecological validity and emotional salience. Participants are immersed in a virtual classroom, engaging with two same-age peer avatars in scenarios designed to simulate realistic experiences of being included or excluded in a group conversation. This shift enables the investigation of social and psychological dynamics in a manner more reflective of everyday peer interactions (Prendergast & Schubert, 2020; Wirth et al., 2010).

The Current Study

To summarise, Cyberball, as a 2D paradigm, has inherent limitations regarding realism, immersion, social presence and levels of engagement, whereas, on the contrary, VR offers potential advantages due to its ability to create more realistic social situations, thus enhancing its ecological validity (Parsons, 2015). From a theoretical standpoint, the perceived realism of a virtual environment is closely linked to emotional immersion: higher visual, behavioural, and social realism increase the sense of presence, which in turn amplifies affective and cognitive responses to social interactions (Slater & Sanchez-Vives, 2016; Cummings & Bailenson, 2016). In the context of social exclusion, greater immersion enhances the credibility of rejection cues, strengthening the validity of the elicited

emotional reactions (Triberti et al., 2018; Fraser et al., 2022). Accordingly, by enhancing realism and social presence, the current VR paradigm aims to elicit exclusion responses that more closely approximate those observed in authentic school interactions. Furthermore, as previously stated, endeavours to transform the 2D Cyberball model into a 3D one did not demonstrate any substantial variation in terms of unfavourable outcomes due to the absence of social presence features and poor social interaction among players (Kassner et al., 2012). As stated before, our research is different and novel as it focuses on investigating social exclusion in VR by simulating a group conversation scenario at school, drawing inspiration from previous literature that used group conversations to assess social exclusion in adults (Prendergast & Schubert, 2020). The development of the new paradigm originates from the limitations of Cyberball, particularly with regard to its simplistic graphic design (low visual realism), the limited manipulation of variables inside and outside the interaction (restricted experimental control), the minimal perceived social interaction (absence of authentic social cues), and the reduced effectiveness of the task in simulating real experiences of social exclusion (overly abstract gameplay; Tuijnman et al., 2021). According to the literature, the virtual experience offering high ecological validity and social presence is an incentive for more interaction, particularly for young users (Parsons, 2015). In turn, it confers a higher level of attention and emotional responses compared to traditional experimental tools and methodology (Triberti et al., 2018). Accordingly, we sought to validate the effects of the VR paradigm by comparing it with the Cyberball paradigm and to examine differences in participants' reported feelings of exclusion. Rather than merely replicating the Cyberball effects, our intention was to benchmark the newly developed paradigm against a well-established experimental model, thereby verifying that it elicits the expected exclusion-related emotional responses while extending these to a more ecologically valid and educationally relevant context. In this sense, the comparison serves as a methodological validation step rather than an attempt at duplication. Experimental investigations already known in the literature indicate that the Cyberball paradigm elicits immediate negative reactions to social exclusion, including nervousness and frustration, which threaten psychological needs such as self-esteem

(Williams & Nida, 2016; Prendergast & Schubert, 2020). Our study, therefore, reframes this investigation within the broader context of educational psychology and VR research, focusing on the role of immersive environments as tools for examining and eventually mitigating social exclusion in schools.

The main research question of this study, therefore, is to determine whether our newly implemented VR paradigm can replicate the effects of the original Cyberball paradigm and, thereby, validate its effectiveness. Given the qualitative nature of this investigation, we articulated the following exploratory expectations: (a) the 3D VR paradigm would evoke stronger perceptions of realism and social presence compared with Cyberball; (b) both paradigms would successfully elicit feelings of exclusion, but emotional expressions and reflections would be richer and more elaborated in VR responses; and (c) adolescents would report more complex and intense emotional reactions than children, consistent with developmental evidence of heightened sensitivity to peer evaluation (Sebastian et al., 2010; Somerville, 2013). These expectations guided the thematic analysis and interpretation of participants' narratives across paradigms and age groups.

Method

Participants and Procedure

The research was approved by the Institutional Ethical Committee board of the University of Bologna (protocol number 0001227). Informed consent was obtained from all participants and their parents or legal guardians. Participants first provided informed assent, while their parents or legal guardians subsequently provided informed consent. Students with intellectual, physical and emotional disabilities (based on parental report in terms of ICD diagnoses) were excluded from the study. This decision was made based on considerations such as inability to understand task instructions, inadequate motor/visual skills for reliable measurement, or potential harm resulting from the exclusion manipulation, especially in cases of children with anxiety problems. While this ethical decision was intended to ensure participants' well-being and prevent distress, it inevitably limits the inclusivity and generalisability of the findings. Excluding children with disabilities or additional

learning needs may have reduced the representativeness of the sample, particularly given that social exclusion experiences can be especially salient for neurodiverse or socially vulnerable groups (Humphrey & Symes, 2010; Kasari et al., 2011). Therefore, the present results should be interpreted as reflecting the reactions of typically developing children and adolescents, with future research encouraged to adapt and test similar paradigms in more inclusive samples. This sampling plan aimed to ensure scientific rigour and ethical integrity in the study.

Students aged 8–16 years were recruited through collaboration with three schools, whose headmasters had previously been engaged in research projects with the University of Bologna. After obtaining the schools' approval, informed consent was sought from the parents or legal guardians of the children and adolescents. Participating classes were chosen randomly. A minimum of one class per grade participated, each consisting of at least 15 students. For the final debriefing and group discussion, each participating class formed a group, for a total of eight classes: two at primary school (17 students each), three at secondary school (20 students each), and three at high school (18-19 students each). Upon completion of the recruitment plan, we obtained a total of 150 participants aged 8–16 years (M=12.54; SD=2.14), of whom 76 were children (8-12 years; 50.7%), 74 adolescents (13-16 years; 49, 3%); 79 were male (52.7%) and 71 female (47.3%). Of these participants, 147 participants were born in Italy (98%). Furthermore, measuring socioeconomic level using the Economic, Social, and Cultural Status (ESCS) indicator (Campodifiori et al., 2010), 88 participants had a high socioeconomic status (58.7%), 60 participants had a medium socioeconomic status (40%) and 2 participants had a low socioeconomic status (1.3%). The students were not informed about the manipulation of social exclusion beforehand. However, they were informed that active participation in a conversation with two virtual classmates from other schools was required. Participation involved experiencing the Cyberball paradigm on one day and the VR environment the next, with the order counterbalanced across participants. Before the termination of the experiment, an inclusion condition of the same paradigm was assessed to neutralise any deception that the experience of social exclusion may have engendered. At the end of the overall experiment, all students were debriefed in a classroom

group context on the purpose of the experiment and the manipulation of social exclusion within Cyberball and VR. During the debriefing, all participants were involved in a final group discussion aimed at collecting students' feedback on the 3D VR paradigm's level of overall realism and how to improve it (e.g., graphic or sound issues, etc.). The insights derived from these group discussions facilitated an in-depth investigation into the ecological validity and realism levels of our 3D VR paradigm, in the context of literature on the utilisation of VR in educational settings (Pantelidis, 2010). This insight also contributed to answering the central research question of the current study (i.e., whether our 3D VR paradigm is effective in assessing social exclusion in a school sample). A one-hour discussion was conducted in each class to explore students' perceptions of the 3D VR paradigm's realism, during which students were invited to express their thoughts and opinions. The discussion was led by the first author and a student intern trained to collect data from this study. In each classroom, a classroom teacher was requested to be present during the group discussion and to act as moderator, based on their deeper relationship with the students. During the group discussion, the leaders and the teacher sought to establish an atmosphere of comfort and relaxation, to ensure that all participants felt secure in expressing their thoughts and opinions. Furthermore, leaders and teachers ensured that all students had the opportunity to express their thoughts and opinions, and that students were not monopolising the conversation. At the end of each discussion, students were invited to provide anonymous written responses to a final open-ended question aimed at collecting individual feedback on the VR paradigm's realism and potential improvements. The final open-ended question was provided and stored anonymously to ensure that all participants could share feedback in a free and safe manner.

Cyberball Paradigm: At the commencement of the online experiment, participants were informed that they would be engaged in a ball-passing game with two other real peers from a different school in the same region. Cyberball (Williams, 2001) is a brief online ball-tossing task used to simulate social inclusion and exclusion. Within the framework of this experiment, both the exclusion and inclusion conditions were designed to span five minutes, encompassing a total of 80 trials. The

participants' incoming ball throws were initiated by the other players at predetermined intervals, and the ball was passed to one of the two players via the right and left arrows. The tosses from the other players were preceded by a random jitter interval ranging from 100 to 400 milliseconds, with a two-second delay preceding each throw.

In the exclusion condition, participants received the ball only twice at the beginning, whereas in the inclusion/neutral condition, they received the ball one-third of the overall trials (therefore 17 times). As a 2D paradigm, Cyberball was presented on a regular computer screen.

VR Paradigm: After entering a virtual classroom and exploring the space for about two minutes to familiarise and acclimatise with it, participants had the opportunity to interact with two other students. The conversation began with a greeting, after which participants were invited to share a school activity in which they had participated. In the exclusion condition, the virtual avatars are designed to ignore participants' input following a pre-set script systematically. In contrast, in the inclusion condition, the avatars respond in a way that engages the students. Both conditions last approximately five minutes, and the overall paradigm, including input, orientation and interaction, does not exceed ten minutes.

Development of the 3D VR paradigm

The virtual classroom was developed using the Unity platform and deployed on the Oculus Quest 2 headset, selected for its high-resolution display, built-in audio, and hand-tracking capabilities, which enhance user immersion and interactivity (Fig. 2). The classroom setting includes typical school furnishings (e.g., desks, blackboard), and participants are positioned centrally alongside the two avatars to ensure standardisation across sessions (Fig. 3). Three pairs of avatars (male and female) were created to represent participants from three developmental stages: middle childhood (ages 8–10), early adolescence (11–13), and middle adolescence (14–16). Each pair was visually tailored to age-specific characteristics in body shape, attire, and facial features.

Fig. 2. Screen capture of the virtual classroom

Fig. 3. Screen capture of the virtual avatars collocation

Six age-appropriate interaction scripts—three depicting inclusion and three exclusion—were developed to simulate peer dialogue by encouraging or denying social engagement. Voice synthesis tools were employed to generate age-appropriate vocal stimuli, and scripts were structured to produce a sense of either exclusion (e.g., being ignored or left out of the conversation) or inclusion (e.g., being addressed and asked questions).

In support of naturalistic verbal interactions, the avatars were programmed with a combination of static and motion animations. Static animations (e.g., breathing, minor posture shifts) ran continuously to simulate neutral behaviours and avoid artificial stillness. Motion animations, on the other hand, were context-sensitive and coordinated with script content to convey 24 distinct emotional states (e.g., enthusiasm, shyness, satisfaction). The timing and type of animation were synchronised with the corresponding audio files to ensure congruence between verbal and non-verbal communication.

Two key features were implemented to enhance social realism. First, a responsive dialogue system allowed avatars to wait for participants' spoken responses at designated points in the conversation, based on real-time vocal input rather than pre-programmed intervals. This approach mitigates awkward silences and fosters a more natural turn-taking experience. Second, an ambient sound detection system enabled avatars to orient toward the participant in response to auditory stimuli (e.g., speech or movement sounds), reinforcing indifference in the exclusion condition and attentiveness in the inclusion condition. These design choices were informed by team-based theoretical discussions on social behaviour and were intended to reproduce authentic interaction dynamics within the constraints of a controlled experimental environment.

Ethical and cyber-security issues

The development of the VR paradigm was guided by ethical and cybersecurity considerations, particularly with regard to user safety, data protection, and psychological well-being. To minimise the risk of cybersickness—a form of motion-induced discomfort associated with VR—no moving elements were included in the environment aside from the avatars. Participants retained full control over their field of vision and were permitted limited movement within a defined space, reducing the potential for sensory mismatch and disorientation (Chardonnet et al., 2015; Jaeger & Mourant, 2001).

The virtual environment was designed to balance immersive realism and psychological comfort. Overly lifelike or emotionally intense stimuli were avoided to reduce the likelihood of distress (Chang et al., 2020). Importantly, the VR application was run in offline mode, and no personal

data was collected or stored, thereby ensuring participant anonymity and data security. Informed consent was obtained from all participants and their legal guardians (where applicable), with clear communication regarding their rights and the study's procedures.

To address the potential adverse emotional effects of simulated exclusion, all participants were subsequently exposed to a social inclusion scenario, implemented using the same VR framework. In this phase, avatars actively engaged the participant by posing questions and responding appropriately, thereby providing a reparative social experience following the exclusion condition.

Measures

The experiment's comprehensive design incorporated quantitative metrics aimed at assessing mood and frustration levels before and following each exclusion condition. Nevertheless, the primary objective of this study is to validate our VR paradigm through the analysis of participants' feelings of exclusion. Hereto, data were collected on three occasions. As for the first and second occasion, after each experimental condition, participants were prompted to express their opinion on each paradigm, using two single open-ended questions (e.g., "What did you like/dislike about the game?"; see open-ended questions in Supplementary Material) aimed to measure participants' feeling of being excluded to check the paradigms' effectiveness and usability for our purpose, as literature indicated it as the best way to measure it (Pantelidis, 2010). Lastly, all participants were debriefed about the study aim and exclusion manipulation, and all of them were then included in a follow-up group discussion aimed at understanding participants' perceptions of the usability, strengths and weaknesses of the 3D VR paradigm. Then, following the conclusion of the group discussions, the participants were invited to submit their thoughts and opinions in the form of an open-ended response, representing the third occasion of data collection. The responses provided by the participants to each of the open-ended questions were entered by the participants in Qualtrics (a specific and professional platform for questionnaires; First release: 2005, Provo, Utah, USA, available at: https://www.qualtrics.com). Group discussions were not recorded, as the institution did not provide consent for the recording of students. However, they followed a predefined script prepared for the final debriefing (see

Supplementary Material) and concluded with the open-ended question inviting all students to provide written feedback.

Data Analysis

An inductive, reflexive thematic analysis (Braun & Clarke, 2019) was conducted using NVivo14 (a specific and professional platform used for qualitative analyses, available at: https://lumivero.com) to explore participants' subjective experiences of social exclusion within both the Cyberball and 3D VR paradigms. A second thematic analysis was conducted to explore participants' feedback on the 3D VR paradigm collected in the group discussion after the final debriefing. An initial coding process was undertaken, which involved the creation of codes that closely adhered to the text. This resulted in a substantial number of codes. During the coding process, some very broad categories were identified to create a first, very basic categorisation of codes. Following the coding process, these extensive categories were addressed individually, with the codes being reorganised into themes using a recursive approach that involved revisiting the text. A preliminary thematic structure was discussed with two independent coders (the first author and a student intern extensively trained in school psychology and qualitative methods). This method was chosen for its flexibility and suitability in capturing the nuanced emotional and cognitive responses of children and adolescents across both immersive environments.

Open-ended responses to the prompt "What did you like/dislike about the game?" were imported from Qualtrics and analysed in NVivo. Responses were then segmented into meaningful units based on expressions of positive or negative valence. Subsequently, data from the first thematic analysis were grouped by paradigm (Cyberball or 3D VR) and age (children or adolescents) to explore potential age-related differences in perceived social exclusion.

Analytic decisions were guided by our developmental framing and the study's blinded design: since participants were unaware that the task involved social exclusion, we organised responses under the prompts "What did you like?" and "What did you dislike?". This structure enabled us to capture both positive and negative reactions while minimising coder bias related to the exclusion hypothesis.

Reflexivity was maintained throughout coding discussions, with researchers acknowledging that interpretation was informed by the existing literature on peer exclusion (e.g., Abrams et al., 2011; Williams & Nida, 2016) and on children's emotional expression and regulation (Crone & Dahl, 2012). Bias control was further addressed by independently coding a subset of responses, followed by collaborative review between the two coders to refine and reconcile interpretative differences (Nowell et al., 2017).

Theme development proceeded through several iterative stages. Initially, individual meaning units were merged into descriptive codes, which were then grouped into sub-themes based on conceptual similarity. Sub-themes were subsequently reviewed, refined, and collapsed into broader, overarching themes to ensure internal coherence and distinctiveness (Braun & Clarke, 2021). Theme saturation was achieved when additional data failed to yield new conceptual insights or modify the thematic structure. This iterative process facilitated depth, reflexivity, and alignment between emergent patterns and the study's developmental and contextual focus (Terry et al., 2017).

The two independent coders conducted the initial round of open coding, during which preliminary codes were generated based on recurring semantic content. These included affective responses (e.g., "feeling ignored," "liking the game"), perceptual feedback (e.g., "realistic environment," "unrealistic animations"), and interpersonal perceptions (e.g., "avatars were rude," "enjoyed talking"). Inter-rater agreement was calculated on 25% of the dataset using Cohen's Kappa and reached an acceptable threshold of $\kappa = .82$.

Following coding, the data were organised into broader categories through thematic clustering, with themes such as "Negative Feelings", "Interactive Features", "VR Features", and "Realism". For instance, the theme "Exclusion" captured statements referring to emotional reactions to being left out (e.g., "I didn't like not getting the ball", "They ignored me when I spoke"). A comparative thematic structure was applied to both paradigms to assess differences in emotional valence, perceived realism, and social dynamics.

Finally, group discussion data from the final debriefing were analysed in NVivo to triangulate findings and identify additional insights into usability and perceived effectiveness of the VR paradigm. These discussions were thematically analysed using the same procedure, with particular attention to concerns about realism (i.e., voice synthesis, animation fluency, and conversational content) and its effect on the credibility of the exclusion experience. Data provided by the second thematic analysis were grouped by school level corresponding to the three aforementioned 3D VR levels developed (i.e., primary, secondary, and high).

The results will firstly delineate the themes related to positive and negative themes raised by the responses given by participants to the open-ended questions following both the Cyberball and VR paradigms, and subsequently, the themes raised by the feedback provided by participants on the group discussion about the 3D VR paradigm. Overall, this qualitative strategy enabled a rigorous exploration of participants' reactions to both paradigms, highlighting not only the emotional impact of social exclusion but also the differential affordances of 3D immersive environments in eliciting such experiences.

Results

Results collected immediately after the peer exclusion simulation with Cyberball and VR show that, overall, most participants perceived the expected feeling of exclusion in each paradigm. Subsequently, through thematic analysis, all comments were coded and organised into categories to evaluate the paradigms' effectiveness. To assess participants' perceptions of exclusion and usability across both paradigms, qualitative responses were grouped into themes and subthemes, as reported in Tables 1–11.

Table 1. Inductive themes raised by children's responses to the question "What did you like about the game?" after the Cyberball paradigm

Theme	Subtheme	N	Description	Representative Quotes
Positive feelings	Fun	1	Students enjoyed the paradigm	"I had fun"
	Being indifferent	1	Students liked that they did not have to do anything	"I enjoyed that I had nothing to do"
Playing features	Beginning	25	Passing the ball at the beginning	"I liked that at the beginning they passed me the ball"
	General features	11	The game itself/playing online	"I liked playing online"
Visual features	Avatars	1	Visual features of the avatars	"I enjoyed the avatars"
	Looking at the names of other players	1	Students could look at the names of the two avatars	"I liked that other players' names were displayed on the screen"
	The ball	3	The graphic of the ball	"I liked the marks on the ball"
Interactive features	Inclusion	2	Being included/ integrated at the beginning	"I liked that at the beginning, I felt I was attending the game"
	Real interaction	3	Interacting with other (real) players	"I enjoyed interacting a bit with the others"
	Acting involvement	6	Playing with others and being involved	"I liked it when we played altogether"
	Passive involvement	1	Watching other players playing	"I enjoyed looking at them playing"
Everything		4	Students enjoyed everything	"I enjoyed everything"
Nothing		8	Students enjoyed nothing	"I did not enjoy anything"

Table 2. Inductive themes raised by children's responses to the question "What did you dislike about the game?" after the Cyberball paradigm

Theme	Subtheme	N	Description	Representative Quotes
Negative feelings	Exclusion	16	Being ignored, excluded, or not considered/involved	"I did not feel involved in the game, and so I felt excluded"
	Internalising symptoms	1	Feeling sad, lonely, or invisible	"I felt like I was not existing"
Playing features	Stop playing	39	No longer receiving the ball	"I did not like the game because after the beginning, I did not receive the ball anymore"
	Not playing	1	Playing too little or not at all	"I did not like that, basically, I did not even attend the game"
	Nothing to do	1	Standing without doing anything	"I did not enjoy that I was standing without doing anything"
Visual features	Graphical features	2	Visual features of the game	"I did not like the graphics of the game"
Interactive features	Players features	33	Avatars' attitude	"The other players did not allow me to play"
	Lack of interaction	1	Few or no chances to interact with the others	"I did not like not being able to interact with the others"
Psychological implications	Realistic situation	1	Students felt like the situation was real	"The situation seemed to me very realistic"
Nothing		1	Students disliked nothing	"I did not dislike anything"

Table 3. Inductive themes raised by adolescents' responses to the question "What did you like about the game?" after the Cyberball paradigm

Theme	Subtheme	N	Description	Representative Quotes
Positive feelings	Fun	3	Having fun at the beginning	"The first moments were quite funny"
	Being indifferent	1	Students liked that they did not have to do anything	"I could rest while they were playing"
Playing features	Beginning	11	Passing the ball at the beginning	"I liked it when at the beginning they were passing me the ball"
	General features	11	The game itself/playing online	"I liked the game itself, that you could pass the ball"
Visual features	Design	3	General features of the graphics	"I enjoyed the light design"
Interactive features	Inclusion	8	Being included/ involved at the beginning	"I liked that at the beginning, everyone was involved in the game"
	Real interaction	3	Interacting with other (real) players	"I enjoyed the idea of virtually playing with other people"
	Acting involvement	3	Playing with others	"I liked to play with other people"
Psychological implications	Ethical considerations	1	Being better mates than the other players	"I enjoyed that I behaved better than them, who were behaving badly towards me"
	Social exclusion	1	Reflecting on social exclusion	"I liked the aim of the game to think about how you feel when you are excluded"
Nothing		15	Students enjoyed nothing	"To be honest, I think there was nothing I enjoyed"

Table 4. Inductive themes raised by adolescents' responses to the question "What did you dislike about the game?" after the Cyberball paradigm

Theme	Subtheme	N	Description	Representative Quotes
Negative feelings	Exclusion	34	Being ignored, excluded, or not considered/involved	"I did not like that I felt totally excluded from the game"
	Internalising symptoms	4	Feeling sad, lonely, or invisible	"I did not like to be a soul in an empty space, it seemed very sad"
	Boredom	5	Feeling the game is boring	"Then it became very boring and then I got distracted by thinking about something else"
Playing features	Stop playing	16	No longer receiving the ball	"I would have preferred to receive the ball a bit more frequently"
	Not playing	2	Playing too little or not at all	"I did not like to take part in a game in which I had not actually played"
	Nothing to do	3	Standing without doing anything	"I did not enjoy that I could not do anything"
Interactive features	Players features	25	Avatars' attitude	"The other players pass the ball only among each other"
	Lack of interaction	5	Few or no chances to interact with the others	"I did not like not being able to interact with the others"
Psychological implications	Realistic situation	4	Students felt like the situation was real	"I felt the situation was realistic because sometimes it happens to me"
	Exclusion planned	2	Designed exclusion moments	"I did not like the attempt to simulate a real life situation that you often experience, not comparable to a virtual environment"
Nothing		1	Students disliked nothing	"Everything was normal"

Table 5. Inductive themes raised by children's responses to the question "What did you like about the game?" after the VR paradigm

Theme	Subtheme	N	Description	Representative Quotes
Conversational features	Talking	10	Talking to other students	"I enjoyed communicating with them"
	Not talking	1	No need to be involved in the conversation	"I liked that they did not talk to me"
	Beginning	5	How the conversation started	"I enjoyed that they provided me with questions at the beginning"
	Topics	5	Topics and experiences that students shared	"I liked that they shared interesting experiences"
VR features	Avatars	1	Looking at the avatars	"I enjoyed that we could see each other"
	Graphic features	14	The overall virtual environment	"I liked the graphic and the environment surrounding me"
	Technical tools	2	Using the VR headset	"I enjoyed because I neved had tried a VR headset before"
Interactive features	Sharing	7	Meeting other students and get to know their experiences	"I enjoyed getting to know what the other students did at school"
	Real interaction	15	Interacting with other (real) players	"I liked to interact and talk with other students"
	Passive involvement	6	Listening to other students	"I enjoyed listening to the other children"
Realism	Realistic environment	2	Feeling like in a realistic environment/ situation	"I like VR because it seemed realistic to me"
Playing features	General features	2	The game itself	"I enjoyed how the game has been developed"
Psychological implications	Reflection about social exclusion	1	Understanding what being excluded means	"I enjoyed to understand what being excluded means"
	Realistic situation	1	Feeling the experience as real	"The experience seemed to me as in real life"
Everything		12	Students enjoyed everything	"I enjoyed everything"
Nothing		1	Students enjoyed nothing	"I did not enjoy anything in that environment"

Table 6. Inductive themes raised by children's responses to the question "What did you dislike about the game?" after the VR paradigm

Theme	Subtheme	N	Description	Representative Quotes
Negative feelings	Exclusion	17	Being ignored, excluded, or not considered	"I did not like to feel excluded"
	Self-blaming	1	Feeling uninteresting and having nothing to share	"I understood they were not interested in my topic, but only to math and science labs"
	Internalising symptoms	5	Negative feelings during situations (e.g., feeling invisible)	"I did not like that they ignored me as if I did not exist or I was not there"
Conversational features	Stop talking	3	No longer talking after the beginning	"I did not like how, after the beginning, they only talked among each other"
	Unable to speak	10	Not being allowed to speak	"I did not like not being able to talk with the other students and not being achieved to join the conversation"
	Unable to act	1	Now knowing what to do or say, or how to behave	"I did not enjoy talking because I was unsure about what I wanted to say"
VR features	Graphical features	2	The overall virtual environment	"I did not like the graphic"
	Avatars	2	Avatars' features	"I did not like how avatars were moving"
Interactive features	Players features	13	Avatars' attitude	"The other players only talked among each other and did not talk to me"
	Lack of interaction	8	Inability to interact with others or lack of engagement from others	"I did not like that they were not interacting with me"
Nothing		5	Students disliked nothing	"I did not dislike anything"

Table 7. Inductive themes raised by adolescents' responses to the question "What did you like about the game?" after the VR paradigm

Theme	Subtheme	N	Description	Representative Quotes
Conversational features	Talking	3	Talking to other students	"I enjoyed sharing my own experience"
	Not talking	2	No need to be involved in the conversation	"I liked that I had not to talk too much"
	Beginning	5	How the conversation started	"At the beginning, they provided me with some questions"
	Topics	5	Topics and experiences that students shared	"Nevertheless, the topics they shared were very interesting"
VR features	Graphic features	20	The overall virtual environment	"I liked how the classroom has been built in the virtual environment"
	Technical tools	4	Using the VR headset	"I enjoyed to try a VR headset for the first time"
Interactive features	Sharing	8	Meeting other students and get to know their experiences	"I was interested in getting to know what the other students did at school"
	Real interaction	7	Interacting with other (real) players	"It was interesting to interact with other peers in a virtual environment"
	Passive involvement	5	Listening to other students	"I anyway enjoyed listening to their experiences"
Realism	Realistic environment	4	Feeling like in a realistic environment/ situation	"I like that the environment seems quite realistic"
Positive feelings	Fun	1	Having fun	"I had a lot of fun"
Psychological implications	Experience	3	Experiencing a new situation	"It has been something new for me that I never had experienced"
	Aim of the paradigm	2	Appreciating what the paradigm is developed for	"It was a very nice idea"
Nothing		3	Students enjoyed nothing	"I did not enjoy anything in that environment"

Table 8. Inductive themes raised by adolescents' responses to the question "What did you dislike about the game?" after the VR paradigm

Theme	Subtheme	N	Description	Representative Quotes
Negative feelings	Exclusion	25	Being ignored, excluded, or not considered	"I felt quite excluded"
	Boredom	2	Getting bored during other students' conversations	"It was boring to listen avatars' conversation"
	Internalising symptoms	6	Negative feelings during situations (e.g., feeling invisible)	"I felt like a ghost"
Conversational features	Stop talking	1	No longer talking after the beginning	"In the end I did not feel part of the conversation anymore"
	Unable to speak	3	Not being allowed to speak	"I did not enjoy to have not been able to communicate with them later on"
	Topics	3	Lack of interest in other students' topics shared	"I did not enjoy speaking about topics which I had much to speak about"
VR features	Sounds	1	Unrealistic or weird voices	"The avatar voice changed every time"
	Avatars	2	Avatars' movements	"The avatar performed weird gestures"
Interactive features	Players features	29	Avatars' attitude	"I did not like how the other students behaved with me"
	Lack of interaction	6	Inability to interact with others or lack of engagement from others	"The others did not interact with me, instead they were interested only on each other"
	Lack of questions	1	Avatars did not provide any other questions	"I was a bit sorry when they did not provide me anymore with other questions"
	Uninterest in participants' topics	3	Avatars were not interested in participants' topics	"They seemed not very interested in my topic"
	Being unheard	2	Avatars were not listening to participants	"I felt unheard and not taken into account"
Realism	Lack of realism	5	The environment did not seem realistic	"I did not like it because it did not seem realistic"
Psychological implications	Being unsure	3	Not recognising oneself in the situation	"I did not like it because I did not recognise myself, I usually speak easily with other people, but the first time I had the conversation with them I felt very shy"
	Uninteresting situation	1	Considering the experience uninteresting	"I was not very interested"

	Unable to act	6	Not knowing what to do, say, or how to act	"I did not know if I had to interrupt them or not"
	Aim of the paradigm	1	Deliberately designed exclusion situations	"I did not enjoy the exclusion feeling simulated on purpose"
	Being observed	1	Playing with others in a virtual environment while the experimenter observes	"I did not enjoy speaking loudly in the virtual world with another person witnessing in the real room"

Table 9. Inductive themes raised by primary school feedback comments after the group discussion

Theme	Subtheme	N	Description	Representative Quotes
Avatar features	General changes	9	General improvements' suggestions for avatars	"Avatars need to be improved"
	Avatars' movements	5	Improvements of avatars' movements	"Don't perform too many gestures"
	Avatars' names	1	Changing avatars' names	"Change names"
	Different avatars	1	Provide different avatars for each simulation	"Change avatars' characters every time someone plays"
	Participants' avatar	1	Providing participants with their own avatar	"You should choose your avatar"
Conversational features	More talking	5	Allowing participants to talk more by reducing the avatars' speech	"They should speak less"
	Terminology	3	Making terminology more suitable for their age	"According to me, you should change the way they speak, because they use adjectives that our generation's children would not have used"
	Topic	5	Choosing topics more suitable for their age	"I would change the conversation among the avatars"
Visual features	Graphical features	13	Modifying or improving the virtual environment (graphics, specific elements, and resolving technical issues)	"Provide a better graphic"
Sound features	Voice improvement	22	Improve the avatars' artificial voices	"The voice was too loud"
	Voice changing	4	Change the avatars' voices by using real students' records	"I would have placed real people's voices recorded"
Guidelines	Instruction changing	2	Changing the instructions (e.g., not pretending to look for available students via a smartphone)	"Looking at the smartphone when receiving notifications"
Nothing		3	Nothing to change	"I found everything realistic"

Table 10. Inductive themes raised by secondary school feedback comments after the group discussion

Theme	Subtheme	N	Description	Representative Quotes
Avatar features	General changes	6	General improvements' suggestions for avatars	"More realistic avatars"
	Avatars' movements	10	Changing or improving the avatars' movements (making them lighter or less active)	"Movements were not overall realistic and maybe they were a bit repetitive"
	Avatars' attitude	4	Making the avatars less enthusiastic and extroverted	"You could understand they were fake also because of the too much enthusiasm they put, they started talking soon"
	Participants' avatar	2	Providing participants with their own avatar	"I would think that each participant should have its own avatar to talk"
Conversational features	More talking	5	Allowing participants to talk more by reducing avatars' speech	"I could have talked more"
	Terminology	4	Making terminology more suitable for their age	"Using another type of language"
	Topic	1	Choosing topics more suitable for their age	"I would try to communicate talking about my real-life topics"
	Exclusion	1	Changing the exclusion method (e.g., being explicit and responding "I don't care about your topic")	"You could make them to tell us to shut up because what you say is not interesting"
	Waiting time	1	Reducing responses' waiting time	"Maybe not allowing to wait for a long time before answering"
	Questions	1	Change the questions	"They were asking quite general questions"
Visual features	Graphical features	19	Modifying or improving the virtual environment (graphics, specific elements, and resolving technical issues)	"You should change the graphic for sure because it is very awful"
	Characters	2	Including other avatars in the classroom (e.g., teachers or other students)	"Add teachers who listen but who do not talk with us"
Sound features	Voice improvement	17	Improve the avatars' artificial voices	"I would have provided avatars with more realistic voices because I perceived their voice was robotic"
	Voice changing	8	Change the avatars' voices by using real students' records	"Maybe it would be better to record the voices of real same-age peers so that we can trust it more"
Guidelines	Instruction changing	2	Allowing participants to move more within the virtual environment	"Having more chances to move"
Nothing		6	Nothing to change	"Nothing, everything seems to me very realistic"

Table 11. Inductive themes raised by high school feedback comments after the group discussion

Theme	Subtheme	N	Description	Representative Quotes
Avatar features	General changes	11	General improvements' suggestions for avatars	"More realistic avatars"
	Avatars' movements	13	Changing or improving the avatars' movements (making them lighter or less active)	"I would try to make characters' movements more natural"
	Avatars' attitude	8	Making the avatars less enthusiastic and extroverted	"I honestly think I immediately noticed it was not real because characters started talking immediately, and I do not think someone who should talk with the other two unknown people starts speaking this way"
	Avatars' names	1	Changing the avatars' names	"I would change the name of the avatars in less typical names so that you can think there are real people to interact with you"
Conversational features	Avatars referring to each other	1	Avoiding the avatars addressing each other by name	"The other two characters were addressing to each other by using their names, while they never said mine"
	Terminology	12	Making terminology more suitable for their age	"The avatars should use a different language"
	Topic	7	Choosing topics more suitable for their age	"I would add topics more suitable for our age"
	Exclusion	5	Changing the exclusion method (e.g., being explicit and responding "I don't care about your topic")	"Make participants understand that avatars are not interested to what it says"
	Waiting time	1	Reducing responses' waiting time	"Provide more time to reply to each student in order to make it seem more realistic"
	Questions	3	Change the questions	"I would try to make avatars ask for another little question to the excluded person, so

				that it does not seem they are excluding you on purpose"
Visual features	Graphical features	10	Modifying or improving the virtual environment (graphics, specific elements, and resolving technical issues)	"I would have changed the virtual classroom, as it seemed too fake"
Sound features	Voice improvement	14	Improve the avatars' voices	"I would improve voices' quality, they look very robotic"
Guidelines	Instruction changing	2	Being alone in the room without the researcher	"I would have preferred to being alone in the room because I would have feel better to interact with the virtual students"
Nothing		9	Nothing to change	"I do not know, it seemed to me already enough realistic"

Overview of themes

Across both paradigms and age groups, thematic analyses revealed a consistent structure comprising the following main themes: *Positive feelings*, *Negative feelings*, *Playing features*, *Visual features*, *Interactive features*, *Conversational features*, *VR features*, *Realism*, and *Psychological implications*. Within these themes, participants' responses were further categorised into subthemes (e.g., *Exclusion*, *Internalising symptoms*, *Real interaction*, *Graphical features*). This shared thematic structure facilitated comparison across paradigms, while the group discussion data (second thematic analysis) revealed additional main themes, including *Avatar features*, *Sound features*, *Visual features*, *Conversational features*, and *Guidelines*. The frequencies reported for specific codes or themes are presented as illustrative counts of participants' responses. These frequencies serve to indicate the relative salience of themes within the dataset rather than to support inferential or quantitative comparisons between groups (Maxwell, 2010; Sandelowski, 2001).

Cyberball paradigm

Children expressed six positive and six negative themes. The most prominent positive theme was Playing features, reported by 36 children (47.4%). This theme included the subthemes *Beginning*

(31.6%), reflecting that children enjoyed being included at the start (e.g., “I liked that they passed me the ball at the beginning.”), and *General features* (14.5%), referring to the appeal of playing online (e.g., “I liked playing online.”). Visual features were mentioned by three participants (3.9%) and included *The ball* (3.9%), referring to appreciation of its markings (e.g., “I liked the marks on the ball.”), *Avatars* (1.3%), and *Player names* (1.3%), as some enjoyed these visual elements (e.g., “I enjoyed the avatars.”, “I liked that other players’ names were displayed on the screen.”). Interactive features also emerged (15.8%), including *Real interaction* (3.9%; e.g., “I enjoyed interacting a little with the others.”) and *Acting involvement* (7.9%; e.g., “I liked it when we played altogether.”).

Children also reported strong negative reactions, with exclusion-related themes dominating. The most cited negative theme was Playing features (54.2%), particularly *Stop playing* (51.3%; e.g., “I did not like the game because I did not receive the ball anymore after the beginning.”). Negative feelings were reported by 17 children (22.4%), including *Exclusion* (21.1%; e.g., “I did not feel involved in the game, and so I felt excluded.”) and *Internalising symptoms* (1.3%; e.g., “I felt like I was not existing.”). Within Interactive features, *Avatars’ attitude* was criticised by 43.4% (e.g., “The other players did not allow me to play.”). Finally, Psychological implications appeared in isolated comments referring to the experience as a *realistic situation* (e.g., “The situation seemed to me very realistic.”).

Among adolescents, five positive and seven negative themes were identified. The primary positive theme remained Playing features (37.8%), including *Beginning* (14.5%; e.g., “I liked it when they were passing me the ball at the beginning.”) and *General features* (14.5%; e.g., “I liked the game itself, that you could pass the ball.”). Visual features included the subtheme *Design* (3.9%; e.g., “I enjoyed the light design.”). Interactive features were also appreciated (7.9%), encompassing *Real interaction* and *Acting involvement* (e.g., “I liked to play with other people.”). Finally, under Psychological implications, adolescents mentioned *Social exclusion* (e.g., “I liked the aim of the game to think about how you feel when you are excluded.”).

Negative feedback was strong, with Negative feelings dominating. The subtheme *Exclusion* was most frequent (44.7%; e.g., "I did not like that I felt totally excluded from the game."), followed by *Internalising symptoms* (5.3%; e.g., "I did not like to be a soul in an empty space, it seemed very sad."). Playing features included *Stop playing* and *Not playing* (18%; e.g., "I did not like to take part in a game in which I had not actually played."). Interactive features involved *Avatars' attitude* (32.9%) and *Lack of interaction* (6.6%; e.g., "The other players pass the ball only among each other."). Finally, Psychological implications again appeared in references to a *realistic situation* (e.g., "I felt the situation was realistic because sometimes it happens to me.").

VR paradigm

For children, seven positive and six negative themes emerged. The most frequently endorsed positive theme was Interactive features, cited by 28 children (36.8%), including subthemes such as *Real interaction* (19.7%; e.g., "I liked to interact and talk with other students."), *Sharing* (9.2%; e.g., "I enjoyed getting to know what the other students did at school."), and *Passive involvement* (7.9%; e.g., "I enjoyed listening to the other children."). VR features (22.4%) included *Graphical features* (18.4%; e.g., "I liked the graphic and the environment surrounding me.") and *Technical tools* (2.6%; e.g., "I enjoyed it because I had never tried a VR headset before."). Conversational features included *Talking* (13.2%; e.g., "I enjoyed communicating with them."), *Beginning* (6.6%; e.g., "I enjoyed that they provided me with questions at the beginning."), and *Topics* (6.6%; e.g., "I liked that they shared interesting experiences."). Finally, Psychological implications appeared as *Reflection about social exclusion* (e.g., "I enjoyed to understand what being excluded means.") and *Realistic situation* (e.g., "The experience seemed to me as in real life.").

The dominant negative theme for children was Negative feelings (39.5%), including *Exclusion* (22.4%; e.g., "I did not like to feel excluded."), *Self-blaming* (0.7%; e.g., "I understood they were not interested in my topic."), and *Internalising symptoms* (6.6%; e.g., "I did not like that they ignored me as if I did not exist."). Conversational features were also criticised, including *Unable to speak* (13.2%; e.g., "I did not like not being able to talk with the other students.") and *Stop talking* (3.9%). Interactive

features contained *Avatars' attitude* (17.1%; e.g., "The other players only talked among each other and did not talk to me.") and *Lack of interaction* (e.g., "I did not like that they were not interacting with me."). VR features included *Graphical features* (2.6%) and *Avatars* (2.6%), referring to unnatural avatar movements.

Among adolescents, six positive and eight negative themes were identified. The most frequently mentioned positive theme was VR features (31.6%), consisting of *Graphic features* (26.3%; e.g., "I liked how the classroom has been built in the virtual environment.") and *Technical tools* (5.3%; e.g., "I enjoyed trying a VR headset for the first time."). Interactive features were also appreciated (26.3%), including *Sharing* (10.5%), *Real interaction* (9.2%), and *Passive involvement* (6.6%). Conversational features appeared in 18.4% of responses, including *Topics* (6.6%; e.g., "The topics they shared were very interesting."). Realism included the subtheme *Realistic environment* (e.g., "I like that the environment seems quite realistic."), and Psychological implications contained *Experience* and *Aim of the paradigm* (e.g., "It has been something new for me that I never had experienced.").

The most frequently reported negative theme was Interactive features, especially *Avatars' attitude* (38.2%; e.g., "I did not like how the other students behaved toward me.") and *Lack of interaction* (7.9%; e.g., "The others did not interact with me, instead they were interested only in each other."). Negative feelings included *Exclusion* and *Internalising symptoms* (32.9%; e.g., "I felt like a ghost."). Conversational features involved *Unable to speak* (3.9%) and *Topics* (3.9%), whereas Realism (6.6%) captured perceptions of *lack of realism* (e.g., "I did not like it because it did not seem realistic."). Finally, Psychological implications contained *Being unsure* (e.g., "I did not recognise myself; I usually speak easily with other people.").

Group discussion feedback

During the group discussions, participants expressed both positive feedback on the 3D VR environment (e.g., realism and novelty) and critical reflections on aspects requiring improvement.

Among primary school students, *Sound features* was the most cited theme (57.9%), including *Voice improvement* (57.9%; e.g., "The voice was too loud.") and *Voice changing* (10.5%; e.g., "I would

have placed real people's voices recorded."). *Visual features* (34.2%) focused on *Graphical features* (e.g., "Provide a better graphic."). *Avatar features* (23.7%) included *General changes* (23.7%; e.g., "Avatars need to be improved.") and *Avatars' movements* (13.2%; e.g., "Don't perform too many gestures."). *Conversational features* included *More talking* (13.2%; e.g., "They should speak less.") and *Topic* (13.2%; e.g., "I would change the conversation among the avatars."). The theme *Guidelines* emerged (7.9%) through *Instruction changing* (e.g., "Looking at the smartphone when receiving notifications."). Three students (7.9%) reported *Nothing to change* (e.g., "I found everything realistic.").

Among secondary school students, *Visual features* was the most cited theme (50%), mainly *Graphical features* (e.g., "You should modify the virtual environment to improve its quality."). *Sound features* followed (44.7%), with *Voice improvement* (44.7%) and *Voice changing* (21.1%; e.g., "It would be better to record voices of real same-age peers."). *Avatar features* (26.3%) comprised *Avatars' movements* (26.3%) and *Avatars' attitude* (10.5%), where participants suggested less enthusiasm and more realism. *Conversational features* included *More talking* (13.2%) and *Terminology* (10.5%). The *Guidelines* theme (5.3%) was represented by *Instruction changing* (e.g., "Having more chances to move.").

Among high school students, *Sound features* was again the most mentioned theme (36.8%), mainly *Voice improvement* (e.g., "I would improve voices' quality; they look very robotic."). *Avatar features* (34.2%) included *Avatars' movements* (e.g., "I would try to make the characters' movements more natural."), *General changes* (28.9%; e.g., "More realistic avatars."), and *Avatars' attitude* (e.g., "The avatars seemed too enthusiastic."). *Conversational features* included *Terminology* (31.6%; e.g., "The avatars should use a different language.") and *Topic* (18.4%; e.g., "I would add topics more suitable for our age."). *Visual features* (26.3%) referred to *Graphical features* (e.g., "I would change the virtual classroom, as it seemed too fake."). The *Guidelines* theme (5.3%) involved *Instruction changing* (e.g., "I would have preferred being alone in the room because I would have felt more

comfortable interacting with the virtual students."). Finally, 23.7% reported *Nothing to improve* (e.g., "It seemed already realistic to me.").

Discussion

Our study successfully elicited emotional responses related to social exclusion in both Cyberball and VR paradigms, aligning with prior theories linking exclusion to sadness and loneliness (Riva & Eck, 2016). Qualitative feedback revealed developmental differences in participants' perception and evaluation, reinforcing both the emotional validity of the paradigms and the importance of age in shaping social-cognitive processing.

When comparing the two paradigms directly, clear distinctions emerged in the nature and depth of participants' experiences. Cyberball, with its simple and unambiguous mechanics, elicited immediate and intense negative emotions, whereas 3D VR generated richer and more multidimensional feedback, reflecting both emotional and cognitive engagement. This contrast highlights the trade-off between emotional immediacy and ecological validity: while Cyberball reliably triggers exclusion-related affect, VR allows a more nuanced exploration of social reasoning and contextual interpretation

In regard to Cyberball, positive responses primarily focused on Playing Features, particularly in the initial inclusion phase. Children described this as "fun", while adolescents appreciated its structure (e.g., "simple", "easy to follow"), reflecting a developmental shift from affective to cognitive evaluation. This pattern aligns with Piaget's developmental stages (1929), where children in the concrete operational stage respond to immediate experiences, while adolescents employ abstract reasoning. Neurodevelopmental findings further support this divergence: adolescents show increased activity in regions tied to social evaluation and emotional regulation (Blakemore & Mills, 2014), leading to more reflective appraisals, as seen in their responses.

Notably, adolescents expressed more intense and frequent Negative Feelings and Internalising Symptoms, such as sadness or feeling invisible. Their reflections often extended to the broader social message of exclusion—absent in children's responses—indicating emerging metacognitive and

social reasoning skills (Sebastian et al., 2010). This developmental sensitivity corresponds with research highlighting adolescence as a period of heightened concern for peer evaluation and social norms (Somerville, 2013). Conversely, children's self-concepts are less reliant on peer feedback, and they often miss subtler social cues (Killen & Rutland, 2011), consistent with our findings.

In comparison, the 3D VR paradigm elicited more diverse and elaborated responses across age groups. Children particularly valued Interactive features and VR features, describing enjoyment not only through participation but also through observation and listening. This engagement likely stemmed from the novelty and immersive aspects of VR, which enhance positive perceptions during initial exposure (Southgate et al., 2019) and align with evidence that younger users respond strongly to audiovisual stimulation (Gori et al., 2012).While primary school students focused on sensory issues like voice clarity and visual appeal, high school students provided more critical assessments, reflecting age-related differences. Adolescents' comments extended beyond the immersive experience to highlight social cues represented under Conversational features, such as unrelatable dialogue and restricted interaction. Furthermore, reports of Internalising symptoms, while numerically similar to children's, were qualitatively more complex. Adolescents also raised concerns about Realism, suggesting that their engagement depended on the psychological plausibility of the social context. These responses align with evidence that adolescents are more sensitive to conversational logic, emotional authenticity, and social cues in digital interactions (Crone & Dahl, 2012; Sebastian et al., 2010).

Taken together, our findings suggest a developmental pathway through which the realism afforded by immersive VR translates into enhanced emotional engagement and, consequently, higher ecological validity. The vividness and interactivity of the 3D environment appeared to intensify participants' sense of social presence, facilitating authentic affective responses even in a simulated exclusion scenario (Slater & Sanchez-Vives, 2016; Cummings & Bailenson, 2016). In both age groups, stronger reports of immersion and perceived realism were associated with richer emotional narratives, supporting the view that realistic sensory and social cues heighten the credibility of

exclusion experiences (Triberti et al., 2018; Fraser et al., 2022). This dynamic illustrates how this methodology can approximate the complexity of peer interactions in school settings. Nonetheless, direct comparisons across conditions revealed that while VR fostered greater realism and engagement, it occasionally reduced the intensity of exclusion-related affect, particularly in younger participants. This pattern may reflect a "novelty effect," whereby fascination with the immersive environment partly buffered negative emotional impact (Makransky et al., 2019). Adolescents, however, displayed more differentiated emotional responses and articulated stronger reflections about social belonging, consistent with their heightened developmental sensitivity to peer evaluation (Sebastian et al., 2010). Hence, the VR condition did not simply magnify Cyberball's effects but reconfigured them, balancing realism and engagement with a moderated emotional reaction. This interpretation highlights the need for longitudinal or repeated-exposure designs to disentangle novelty from stable ecological effects.

Age-related trends in the debriefing comments further illuminate how realism and design features were experienced and evaluated. Primary school students focused on sensory issues like voice clarity and visual appeal (57.9% requested voice improvements), while high school students critiqued deeper interactional aspects. High school students provided the most nuanced feedback, questioning the social credibility of avatars and expressing dissatisfaction with dialogue content and exclusion logic. This trajectory supports prior work showing that as social cognition matures, expectations for narrative coherence and emotional plausibility increase (Sebastian et al., 2010).

Participants' suggestions during group discussions reflected concrete perceptions of realism deficits rather than merely experiential impressions**.** Many noted that avatar behaviour, movement, and language felt unnatural, disrupting immersion and plausibility. This distinction between *experienced realism* and *perceived improvement needs* clarifies the dual nature of participants' feedback: while the experience was emotionally effective, technical and conversational inconsistencies limited its credibility. This aligns with findings that mismatches in verbal and nonverbal cues can weaken presence and emotional engagement (Slater & Sanchez-Vives, 2016;

Fraser et al., 2022). The plausibility illusion—critical for emotional investment—is especially fragile among adolescents, whose heightened social sensitivity makes them more responsive to inconsistencies (Georgescu et al., 2014). Thus, participants' improvement suggestions (e.g., more natural dialogue, better animations, enhanced voice realism) represent practical insights for strengthening the psychological fidelity of 3D VR paradigms.

In sum, the VR paradigm successfully elicited social-emotional responses, supporting its methodological promise in psychological research. VR enables controlled simulations of complex social situations, often difficult to manipulate in real-world settings (Parsons & Rizzo, 2008). Its application in modelling phenomena like the bystander effect (Slater et al., 2006) and social judgment has already demonstrated its capacity for eliciting ecologically valid behaviour. Our findings therefore suggest that VR provides a richer and developmentally sensitive environment for studying social exclusion, though its effectiveness depends on maintaining a credible sense of social realism. The thematic analysis demonstrates that Cyberball, although simple and abstract, may sometimes evoke stronger negative emotions due to its stark and unmistakable exclusionary mechanics, especially among adolescents who interpret the lack of interaction as deliberate and socially meaningful. Meanwhile, VR—despite its enhanced realism and immersive features—may inadvertently dilute the exclusion experience among younger participants, particularly if the novelty of the technology or the inconsistency in avatar behaviour becomes a distraction. Hence, poorly executed VR may paradoxically reduce the psychological salience of social exclusion, underscoring that emotional impact hinges more on the authenticity of social context than on technological sophistication.

Limitations

This study has several limitations. First, while rich in detail, the qualitative design restricts generalisability. The absence of standardised psychometric tools limits the ability to quantify emotional outcomes. Given that the present findings derive from qualitative data, the study should be regarded as a preliminary qualitative benchmark of the newly developed VR paradigm. Rather

than establishing psychometric or behavioural equivalence, our results provide initial evidence that the paradigm elicits theoretically consistent emotional and cognitive patterns of exclusion. Future mixed-method work will be necessary to examine convergent validity using physiological, behavioural, or self-report measures. Second, technical limitations—such as robotic avatar behaviour and voice synthesis—may have impaired the ecological validity of the VR condition, particularly for older adolescents. Also, no direct feedback was collected on the realism of the Cyberball paradigm, precluding a full comparative analysis. Lastly, the sample was drawn from a culturally homogeneous Italian population, limiting cross-cultural applicability.

Practical Implications and Future Directions

From a theoretical perspective, the findings extend developmental and social-cognitive models of peer exclusion by showing how immersive environments can elicit nuanced emotional and reflective responses aligned with age-related differences in social reasoning. Methodologically, immersive VR provides a controlled yet ecologically rich setting for examining complex peer-interaction processes that are difficult to reproduce in traditional paradigms. Building on this theoretical and methodological foundation, immersive VR can also be translated into school-based interventions, offering opportunities for students to reflect on inclusion, empathy, and group dynamics within safe, controlled environments.

Immersive VR environments can be leveraged in social and emotional learning (SEL) programs to help students reflect on inclusion, empathy, and group dynamics (Hamilton et al., 2021). Such applications also align with teacher-training initiatives that use experiential simulations to build educators' awareness of exclusion and bias in the classroom (Wang & Li, 2024). Once refined and validated further, the current paradigm could serve as a tool for developing empathy-training interventions and peer-inclusion curricula, contributing to broader goals of school well-being and relational competence. Recent VR applications have successfully supported CBT-based interventions and social-emotional training (Freeman et al., 2017), including empathy enhancement (Alcalde-

Llergo et al., 2023) and language disorder support (Arts et al., 2024). VR's adaptability makes it ideal for customising interventions by age, gender, or classroom dynamics (Villena-Taranilla et al., 2022).

To fully realise these benefits, future developments should focus on enhancing the overall realism and interactivity of VR experiences while maintaining age-appropriate complexity. This includes improving behavioural and conversational authenticity, ensuring consistency in social cues, and designing adaptive interaction systems that match users' developmental levels. Rather than emphasising specific technical features—as previously discussed—future research should aim to balance ecological validity with emotional impact, ensuring that realism enhances rather than distracts from the intended psychological experience. In sum, this study underscores both the value and the challenges of using VR to simulate social exclusion in developmental populations. While Cyberball remains effective through its simplicity and clarity of exclusion, a well-designed VR paradigm provides a richer and more dynamic means of studying social-emotional processes. When executed effectively, VR can combine ecological validity and developmental sensitivity, making it not only a powerful research instrument but also a promising educational and therapeutic tool for promoting empathy, inclusion, and emotional understanding in young populations.

Conclusions

This study aimed to validate a novel 3D VR paradigm for simulating peer exclusion in school-aged children and adolescents, and to compare its perceived impact to that of the widely used Cyberball paradigm. The findings suggest that while both paradigms effectively induced feelings of exclusion, the VR environment offered greater realism, interactivity, and emotional engagement.

Despite the limitations related to technological realism and generalisability, the results affirm the potential of immersive VR as a viable and innovative approach for investigating and addressing social dynamics in educational contexts. Future research should further refine avatar interactions and expand the demographic scope of participants to enhance both the scientific rigour and practical applicability of the paradigm.

By bridging the gap between experimental control and ecological validity, the proposed VR paradigm marks a significant step forward in the study of social exclusion and its psychological impact among youth.

References

Abrams, D., Weick, M., Thomas, D., Colbe, H., & Franklin, K. M. (2011). On-line ostracism affects children differently from adolescents and adults. *British Journal of Developmental Psychology, 29*(1), 110–123. https://doi.org/10.1348/026151010X494089

Alcalde-Llergo, J. M., Yeguas-Bolívar, E., Aparicio-Martínez, P., Zingoni, A., Taborri, J., & Pinzi, S. (2023). A VR serious game to increase empathy towards students with phonological dyslexia. *2023 IEEE International Conference on Metrology for Extended Reality, Artificial Intelligence and Neural Engineering (MetroXRAINE 2023) – Proceedings*, 470–475. https://doi.org/10.1109/MetroXRAINE58569.2023.10405809

Arts, E., De Castro, B. O., Luteijn, E., Elsendoorn, B., & Vissers, C. T. W. M. (2024). Interactive virtual reality training to improve socio-emotional functioning in adolescents with developmental language disorders: A feasibility study. *Clinical Child Psychology and Psychiatry, 29*(3), 678–693. https://doi.org/10.1177/13591045231220694

Badger, J. R., Rovira, A., Freeman, D., & Bowes, L. (2023). Developing a virtual reality environment for educational and therapeutic application to investigate psychological reactivity to bullying. *Virtual Reality*, *27*(3), 2623-2632.

Baumeister, R. F., & Leary, M. R. (1995). The need to belong: Desire for interpersonal attachments as a fundamental human motivation. *Psychological Bulletin, 117*(3), 497–529. https://doi.org/10.1037/0033-2909.117.3.497

Blakemore, S. J., & Mills, K. L. (2014). Is adolescence a sensitive period for sociocultural processing? *Annual Review of Psychology, 65*, 187–207. https://doi.org/10.1146/annurev-psych-010213-115202

Braun, V., & Clarke, V. (2019). Reflecting on reflexive thematic analysis. *Qualitative Research in Sport, Exercise and Health, 11*(4), 589–597. https://doi.org/10.1080/2159676X.2019.1628806

Braun, V., & Clarke, V. (2021). One size fits all? What counts as quality practice in (reflexive) thematic analysis? *Qualitative Research in Psychology, 18*(3), 328–352. https://doi.org/10.1080/14780887.2020.1769238

Brown, M., McCormack, M., Reeves, J., Brooks, C., & Grajek, S. (2020). *2023 EDUCAUSE Horizon Report: Teaching and Learning Edition.* EDUCAUSE.

Campodifiori, E., Figura, E., Papini, M., & Ricci, R. (2010). *Un indicatore di status socio-economico-culturale degli allievi della quinta primaria in Italia.* Istituto nazionale per la valutazione del sistema educativo di istruzione e di formazione (INVALSI).

Chang, E., Kim, H. T., & Yoo, B. (2020). Virtual reality sickness: A review of causes and measurements. *International Journal of Human–Computer Interaction, 36*(17), 1658–1682. https://doi.org/10.1080/10447318.2020.1778351

Chardonnet, J. R., Mirzaei, M. A., & Mérienne, F. (2015). Visually induced motion sickness estimation and prediction in virtual reality using frequency components analysis of postural sway signal. *Proceedings of the International Conference on Artificial Reality and Telexistence and Eurographics Symposium on Virtual Environments (ICAT-EGVE 2015)*, 9–16. https://doi.org/10.2312/egve.20151304

Crone, E. A., & Dahl, R. E. (2012). Understanding adolescence as a period of social-affective engagement and goal flexibility. *Nature Reviews Neuroscience, 13*(9), 636–650. https://doi.org/10.1038/nrn3313

Cummings, J. J., & Bailenson, J. N. (2016). How immersive is enough? A meta-analysis of the effect of immersive technology on user presence. *Media Psychology, 19*(2), 272–309. https://doi.org/10.1080/15213269.2015.1015740

Fraser, A. D., Branson, I., Hollett, R. C., Speelman, C. P., & Rogers, S. L. (2022). Expressiveness of real-time motion-captured avatars influences perceived animation realism and perceived quality of social interaction in virtual reality. *Frontiers in Virtual Reality, 3*, 981400. https://doi.org/10.3389/frvir.2022.981400

Freeman, D., Reeve, S., Robinson, A., Ehlers, A., Clark, D., Spanlang, B., & Slater, M. (2017). Virtual reality in the assessment, understanding, and treatment of mental health disorders. *Psychological Medicine, 47*(14), 2393–2400. https://doi.org/10.1017/S003329171700040X

Georgescu, A. L., Kuzmanovic, B., Roth, D., Bente, G., & Vogeley, K. (2014). The use of virtual characters to assess and train non-verbal communication in high-functioning autism. *Frontiers in Human Neuroscience, 8*, 807. https://doi.org/10.3389/fnhum.2014.00807

Gori, M., Sandini, G., & Burr, D. (2012). Development of visuo-auditory integration in space and time. *Frontiers in Integrative Neuroscience, 6*, 77. https://doi.org/10.3389/fnint.2012.00077

Hamilton, D., McKechnie, J., Edgerton, E., & Wilson, C. (2021). Immersive virtual reality as a pedagogical tool in education: a systematic literature review of quantitative learning outcomes and experimental design. *Journal of Computers in Education*, *8*(1), 1-32.

Humphrey, N., & Symes, W. (2010). Perceptions of social support and experience of bullying among pupils with autistic spectrum disorders in mainstream secondary schools. *European Journal of Special Needs Education, 25*(1), 77–91. https://doi.org/10.1080/08856250903450855

Jaeger, B. K., & Mourant, R. R. (2001). Comparison of simulator sickness using static and dynamic walking simulators. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 45*(27), 2083–2087. https://doi.org/10.1177/154193120104502709

Kasari, C., Locke, J., Gulsrud, A., & Rotheram-Fuller, E. (2011). Social networks and friendships at school: Comparing children with and without ASD. *Journal of Autism and Developmental Disorders, 41*(5), 533–544. https://doi.org/10.1007/s10803-010-1076-x

Kassner, M. P., Wesselmann, E. D., Law, A. T., & Williams, K. D. (2012). Virtually ostracized: Studying ostracism in immersive virtual environments. *Cyberpsychology, Behavior, and Social Networking, 15*(8), 399–403. https://doi.org/10.1089/cyber.2012.0113

Killen, M., & Rutland, A. (2011). *Children and social exclusion: Morality, prejudice, and group identity.* Wiley-Blackwell. https://doi.org/10.1002/9781444396317

Lin, X. P., Li, B. B., Yao, Z. N., Yang, Z., & Zhang, M. (2024). The impact of virtual reality on student engagement in the classroom–a critical review of the literature. *Frontiers in Psychology*, *15*, 1360574.

MacDonald, G., & Jensen-Campbell, L. A. (2010). *Social pain: Neuropsychological and health implications of loss and exclusion.* American Psychological Association. https://doi.org/10.1037/12351-000

Makransky, G., Terkildsen, T. S., & Mayer, R. E. (2019). Adding immersive virtual reality to a science lab simulation causes more presence but less learning. *Learning and Instruction, 60*, 225–236. https://doi.org/10.1016/j.learninstruc.2017.12.007

Marinucci, M., & Riva, P. (2025). Homelessness in Virtual Reality: Experiencing Social Exclusion Improves Attitudes and Behaviors Toward Unhoused People. *Cyberpsychology, Behavior, and Social Networking*, *28*(1), 65-71.

Maxwell, J. A. (2010). Using numbers in qualitative research. *Qualitative Inquiry, 16*(6), 475–482. https://doi.org/10.1177/1077800410364740

Nelson, E. E., Jarcho, J. M., & Guyer, A. E. (2016). Social re-orientation and brain development: An expanded and updated view. *Developmental cognitive neuroscience*, *17*, 118-127.

Nowell, L. S., Norris, J. M., White, D. E., & Moules, N. J. (2017). Thematic analysis: Striving to meet the trustworthiness criteria. *International Journal of Qualitative Methods, 16*(1), 1609406917733847. https://doi.org/10.1177/1609406917733847

Pantelidis, V. S. (2010). Reasons to use virtual reality in education and training courses and a model to determine when to use virtual reality. *Themes in Science and Technology Education, 2*(1–2), 59–70.

Parsons, T. D. (2015). Virtual reality for enhanced ecological validity and experimental control in the clinical, affective and social neurosciences. *Frontiers in Human Neuroscience, 9*, 660. https://doi.org/10.3389/fnhum.2015.00660

Parsons, T. D., & Rizzo, A. A. (2008). Affective outcomes of virtual reality exposure therapy for anxiety and specific phobias: A meta-analysis. *Journal of Behavior Therapy and Experimental Psychiatry, 39*(3), 250–261. https://doi.org/10.1016/j.jbtep.2007.07.007

Piaget, J. (1929). *The child's concept of the world.* Routledge & Kegan Paul.

Phillips, E., Jarden, A., & Bowles, T. (2025). A study of virtual reality and the empathetic experience in Australian secondary students. *The Australian Educational Researcher*, *52*(1), 159-183.

Prendergast, C. N., & Schubert, T. (2020). Investigating reflexive responses to explicit and implicit forms of social exclusion using immersive virtual environment technology. *Frontiers in Psychology, 11*, 575783. https://doi.org/10.3389/fpsyg.2020.575783

Riva, P., & Eck, J. (2016). *Social exclusion: Psychological approaches to understanding and reducing its impact.* Springer. https://doi.org/10.1007/978-3-319-33033-4

Sanchez-Vives, M. V., & Slater, M. (2005). From presence to consciousness through virtual reality. *Nature Reviews Neuroscience, 6*(4), 332–339. https://doi.org/10.1038/nrn1651

Sandelowski, M. (2001). Real qualitative researchers do not count: The use of numbers in qualitative research. *Research in Nursing & Health, 24*(3), 230–240. https://doi.org/10.1002/nur.1025

Sebastian, C., Viding, E., Williams, K. D., & Blakemore, S. J. (2010). Social brain development and the affective consequences of ostracism in adolescence. *Brain and Cognition, 72*(1), 134–145. https://doi.org/10.1016/j.bandc.2009.06.008

Silseth, K., Steier, R., & Arnseth, H. C. (2024). Exploring students' immersive VR experiences as resources for collaborative meaning making and learning. *International Journal of Computer-Supported Collaborative Learning*, *19*(1), 11-36.

Slater, M., Antley, A., Davison, A., Swapp, D., Guger, C., Barker, C., Pistrang, N., & Sanchez-Vives, M. V. (2006). A virtual reprise of the Stanley Milgram obedience experiments. *PLoS ONE, 1*(1), e39. https://doi.org/10.1371/journal.pone.0000039

Slater, M., & Sanchez-Vives, M. V. (2016). Enhancing our lives with immersive virtual reality. *Frontiers in Robotics and AI, 3*, 74. https://doi.org/10.3389/frobt.2016.00074

Somerville, L. H. (2013). The teenage brain: Sensitivity to social evaluation. *Current Directions in Psychological Science, 22*(2), 121–127. https://doi.org/10.1177/0963721413476512

Southgate, E., Smith, S. P., Cividino, C., Saxby, S., Kilham, J., Eather, G., Scevak, J., Summerville, D., Buchanan, R., & Bergin, C. (2019). Embedding immersive virtual reality in classrooms: Ethical, organisational and educational lessons in bridging research and practice. *International Journal of Child-Computer Interaction*, 19, 19–29. https://doi.org/10.1016/j.ijcci.2018.10.002

Tassinari, M., Aulbach, M. B., & Jasinskaja-Lahti, I. (2022). The use of virtual reality in studying prejudice and its reduction: A systematic review. *PloS one*, *17*(7), e0270748.

Terry, G., Hayfield, N., Clarke, V., & Braun, V. (2017). Thematic analysis. In C. Willig & W. Stainton-Rogers (Eds.), *The SAGE handbook of qualitative research in psychology* (2nd ed., pp. 17–37). Sage

Triberti, S., Brivio, E., & Galimberti, C. (2018). On social presence. In *Managing social presence in virtual learning environments* (pp. 21–38). IGI Global. https://doi.org/10.4018/978-1-5225-3229-3.ch002

Tuijnman, A., Kleinjan, M., Chen, S., Engels, R. C. M. E., & Granic, I. (2021). A game-based assessment of the effects of rejection on young adults. *Proceedings of the ACM on Human–Computer Interaction, 5*(CHI PLAY), 1–22. https://doi.org/10.1145/3474681

Villena-Taranilla, R., Tirado-Olivares, S., Cózar-Gutiérrez, R., & González-Calero, J. A. (2022). Effects of virtual reality on learning outcomes in K–6 education: A meta-analysis. *Educational Research Review, 35*, 100434. https://doi.org/10.1016/j.edurev.2022.100434

Wang, Q., & Li, Y. (2024). How virtual reality, augmented reality and mixed reality facilitate teacher education: A systematic review. *Journal of Computer Assisted Learning*, *40*(3), 1276-1294.

Williams, K. D. (2001). *Ostracism: The power of silence.* Guilford Press.

Williams, K. D., Cheung, C. K. T., & Choi, W. (2000). Cyberostracism: Effects of being ignored over the internet. *Journal of Personality and Social Psychology, 79*(5), 748–762. https://doi.org/10.1037/0022-3514.79.5.748

Williams, K. D., & Nida, S. A. (2016). *Ostracism, exclusion, and rejection.* Psychology Press. https://doi.org/10.4324/9781315308470

Wirth, J. H., Sacco, D. F., Hugenberg, K., & Williams, K. D. (2010). Eye gaze as relational evaluation: Averted eye gaze leads to feelings of ostracism and relational devaluation. *Personality and Social Psychology Bulletin, 36*(7), 869–882. https://doi.org/10.1177/0146167210370032

Supplementary Material

Final debriefing and open-ended questions

Our experiment is over, we thank you for participating. We want to take this moment to give you some important information about this experiment. The aim of the research was not to compare two video games with different technological modes, as was explained to you at the beginning, but actually, the aim was to see which of the two games was more able to let you feel excluded by other students of the same age as you. In order for the simulation to be as realistic as possible, we had to tell you at the beginning of each experiment that the other two online participants were students of your age who were carrying out the same experiment at the same time from two other schools in Emilia Romagna. Actually, the other two participants were two digital avatars that followed specific commands established before the experiment, and their actions towards you were the same for all of you, so you all interacted with the exact same avatars that behaved in the exact same way with all of you. This is the main reason why we asked you, at the end of each individual experiment, not to talk to your classroom and school mates about the experiment for any reason until the total experiment was over for all students in the school. Now, wanting to have the most reliable data possible, we would like to ask you to please be truthful and tell us if you heard any details or any information about the experiment from other mates before running the experiment yourself so that we can mark your participation code and add this information to the database. Finally, we would like to tell you that we remain at your disposal if you would like a one-to-one meeting for further clarifications or if you have any specific questions for us. If you need this, just ask your teachers and we, through them, will arrange a meeting with you here at school. Also, when we have analysed the data and obtained the results, we will organize, together with the headmaster, a meeting with you, your teachers and parents, to better explain what we have done and what we have achieved.

- Thinking about the moment when you entered the virtual reality through the headset, what would you do to improve that situation/interaction and make it more realistic within the virtual environment?

Cyberball paradigm instructions and open-ended questions

We will now let you enter an online platform where you will play with two other students of your age from two other schools in Emilia Romagna who are carrying out the same experiment at the same time. Before you enter, you will have the chance to enter your name and a picture of yourself taken through the computer's webcam, and the other two players will do the same, so that all three of you can see your names and pictures next to your avatar. The game consists of passing a ball between all

players. Each time the ball comes to you, you will have to use the right arrow to pass it to the student on your right and, vice versa, the left arrow to pass it to the student on your left. Before you start the real game with the other two students, we'll give you a quick one-shot test to make sure you understand how the controls work. Then we'll quickly contact our colleagues in the other two schools to make sure the other two students are ready, and once all three of you are ready, we'll let you go ahead and you can start playing.

- What did you like about the game?
- What did you dislike about the game?

Virtual Reality paradigm and open-ended questions

We will now take you into a three-dimensional environment built through virtual reality using a headset. Once you have put on the headset, you will find yourself sitting in a virtual classroom together with two other students of your age from two other schools in Emilia Romagna, who are carrying out the same experiment at the same time, and who will be seated on the other sides of the desk. The virtual environment is ready and set up, once we have quickly heard from our colleagues in the other two schools to make sure that the other two students are ready. We will let you enter the virtual environment through the headset and give you two minutes to orient yourself inside the virtual environment and look around. After two minutes you can start to interact. In the meantime, we ask you to think of an interesting activity that you have done at school recently or in the previous months, whether in school or out of school, because this will be the topic that we want you to talk about with the others: we want each of you to share a school activity that you find interesting and discuss it among yourselves. The only two recommendations we make to you is to try to intervene when the other two are not talking and when they deliberately ask you to speak or turn towards you, so as to avoid talking over each other in order for the conversation not to become chaotic, and to stay seated all the time avoiding to walk in the VR room, as you can risk falling in the real environment. To avoid any problems and provide you with more security, we will monitor you via computer during the entire time you are inside the virtual environment. When the time for talking is over, we will interrupt the connection with the virtual environment and notify you so that you know when you can take off the headset. We ask you to actively and attentively participate in the conversation with the other two students because once you have exited virtual reality, we will ask you again to fill out a questionnaire, this time containing information about your experience in the virtual environment and what you talked about inside.

- What did you like about the game?

- What did you dislike about the game?

VR paradigm's scripts

LEVEL: EXCLUSION- CHILD (8-10)

Child 1 (Luca): Hi! I am Luca. And what's your name? (Referred to participant) (Enthusiasm, curiosity) Participant: (avatars look at the participant who introduces himself)

Child 1 (Luca) Hi! What's your name (referring to the avatar)? Child 2 (Martina): Hi! I am Martina! (Joy, enthusiasm)

Child 1 (Luca): What's the last interesting thing you did at your school?

Child 2 (Martina): Mmh, I don't know... the first thing that comes to mind is a trip we took to nature to do a science project. We went to a forest and saw the trees and the animals there! (Enthusiasm)

Child 1 (Luca): Wow! What about you? (Referred to participant) Participant: (avatars look at the participant answering the question)

Child 1 (Luca): Aah, OK. Martina how lucky you are to have done this so interesting thing. I like nature so much and I like discovering new things about plants and animals. (Admiration, interest)

Child 2 (Martina): Yes! It was really great! We saw a beautiful forest. There were very tall trees and we saw lots of animals living there (Enthusiasm, Wonder)

Child 1 (Luca): And what did you do while visiting the forest? Did you see any particular animals? (Curiosity, interest)

Child 2 (Martina): Yes! We saw how different trees are from each other and how they have leaves and bark. It was wonderful to discover that each tree has its own history and its own important role in the forest. We also saw many animals, like squirrels jumping and colourful birds in the trees (Enthusiasm, Wonder)

Child 1 (Luca): Wow! That sounds really a too good experience! My dream is to be able to see a forest like that one day. It must have been amazing to observe animals in nature. (Admiration)

Child 2 (Martina): Yes, it was a magical moment! We were surrounded by nature and didn't hear the noise of the city. I loved hearing the sound of the leaves and the birds singing. I felt like a real explorer!

(Happiness, nostalgia)

Child 1 (Luca): How nice! I also like nature and I like being outdoors. When I'm in nature, I feel immersed in the world around us. (Sharing, reflection)

Child 2 (Martina): True! Nature inspires us and makes us feel part of something bigger. Although at the

beginning I was a bit afraid of soiling my clothes or tripping over tree roots, I learnt to be brave. Now I am no longer afraid and I have had a lot of fun. I realised that it's important to be in nature even if you can fall, because even if you get hurt it doesn't hurt forever! (Sharing, Gratitude)

Child 1 (Luca): What bravery, Martina! You are a real explorer! How nice that you were lucky enough to do something so special. (Admiration, happiness)

Child 2 (Martina): Thank you, Luca. And have you done anything nice at school lately? (Curiosity, interest)

Child 1 (Luca): Mmh... A while ago we did an art project in which we created paintings. We used a lot of colours and drew our landscapes, towns and typical things. It was like travelling through our region. (Enthusiasm, pride)

Child 2 (Martina): How nice, Luca! I love art too! I would like to see your little works to know the places and what you have drawn. Did you add anything special to your artwork? (Curiosity, interest)

Child 1 (Luca): Yes! In the paintings I drew the historical houses and buildings of the cities, such as medieval towers and Renaissance palaces. I also drew the typical things we eat, like tortellini and Parmesan cheese. I tried to draw everything precisely so that those who see my drawings can recognise our region.

(Enthusiasm, pride)

Child 2 (Martina): How beautiful! Surely your drawings are beautiful and show the beautiful things of our region. It would be nice to see them up close. Maybe you can ask the teachers to organise an exhibition with your artwork! (Enthusiasm, curiosity, reflection)

Child 1 (Luca): What a great idea! It can be done to show how beautiful our drawings are, not only to our schools, but also to other people who might see how good we are. We have to talk to the teachers and see if it can be done! That would be really great! (Enthusiasm, determination)

Child 2 (Martina): You're right, Luca! You have to beg your teachers to do this. It will be a unique experience! (Enthusiasm, determination)

Child 1 (Luca): Yes! We should also ask all the other children and all the teachers at our school. We could do things together during the exhibition, like start painting all together. That way we can show the others how nice it is to paint too. (Enthusiasm, sharing)

Child 2 (Martina): What a fantastic idea, Luca! I'm sure many children will be happy to participate and try their hand at painting. (Enthusiasm, desire to learn)

Child 1 (Luca): True! We need to have an exhibition where not only the children from our school but everyone can participate. We can get the families and the townspeople to come and invite them to see our handicrafts! (Determination, Pride)

Child 2 (Martina): I really like your idea! It would be too nice to see all the habitants looking at the school's handiworks and admiring what you have done. (Appreciation)

LEVEL: EXCLUSION- PRE-ADOLESCENT (11- 13)

Boy 1 (Sara): Hi! I'm Sara! (Enthusiasm)

Boy 2 (Angelo): Hi Sara! I'm Angelo, nice to meet you! And what's your name? (Happiness) Participant: (avatars turn to look at the participant introducing themselves)

Boy 1 (Sara): What was the last activity you did at school? (Curiosity)

Boy 2 (Angel): I don't know... I don't think it's interesting, but the last thing we did was a maths workshop. (Emphasis and enthusiasm)

Boy 1 (Sara): Ah, nice, what about you? (Referred to participant) Participant: (avatars turn to look at the responding participant)

Boy 1 (Sara): Ah, OK. Wow, Angelo, your lab sounds really interesting! I really like maths. What have you been up to? (Curiosity)

Boy 2 (Angel): We did fractions in a whole new way! We learnt how to add, subtract, multiply and divide fractions in ways I never imagined. (Excitement)

Boy 1 (Sara): Really! And how? I like solving problems, but fractions seem really interesting. How did you do it? (Interest)

Boy 2 (Angelo): It was a lot of fun! Our teacher proposed maths games where we had to divide food between friends and divide spaces. We solved everyday problems using fractions and discovered how they can be useful in everyday life. It was really fun! (Excitement)

Boy 1 (Sara): Wow, that sounds really interesting! I guess it was a fun assignment! (Admiration)

Boy 2 (Angel): Absolutely, Sara! It was an incredible experience. I learnt that fractions are useful and can simplify our lives. I was really happy to discover all that! (Enthusiasm and elation)

Boy 1 (Sara): I'm happy for your experience! It's great when we can learn while having fun and use the knowledge in real life. (Satisfaction)

Boy 2 (Angel): Yes, that's really great! And you, Sara, what was the last thing you did at your school? (Curiosity)

Boy 1 (Sara): Mmh, I can think of a science project on the human body. It was really interesting! (Enthusiasm)

Boy 2 (Angel): Wow, that sounds cool! I'd like to understand how our bodies work. What exactly did you do? (Curiosity)

Boy 1 (Sara): We studied the various systems of the human body, such as the digestive system, the

circulatory system and the respiratory system. We also built a three-dimensional model of the human body to better understand what each organ does. It was a really great experience! (Wonder)

Boy 2 (Angelo): That must have been really exciting! I like the idea of studying the human body and understanding how it works. Our body is incredible! (Admiration)

Boy 1 (Sara): That's right, I really agree! It was a great way to learn! (Enthusiasm) Boy 2 (Angel): It sounds really incredible! What did you like the most? (Curiosity)

Boy 1 (Sara): The brain and the nervous system. It was amazing to discover that the brain receives

information and sends signals through the nervous system to make us move and think. (Wonder and excitement)

Boy 2 (Angel): Wow, I can't even imagine how much fun that was! I didn't know that the brain influences our thinking and behaviour. Did you also do any hands-on activities? (Interest)

Boy 1 (Sara): Yes. We were divided into groups and each of us was able to investigate a specific system of the human body. My group focused on the skeletal system. (Interest)

Boy 2 (Angel): Ah, beautiful! And what exactly did you do? (Curiosity)

Boy 1 (Sara): We examined the bones, learning their names and functions. We also looked at the

importance of the joints and muscles that enable us to move. But the most interesting part was when we created a model of the skeletal system with recycled materials. (Enthusiasm)

Boy 2 (Angel): What a great idea! I'm sure it was a lot of fun. How did you make the model? (Curiosity)

Boy 1 (Sara): We used various materials, such as cardboard, toothpicks and paint. We built the skeleton so that it stood straight and we could see all the parts, such as the skull, vertebrae, ribs and limb bones. It was fascinating to see how all these bones connect and form the structure of our body. (Wonder and

excitement)

Boy 2 (Angel): It must have been really nice to see your finished model. (Admiration)

Boy 1 (Sara): Absolutely! Every time we looked at our model, we thought our body looked like that. Also, they explained to us how important it is to eat well and exercise. (Satisfaction)

Boy 2 (Angelo): I'm sure this experience has made you learn a lot of new things. This is really great! (Pride)

Boy 1 (Sara): Thank you, Angelo! It was a very important project. Now I'm even more interested in the human body and science. (Enthusiasm)

LEVEL: EXCLUSION- ADOLESCENT (14-16)

Boy 1 (Alessandra): Hey, hi! My name is Alessandra. And you?

Boy 2 (Davide): Hi Alessandra! I'm Davide, nice to meet you! And you? (Happiness) Participant: (avatars look at the participant who introduces himself)

Boy 1 (Alessandra): How are you? Have you done anything interesting at school lately? (Curiosity)

Boy 2 (Davide): Mmh, I don't know. The last thing I can think of is a scientific lab project on the effect of sunlight on plants. We looked at how light affects the growth and development of plants. It was an

interesting topic to explore! (Enthusiasm)

Boy 1 (Alessandra): Hmm, got it. How about you? Participant: (avatars look at the responding participant)

Boy 1 (Alessandra): Ah, OK. Wow, Davide! Your project sounds really interesting! How did you structure your experiment? (Curiosity)

Boy 2 (Davide): We created suitable conditions for sunlight exposure for a group of identical plants. Some

plants were placed in full sunlight, while others were placed in a shaded area. We left some plants indoors, away from direct sunlight. During the experiment, we measured the plants' growth, number of leaves,

height and general health. We wanted to understand the effects of sunlight on plants.

Boy 1 (Alessandra): Wow, that sounds like a really good experiment! And what were your discoveries? What did you learn? (Curiosity)

Boy 2 (Davide): It was really interesting! We noticed that the plants exposed to direct sunlight grew more

than the plants in the shade. The plants exposed to sunlight had stronger stems and bigger, greener leaves. In contrast, the plants in the shade showed slower growth and the leaves were paler. We also observed that the indoor plants grew very weak and had yellow leaves. (Thrill of discovery)

Boy 1 (Alessandra): Wow! So, direct sunlight makes plants grow and develop better. I never thought about how important sunlight is. (Wonderful)

Boy 2 (Davide): Exactly! It is amazing how light, which we often take for granted, plays such an important role in plant life. This experiment gave us a better understanding of the relationship between plants and the environment. It is as if we have unlocked a little secret of nature! (Wonder)

Boy 1 (Alessandra): I am really happy that you shared this experience with me, Davide. It's great to see how science allows us to discover the world. (Satisfaction)

Boy 2 (Davide): I too am happy that I was able to share my project with you, Alessandra. I discovered how exciting science can be. (Pride)

Boy 1 (Alessandra): I totally agree! We did an equally interesting science workshop. We focused on sets and graphs. (Interest)

Boy 2 (Davide): Ah cool! And how did you feel about doing sets and graphs? (Curiosity)

Boy 1 (Alessandra): It was difficult but at the same time exciting. In each set, we entered data. Afterwards, we used software to analyse the data and create the graphs. It was amazing to discover

that data can be represented with graphs, which allowed us to discover new things about the phenomenon we were observing. (Enthusiasm)

Boy 2 (Davide): Interesting! I like the idea of working with graphic designers. It would be great if we could exchange our work to see what we've done! (Enthusiasm)

Boy 1 (Alessandra): Yes, that would be really interesting! Then between us we could share our experiences, discuss our discoveries and learn even more from each other. (Curiosity)

Boy 2 (Davide): Wow cool! I guess you enjoyed it. It's important to compare and take cues from each other. (Enthusiasm)

Boy 1 (Alessandra): I agree! Science is very interesting and we should appreciate it more because it allows us to know ourselves and the world. (Passion)

Boy 2 (Davide): You're right, Alessandra. It's wonderful to see how science can help us to learn new things. (Marvel)

Boy 1 (Alessandra): Exactly! There are so many situations where you can use science (Enthusiasm)

Boy 2 (Davide): I'm sure the projects we've done are incredible. It's interesting to see how each time you get a different result. (Interest)

LEVEL: INCLUSION-CHILD (8-10)

(Child 1 - Andrea): Hello! My name is Andrea (enthusiasm). I am really curious to meet you.

(Child 2 - Clara): Hi Andrea! I'm Clara (happiness). I'm happy to meet you too. And what's your name? Participant: (avatars look at the participant who introduces himself)

(Child 1 - Andrea): Did you do something interesting at school? Something that really excited you? (curiosity)

(Child 2 - Clara): Well, actually yes! I can think of a really exciting little science project. We built a volcano and made it erupt using special ingredients. It was spectacular! (enthusiasm)

(Child 1 - Andrea): Wow! What about you?

Participant: (avatars look at the participant answering and continue to look at him referring to him in subsequent questions)

(Child 1 - Andrea): Wow, that sounds really interesting! Can I ask you what you did specifically? (curiosity) Participant: (avatars look at the responding participant)

(Child 2 -Clara): How nice! And how was it for you? (Curiosity)

Participant: (avatars look at the responding participant)

(Child 1 - Andrea): I guess. Clara, what did you do specifically? (Curiosity)

(Child 2 - Clara): We mixed liquids and substances that the teachers gave us and explained how to mix, what to put before and after inside the volcano, and at the end we poured hot water to make the lava come out. It was amazing to see the smoke and fake lava coming out of the volcano! (enthusiasm)

(Child 1 - Andrea): That sounds really exciting! It must have been a lot of fun. How did you feel when you saw the lava coming out of the volcano? (Curiosity)

(Child 2 - Clara): I felt so excited and happy! It was like I was a real scientist doing experiments. I like it when we can do practical things instead of just listening to the teachers. (joy)

(Child 1 - Andrea): I'm so glad you had such a good time. And have you ever done a science project like that? Would you like to build a volcano? (Addressed to participant)

Participant: (avatars look at the responding participant)

Child 1 - Andrea): Understood. Clara, did you have any difficulty building the volcano? (interest)

(Child 2 - Clara): At first, I was a bit confused about how to do it and how to put together all the materials the teachers had given us. I felt a bit down because I wanted everything to go well. But then I asked the

teacher for help and she slowly explained how to do it. I felt better when I understood how to do it. (initial confusion, relief)

(Child 1 - Andrea): Good thing you asked for help and your teacher helped you. (approval)

(Child 2 - Clara): Yes, at first I was a bit shy and didn't want to ask for help, but then I realised it was really necessary. After I did it, I felt much better! (realisation, relief) What would you have done in my place? (addressed to participant)

Participant: (avatars look at the responding participant)

(Child 2 - Clara): I guess. What about you, Andrea? Did you do anything interesting at school? (Curiosity)

(Child 1 - Andrea): Mmh, the last interesting thing I remember was a nature trip last week. We went to a park and saw lots of plants and animals. It was wonderful! I felt happy and amazed the whole day. (happiness, wonder)

(Child 2 - Clara): Wow, that sounds really good! I would love to do something like that. That must have been really interesting. (admiration)

(Child 1 - Andrea): It was fantastic! I was fascinated by the beauty of nature. It was like entering a new world! (admiration, wonder) It was like there were so many new things to see that I had never seen before. I felt really lucky to see that park. (Gratitude)

(Child 2 - Clara): You make me too curious. Have you ever done a similar trip with the school to a park? (Addressed to participant)

Participant: (avatars look at the responding participant)

(Child 2 - Clara): I see. Andrea, what kind of animals did you see on the trip? (Curiosity)

(Child 1 - Andrea): We saw so many different animals! There were colourful birds, squirrels hopping around in the trees and even a family of fawns running around in the middle of the park. It was exciting to be able to observe the animals so closely. (enthusiasm)

(Child 2 - Clara): Wow, you made me want to take a trip to the park too! How did you feel while observing the animals? (Curiosity)

(Child 1 - Andrea): I felt incredibly lucky and fascinated. Every time I saw an animal and could approach it without fear I felt a wonderful and mysterious world. It was a day all about nature. (wonder, connection)

(Child 2 - Clara): It sounds like a magical experience! I would love to have the chance to watch the animals so closely. It's like living inside nature. (enthusiasm)

(Child 1 - Andrea): It really is an amazing adventure! I discovered that it's wonderful to spend so much time inside a park where there are only plants and animals. I felt so lucky, don't you agree? (appreciation)

Participant: (avatars look at the responding participant)

(Child 2 - Clara): It's really true, they are wonderful experiences, and I'm so glad we told each other these stories! (Gratitude)

(Child 1 - Andrea): I too am happy to have talked to you. It's nice to talk about our experiences and see how curious we are about the world around us. (satisfaction)

LEVEL: INCLUSION - PRE-ADOLESCENT (11-13)

Boy 1 (Giulia): Hi! I'm Giulia, and you? (enthusiasm)

Boy 2 (Eugenio): Hi! I'm Eugenio, pleased to meet you! And you? (enthusiasm) Participant: (avatars look at the participant who introduces himself)

Boy 1 (Giulia): Nice to meet you! What have you been up to at school? Participant: (avatars look at the responding participant)

Boy 1 (Giulia): That sounds very interesting! And what exactly did you do? Participant: (avatars look at the responding participant)

Boy 2 (Eugenio): Cool! And how did it feel?

Participant: (avatars look at the responding participant) Boy 1 (Giulia): I can imagine. And you, Eugenio?

Boy 2 (Eugenio): I don't know, it occurs to me that we took a trip to the natural science museum last year. We were able to see and learn new things about plants, animals and rocks. It was a lot of fun! (enthusiasm)

Boy 1 (Giulia): Wow, that sounds really interesting! I'd like to be able to go to a natural science museum too. Have you ever seen a natural science museum? (Addressed to participant)

Participant: (avatars look at the responding participant)

Boy 1 (Giulia): Understood. What was the best part of the visit for you, Eugenio? (Curiosity)

Boy 2 (Eugenio): Well, one of the most beautiful things was seeing the fossils and learning more about our planet. It's amazing how many things there are in nature and how many animals exist. Do you like nature? (admiration)

Participant: (avatars look at the responding participant)

Boy 1 (Giulia): I really like looking at animals and plants. Nature is beautiful! We took a trip to the cookery workshop. We learnt how to make homemade pasta, gnocchi and many other dishes. It was fun kneading and then eating what we had made! (enthusiasm)

Boy 2 (Eugenio): How nice! I like the idea of learning to cook something good to eat. How about you? Do you like the idea of cooking? Have you ever done a cooking workshop?

Participant: (avatars look at the responding participant) Boy 2 (Eugenio): OK, did you have fun?

Boy 1 (Giulia): Yes! I had a really good time. It was a different trip from the others, and everything we ate tasted even better knowing that we had prepared it ourselves! (enthusiasm)

Boy 2 (Eugenio): Wow, that sounds really fun! Cooking will definitely be a unique experience and I would like to go on this trip too. What have you prepared? (curiosity)

Boy 1 (Giulia): We learnt how to make homemade pasta, gnocchi and much more. We used fresh ingredients such as mushrooms and spinach, but the most fun part was making the gnocchi! (enthusiasm) We were helped by a very good chef who explained how we had to move our hands to give the gnocchi a perfect shape. It was so much fun! (enthusiasm)

Boy 2 (Eugenio): I envy you. We've never been taken to a cookery workshop. Did you eat the things you prepared? (curiosity)

Boy 1 (Giulia): Of course! After we finished cooking, we ate everything. It was like a reward for our work. Maybe they looked even better to us because we had made them. (satisfaction) It was a really incredible experience and, in particular, my companions and I laughed a lot. The chef also explained to us that cooking is part of every region's culture and that a simple dish of pasta can unite even the most diverse people. (satisfaction)

Boy 2 (Eugenio): You're right, thinking about it, cooking is also important because it's part of the tradition. What do you think?

Participant: (avatars look at the responding participant)

Boy 2 (Eugenio): OK, it's nice that you were able to share this experience with your classmates.

(appreciation). The most beautiful part must have been kneading with your hands! Did you find it difficult?

Boy 1 (Giulia): Some things were a bit complicated, but the chef had a lot of patience and was always behind us. In the end, we all managed to prepare delicious dishes! (satisfaction)

Boy 2 (Eugenio): How nice to learn this way. Maybe one day you and your mates could all cook dinner together. (enthusiasm)

Boy 1 (Giulia): Yeah, that would be really fun! I’m looking forward! (enthusiasm)

LEVEL: INCLUSION-ADOLESCENTS (14-16)

Boy 1 (Nicola): Hi! I'm Nicola. What are your names?

Boy 2 (Caterina): Hi! I'm Caterina, nice to meet you! And you?

Participant: (avatars turn to look at the participant introducing themselves)

Boy 1 (Nicola): Nice to meet you! What's the last interesting thing you two did at school?

Boy 2 (Caterina): Well, I think the most interesting one was a science project where we explored the environment of our city. It was very cool! (enthusiasm)

Boy 1 (Nicola): Nice! We did a cool project too, but in technology, where we programmed and developed a little game. What did you do? (Curiosity)

Participant: (avatars look at the participant answering and continue to look at him referring to him in subsequent questions)

Boy 1 (Nicola): That sounds very interesting, what did you do specifically? (Curiosity) Participant: (avatars look at the participant while responding)

Boy 2 (Caterina): I see. Did you enjoy it? What did you feel at that moment? (Curiosity) Participant: (avatars look at the participant while responding)

Boy 1 (Nicola): I can imagine. And you, Caterina, what exactly did you do in your project? (Curiosity)

Boy 2 (Caterina): We learnt to recognise the species of plants and animals in our city. We also visited a nature park to directly observe the environment. It was really interesting to discover how each species performs a specific function! (enthusiasm)

Boy 1 (Nicola): Wow, that sounds really interesting! I like the idea of exploring the environment and seeing what it's like. Have you ever done anything similar with the school?

Participant: (avatars look at the responding participant)

Boy 1 (Nicola): Understood. How did you feel during the project? (Curiosity)

Boy 2 (Caterina): I felt very involved. It was like being a real scientist, observing nature, collecting data and doing experiments. I also liked it when we reconstructed the environment ourselves to better understand how it works! (enthusiasm)

Boy 1 (Nicola): Nice! The technology project we did was interesting as well. We created a little game using computer algorithms. (enthusiasm)

Boy 2 (Caterina): Top that cool! They never made us use algorithms. Did you guys ever do anything about computer science at school?

Participant: (avatars look at the responding participant)

Boy 2 (Caterina): OK, Nicola, did you find it difficult? (Curiosity)

Boy 1 (Nicola): A little bit, to be honest, but then I had fun. It was fun to create characters, levels and challenges. I also enjoyed solving the problems that arose and improving the game! (enthusiasm)

Boy 2 (Caterina): That's really interesting! I like the idea of developing a game using programming. It would be great if they made us do it too. (enthusiasm)

Boy 1 (Nicola): Yes, it would be really useful, even as an alternative activity to the usual school lessons. What do you think? (satisfaction)

Participant: (avatars look at the responding participant)

Boy 1 (Nicola): I see, in the meanwhile I was thinking, Caterina, have you ever thought of proposing this project to your teachers? It could be a fun way to learn and put digital knowledge into practice! (Curiosity)

Boy 2 (Caterina): Good idea! We should definitely talk to them and see if there is a possibility of introducing a similar project in our school. I'm convinced that many of our classmates would love to participate! Wouldn't you be happy if they asked you? (enthusiasm)

Participant: (avatars look at the responding participant)

Boy 1 (Nicola): I'm sure that if you can present your project convincingly, your teachers will be happy to give you this opportunity. You just have to make sure you are convincing (determination) Do you have any ideas for being convincing?

Participant: (avatars look at the responding participant)

Boy 2 (Caterina): Exactly! We have to show them how motivated we are. I think we could also involve the other kids from the school, forming a small team to develop the game together. (enthusiasm)

Boy1 (Nicola): Yes, it would be great to work together with other students. You could exchange ideas, collaborate and learn even more. Maybe you could even enter a competition. (enthusiasm)

Boy 2 (Caterina): I like how you're thinking big! I’m looking forward to start organising. (determination)

CHAPTER 4

Experiencing Peer Exclusion in 3D:

An Immersive Virtual Environment Study

Giuseppe De Luca[1,2], Martina Benvenuti[1], Dieter Baeyens[2], Gerrit Meixner[3], Tung Khau[3], Elvis Mazzoni[1], Friederike Blume[4,5]

[1] University of Bologna, Department of Psychology, Italy

[2] KU Leuven, Parenting and Special Education Research Unit, Belgium

[3] Heilbronn University, Usability and Interaction Technology Laboratory, Germany

[4] DIPF | Leibniz Institute for Research and Information in Education, Frankfurt/Main, Germany

[5] IDeA Research Centre for Individual Development and Adaptive Education of Children at Risk, Frankfurt/Main, Germany

Bibliographical reference:
De Luca, G., Benvenuti, M., Baeyens, D., Meixner, G., Khau, T., Mazzoni, E., Blume, F (*Under Review*) Experiencing Peer Exclusion in 3D: An Immersive Virtual Environment Study. In *Acta Psychologica*.

Abstract

Peer exclusion is linked to adverse outcomes, including reduced mood and unmet psychological needs. While the 2D Cyberball paradigm is widely used to simulate peer exclusion, its limited ecological validity has raised concerns. Therefore, this study compared the 2D Cyberball paradigm with a newly developed 3D Virtual Reality (VR) paradigm simulating peer exclusion in a classroom conversation.

Seventy-six children (aged 8–12) and seventy-four adolescents (aged 13–16) participated in a counterbalanced within-subject design. Participants experienced both paradigms in two separate sessions. Mood and psychological needs were assessed before and after each paradigm. Moderator variables included paradigm features, social support, and previous rejection experiences. Repeated-measures ANOVAs were conducted.

Both paradigms led to a decrease in positive mood and psychological needs and an increase in negative mood. However, stronger negative effects emerged after the 2D Cyberball paradigm. The 3D VR paradigm was perceived as more realistic and immersive, and its effects remained consistent across levels of the moderator variables, indicating robustness in responses. Adolescents showed stronger emotional and motivational reactions than children in the 3D VR condition, but not in the 2D Cyberball condition, suggesting greater developmental sensitivity of the immersive simulation.

Overall, results confirm that the 3D VR paradigm effectively simulates peer exclusion while offering higher ecological validity than the 2D version. Although the 2D Cyberball paradigm elicited more intense negative effects, the 3D VR paradigm better captured naturalistic and age-related differences in peer exclusion experiences, thereby providing a more developmentally appropriate and ecologically valid research tool.

Keywords: Peer exclusion, Virtual Reality, Cyberball paradigm, mood, psychological needs

Introduction

Children and adolescents interact with their peers daily, at school and during leisure time. These relationships shape the developmental context, thereby impacting a variety of outcomes (e.g., cognitive development; see Bronfenbrenner, 2005). Studies investigating the immediate, short-term effects of peer relationships used different methodological approaches, such as the 2D Cyberball paradigm, a computerised ball-tossing game (Williams, 2001). However, a direct comparison of the immediate effects of peer exclusion, as investigated using both the Cyberball paradigm and a paradigm with presumably higher ecological validity, was missing so far. Therefore, the main aim of this research was to compare two approaches, that is, a naturalistic 2D Cyberball paradigm and a 3D VR paradigm, to measure the effects of peer exclusion within the school context on students' mood and psychological needs. Furthermore, in accordance with the developmental disparities in peer relationships (e.g., Lila et al., 2020), the present research aimed to assess the differential effects of peer exclusion as simulated using the two paradigms among children (aged 8–12) and adolescents (aged 13–16).

Peer Exclusion

Peer exclusion refers to the condition in which an individual feels excluded or rejected by peers or peer groups (e.g., from an activity, a play, or a discussion; see Buhs et al., 2006). Individuals can be excluded by peers both emotionally, for instance by being ignored, or physically, for instance by not being chosen during a play or an activity (Riva & Eck, 2016). Additionally, peer exclusion can be classified into two distinct categories: direct and explicit versus indirect and implicit. The former is characterised by an explicit declaration of exclusion, such as when an individual makes a request to join others in a play activity and the group clearly declines the invitation (Killen & Rutland, 2011). The latter can be characterised by the absence of

such a declaration and could be exemplified by a child or adolescent speaking to a group of peers who respond by pretending not to hear them (Malti et al., 2012).

The extant literature provided robust evidence for negative short-term effects of peer exclusion. Studies have shown that exclusion elicits negative mood (i.e., feelings of sadness, tension, and rejection), lowers self-esteem, and diminishes perceived meaning in life (Abrams et al., 2011). These effects arise because children and adolescents feel disconnected from peers, perceive themselves as lacking competence in social relationships, and experience reduced autonomy and control (Asscheman et al., 2020). Taken together, these findings underscore the immediate negative consequences of peer exclusion. Overall, the evidence highlights that even brief episodes of peer exclusion can substantially threaten core psychological needs and emotional well-being in students.

Importantly, the immediate emotional consequences of peer exclusion have been found to vary according to individual and contextual factors. Prior research has shown that the effects of exclusion on mood and psychological needs are moderated by several variables. Gender has been found to play a significant role both in the behaviours associated with exclusion and its impact. Males tended to display more overt, physical, and direct behaviours, whereas females tended to engage in covert, emotional and indirect behaviours (Warrington & Younger, 2011). With regard to outcomes, females were more frequently responded with greater sensitivity and perceived exclusion as less ethical than males (Horn, 2003). Friendship and social support functioned as protective factors for both genders, though more strongly for females (Arslan, 2018). By contrast, prior rejection experiences constituted a risk factor for further exclusion regardless of gender (Will et al., 2016). Together, these findings illustrate that the emotional impact of peer exclusion is not

uniform but shaped by gender-specific coping patterns, relational contexts, and personal histories of social rejection.

Beyond gender and relational history, the developmental stage critically shaped the experience of exclusion. Evidence indicated that while the peer exclusion negatively affected both children and adolescents, its impact is particularly pronounced during adolescence (Fuhrmann et al., 2019). This heightened sensitivity reflects the increasing importance of peers during the transition from childhood to adolescence (Steinberg & Morris, 2001). Brain regions involved in socio-emotional functioning undergo substantial development at this stage (Sebastian et al., 2010), supporting adolescents' growing autonomy and independence from parents, which is achieved largely through reliance on peers (Nelson et al., 2005). Close peer relationships provide emotional security, social connection, and opportunities to develop social skills relevant for everyday life and future contexts (Wentzel, 1998, Rubin et al., 2015). Peer group formation further enables adolescents to relate to others with shared interests and hobbies (Lila et al., 2020). However, because adolescents perceive their social status as fragile and highly sensitive to peer evaluation, rejection and exclusion can undermine self-concept and adjustment (Brown & Larson, 2009). Over time, repeated experiences of peer exclusion have been linked to internalising problems such as anxiety, depression, withdrawal, loneliness, and school disengagement (Kingery et al., 2011). Hence, adolescence represents a developmental phase of heightened vulnerability to the psychological costs of peer exclusion, making it a critical period for studying and addressing the mechanisms underlying these experiences.

Experimental Paradigms Inducing Peer Exclusion

Peer exclusion simulations have enabled the investigation of its immediate effects of using an economical and convenient methodology that does not require the presence of actual peers

(Scheithauer et al., 2013). Such simulations are essential for studying peer exclusion in controlled settings and for permitting causal inferences (Wölfer & Scheithauer, 2013). Among these, the 2D Cyberball paradigm (Williams, 2001) remains the most widely used method of manipulating peer exclusion.

The 2D Cyberball Paradigm

The 2D Cyberball paradigm is an online ball-tossing game presented on a regular screen, in which participants believe they are playing with two real peers, though they are in fact interacting with standardised avatars. To enhance realism, the test manager provides bibliographic information about the avatars. All players pass a ball among each other. In the peer exclusion condition, the participant receives the ball only twice at the beginning of the game and is then no longer included in the exchanges, whereas in the inclusion condition, they receive it frequently. The percentage of the number of tosses directed to the participant g reflects the degree of inclusion or exclusion.

The 2D Cyberball paradigm has been shown to effectively simulate peer exclusion by reducing key psychological needs, such as belonging, control, certainty, self-esteem, and meaningful existence (Abrams et al., 2011). Rooted in Williams' (2001) ostracism model, it has been found to reliably induce negative affect (e.g., such as sadness, anger, and discomfort) when participants are ignored, fostering feelings of alienation, reduced social influence, and diminished self-worth. Despite its strengths, the 2D Cyberball paradigm has notable limitations in capturing the complexity of real-life social dynamics.

First, the 2D Cyberball paradigm presents limited ecological validity (i.e., generalisability of findings to real-life contexts; Parsons, 2015). Participants interact only through ball passing, without verbal or behavioural exchanges, thus limiting opportunities to react as they would in

everyday exclusion, and thereby hampering ecological validity (Prendergast & Schubert, 2020). Secondly, the simple graphics and basic design of the 2D Cyberball paradigm may be unengaging, particularly for children and adolescents accustomed to high-quality video games and immersive environments. This lack of realism may lead to boredom, which could confound the effects of exclusion by introducing frustration unrelated to the manipulation itself (Tuijnman et al., 2021).

Increasing ecological validity may refine insights from traditional studies using the 2D Cyberball paradigm. By providing more naturalistic environments, 3D VR paradigms can simulate peer exclusion in ways that elicit emotional and behavioural responses more closely aligned with real-world experiences. Such settings may enhance the authenticity of exclusion, thereby strengthening the validity of observed outcomes. However, research comparing the ecological validity of peer exclusion manipulations remains scarce. Early efforts to adapt the 2D Cyberball paradigm into 3D VR (e.g., Kassner et al., 2012) have thus far yielded no substantial differences in participant responses between the 2D and 3D versions.

These limitations highlight the need for a new paradigm that preserves the methodological strengths of the 2D Cyberball paradigm while enhancing ecological validity through improved graphic design, richer peer interactions, and greater applicability in educational contexts. A 3D VR paradigm has the potential to meet these requirements (Mavromihelaki et al., 2014), warranting closer examination of how it may overcome the constraints of 2D approaches and advance understanding of mechanisms underlying peer exclusion.

3D VR Paradigms

3D VR is an increasingly utilised immersive technology that offers enhanced ecological validity compared to traditional 2D approaches such as the 2D Cyberball paradigm (Brown et al., 2020). Its strength lies in the capacity to replicate real-life settings and social dynamics more

naturally, thereby eliciting responses that closely mirror everyday experiences (Parsons, 2015). This realism underpins its ecological validity—the extent to which findings can generalise beyond the lab—which explains its growing adoption in educational research (Chirico et al., 2018). Unlike video games or 2D online tasks, 3D VR enables the design of experimental situations that more closely resemble authentic social interactions. Evidence from school-based studies supports the effectiveness of 3D VR paradigms for simulating both social and learning experiences (Villena-Taranilla et al., 2022).

Key features of 3D VR features like immersion, presence, involvement, and realism contribute to ecological validity by increasing students' focus on the virtual environment, attention, and emotional responses to the virtual environment (Riva et al., 2004). In this context, immersion refers to the perceived authenticity of the virtual experience, presence to the subjective sensation of *being there*, involvement to the perceived focus of the virtual scenario while filtering out external stimuli, and realism to the fidelity of real-life comparison (Di Natale et al., 2020). The characteristics enable participants to actively engage with tasks and activities in ways that approximate real-life behaviour (Villena-Taranilla et al., 2022). Accordingly, 3D VR constitutes a promising tool for educational research by providing a methodologically rigorous yet ecologically valid alternative to traditional paradigms. In particular, three-dimensional group conversations represent a potent simulation of peer exclusion scenarios, allowing for a more nuanced investigation of social interaction (Prendergast & Schubert, 2020). This evidence provides the foundation for employing 3D VR to simulate peer exclusion.

The Present Study

The primary objective of the present study was to validate the newly developed 3D VR paradigm by comparing its effects with those of the established 2D Cyberball paradigm for

simulating peer exclusion. For analyses that examined potential age-related differences, participants were grouped into children (8–12 years) and adolescents (13–16 years). Based on prior evidence, the following hypotheses (H) were derived.

H1: Peer exclusion was expected to increase participants' perceptions of exclusion and negative mood, while decreasing positive mood and psychological needs. These effects were expected irrespective of paradigm or age group.

H2a: Compared to the 2D Cyberball paradigm, the 3D VR paradigm was expected to yield stronger effects, leading to greater increases in perceived exclusion and negative mood, and greater decreases in positive mood and psychological needs.

H2b: The 3D VR paradigm would elicit higher ratings of immersion, presence, involvement, and realism than the 2D Cyberball paradigm.

H3a: Both paradigms were expected to exert stronger effects on mood and psychological needs among adolescents than among children.

H3b: Adolescents were expected to report higher levels of exclusion perception, immersion, presence, involvement, and realism than children.

H4. Peer exclusion was expected to have stronger effects on mood and psychological needs in female participants than in male participants, irrespective of paradigm.

H5. Received social support and prior rejection experiences were expected to moderate the relationship between peer exclusion and mood and psychological needs, irrespective of the paradigm. Specifically, social support was hypothesised to reduce the strength of these associations, whereas prior rejection experiences were expected to increase them.

Methods

Sample

The sample consisted of $N = 150$ students, aged between 8.33 and 16.08 years ($M = 12.54$, $SD = 2.14$). Of these, 76 were classified as children (aged 8–12; 50.7%; $M = 9.33$, $SD = 1.10$) and 74 as adolescents (aged 13–16; 49.3%; $M = 14.69$, $SD = 1.19$). Recruitment was conducted in regular education schools, as the country under study does not have dedicated schools for students with special educational needs. Consequently, the educational system is characterised by inclusive education, whereby students with and without special educational needs attend the same educational institutions. Students self-identified their gender by selecting from three options: male, female, or diverse. No participant selected the third option, resulting in two gender groups (male, female). Regarding socioeconomic status (SES), 88 participants, (58.7%) were from high-SES families, 60 participants (40%) from intermediate-SES families, and two from low-SES families (1.3%), as determined by INVALSI (Campodifiori et al., 2010). Students did receive no remuneration for their participation, though both schools and students were informed about the overall study findings.

Ethics Information

The research received approval from the University Institutional Ethical Committee Board of the University of Bologna (protocol number 0001227). Informed consent was obtained from all participants and their parents or legal guardians, as well as from the participants themselves.

Power Analysis

An a priori power analysis revealed that a sample of at least 150 participants was needed to detect main effects and two-way (within-between) interaction effects between the two paradigms in a repeated-measures ANOVA. Calculations were based on Abrams and colleagues

(2011), as the expected effect of peer exclusion manipulation on mood and psychological needs was small to medium with an effect size of $f = 0.15$, a power of .80, and an alpha of .05 (using G*Power 3.1).

Study Design

Data collection took place between October and December 2023, following the start of the school year in September. Participants were actively deceived regarding the study's purpose; they were informed that the research aimed to compare the psychological effects of two different video games presented in two formats, 2D and 3D, to identify the superior version. Students reported by teachers to have intellectual disabilities, physical impairments, or emotional difficulties were excluded if such conditions prevented them from understanding task instructions, hindered task completion due to motor or visual limitations, or posed a high risk of harmful impact from the exclusion manipulation (e.g., anxiety problems). Specifically, two students were excluded from the data collection: one due to intellectual disability and one due to emotional difficulties. Excluded students, as well as those unwilling to participate, continued with their regular school activities.

Each participant completed two experimental sessions on separate days within the same week, with a maximum interval of six days. To prevent bias, participants were asked not to discuss the experiment between sessions. To mitigate the negative impact of exclusion, an inclusion condition always followed each exclusion condition, using the same paradigm (i.e., 2D Cyberball paradigm or 3D VR paradigm; see the following section for details). After data collection, students were debriefed via group discussion and flyers detailing the study's aims and procedures (see Supplementary Material). These also contained a single-item measure assessing whether participants had shared information about the study's true aims between sessions.

Experimental Conditions

2D Cyberball. The 2D Cyberball paradigm (Williams, 2001) consisted of an online ball-tossing game presented on a standard laptop computer screen (11.6-inch diagonal). Participants were told they would play with two peers from another regional school, although the co-players were standardised avatars (see Supplementary Material). The task comprised 80 trials over five minutes, including both exclusion and inclusion conditions. Participants directed the ball using a standardised QWERTY keyboard, while avatar throws incorporated random jitter intervals (100-400 ms), with each throw lasting 2000 ms. In the exclusion condition, participants received the ball only twice at the beginning of the game, whereas in the inclusion condition, they received the ball one-third of the trials (17 times).

3D Virtual Reality. A 3D VR paradigm was developed featuring two avatars (one male, one female) engaged in a school-related discussion (see Figure 1 and Figure 2). Three versions were tailored to primary, junior, and high school students, with adaptations in avatar design, voices, language, and themes. Despite these variations, each scenario maintained a consistent structure involving a conversational task (see Figure 3). Participants were informed they would interact with real peers from other regional schools (see Supplementary Material). Following a two-minute orientation phase in the VR environment, the interaction commenced (see Supplementary Material). In the exclusion condition, avatars ignored the participant's input and conversed only with each other according to a pre-scripted dialogue. In the inclusion condition, avatars responded positively to the participant (e.g., "Nice!"). Each condition lasted five minutes, with total interaction time, including orientation, not exceeding ten minutes. The 3D VR paradigm was implemented using the Oculus Meta Quest 2 device (Meta, 2022).

Figure 1

Screen Capture of the Virtual Environment Designed for Preadolescents

Figure 2

Screen Capture of the Virtual Classroom

Figure 3

Screen Capture of the Virtual Environment Conversational Task

Procedure

The sample was recruited by contacting the headmasters of three schools. Upon their approval, informed consent was obtained from parents and legal guardians. Teachers then provided anonymised class data, including the number of students whose parents had consented to participate and identifying (via anonymised set-up codes) those with atypical developmental problems, who were deemed ineligible.

Parents completed questionnaires assessing family SES (Campodifiori et al., 2010), and demographic information (i.e., child's gender, age, Grade and school type attended). Participants completed questionnaires on prior social rejection experiences and perceived social support from parents, teachers, and friends (Children & Adolescents Social Support Scale, CASSS; Gini et al., 2009). All questionnaires were sent out through Qualtrics (XM, 2023). All data were anonymised

through the set-up code system. Participants were then randomly assigned (counterbalanced via the code) to complete either the 2D Cyberball paradigm or the 3D VR paradigm first.

Each participant took part in two test sessions, conducted individually in a quiet room at school during regular hours. The first session lasted 30-40 minutes and comprised baseline and post-measures alongside exposure to either the 2D Cyberball or the 3D VR paradigm. The second session, scheduled one to six days later, followed the same procedure and included exposure to the paradigm not used in the first session.

Measures

Demographic Variables. Information on participants' age and gender was reported by parents at the beginning of the study via closed-ended questions. Gender was assessed with a single item offering three response options: male, female, and diverse. Age was reported in years and months.

Socioeconomic Status. Socioeconomic status (SES) was assessed using the Italian National Institute for the Evaluation of the Education and Training System (INVALSI) questionnaire (INVALSI; Campodifiori et al., 2010). The measure comprises three factors: parents' employment status (one item with nine response options, ranging from *Unemployed* to *Director* or *Freelancer*), parents' educational level (one item with seven response options, ranging from *Primary school* to *PhD*), and possession of specific properties (e.g., number of rooms and books). Educational level and employment status items were scored on a scale from 0 to 5, while property possession items were coded dichotomously (0 = absent, 1 = present). A composite SES index was obtained by summing the three subscale scores, yielding values from 0 to 25, with higher scores indicating higher SES.

Mood and Psychological Needs. A 36-item scale developed by Williams and colleagues (2000) was used to assess participants' perception of exclusion, mood, and psychological needs. The scale comprised five items for each psychological need (belonging, control, certainty, self-esteem, meaningful existence), eight mood items (good, bad, happy, sad, pleasant, angry, friendly, unfriendly), and two manipulation check items assessing perceived exclusion. The Italian version of this scale (Timeo et al., 2020) was administered before and after every exclusion condition, to assess the changes in mood and psychological needs. Responses were given on a 5-point Likert scale (1 = *not at all*, 5 = *extremely*). Higher scores reflected greater needs' satisfaction, stronger endorsement of the respective mood, and stronger perceptions of exclusion.

To validate the factor structure, two CFAs were conducted. For mood, a two-factor model with correlated latent factors for positive mood ('good', 'happy', 'pleasant', 'friendly') and negative mood ('bad', 'sad', 'angry', 'unfriendly') indicated the best fit (cf. Hu & Bentler, 1999), $\chi^2(12) = 18.207$, $p = .110$l CFI = 0.983, TLI = 0.960, RMSEA = 0.059 (90% CI = 0.000–0.110, p-close = .352), SRMR = 0.039. Standardised factor loadings ranged from .442 to .719 (positive mood) and from .376 to .666 (negative mood) and were all significant ($p < .001$) except the mood 'bad' (loading = .137, ns). This supports that the scale differentiated between positive and negative mood (Supplementary Material, Tables S1, S2).

For psychological needs, a one-factor model ('belongingness', 'self-esteem', 'certainty', 'control', 'meaningful existence') with correlated latent factors fitted the data best (Hu & Bentler, 1999), $\chi^2(224) = 247.143$, $p = .138$, CFI = 0.985, TLI = 0.980, RMSEA = 0.026 (90% CI = 0.000–0.044, p-close = .989), SRMR = 0.064. Standardised loadings were generally strong: belongingness (.332-.516), self-esteem (.625-.911), meaningful existence (.395-.634), control (.182-.527, with one weaker loading on the fourth item, .182, $p = .040$), and certainty (.240-.697).

All loadings were significant at $p < .05$, indicating items contributed meaningfully to their respective constructs (Supplementary Material, Tables S3, S4, S5).

Cronbach's alpha values indicated satisfactory to excellent reliability: positive mood ($\alpha = .87$), negative mood ($\alpha = .80$), psychological needs ($\alpha = 0.94$), and manipulation check *(*$\alpha = 0.79$). Accordingly, composite sum scores for each subscale were computed for subsequent analysis.

Previous Rejection Experiences. Participants' previous rejection experiences were assessed with a 25-item self-report scale developed in line with our operationalisation of peer exclusion. Items were drawn from established questionnaires on peer relations (Achenbach, 1991; Asher et al., 1984; Knickenberg et al., 2022; Ladd et al., 2009; Marcoen et al., 1987; Schmidt et al., 2019; Secker et al., 2009; Skårbrevik, 2005) and translated into Italian using forward-backwards translation. The items captured both behaviours experienced and emotions felt, covering the following domains: exclusion from school activities (3 items), exclusion from play (3 items), exclusion from talking/discussion (2 items), emotional and physical exclusion (2 items), direct and indirect exclusion (3 items), implicit and explicit exclusion (3 items), negative mood (3 items), loneliness (3 items), and lack of feedback (3 items). Responses were provided on a 5-point Likert scale (1 = *completely disagree*, 5 = *completely agree*), with higher scores indicating greater rejection experiences.

An exploratory factor analysis (EFA) was conducted to validate the scale's factor structure. Suitability was confirmed by the Kaiser–Meyer–Olkin measure (KMO = 0.953) and Bartlett's Test of Sphericity, $\chi^2(276) = 2839.266$, $p < .001$. Using Maximum Likelihood extraction, the optimal solution was a single factor, supported by an eigenvalue > 1 rule ($\lambda = 13.552$), inspection of the scree plot, and parallel analysis (first factor's eigenvalue = 13.552 vs. simulated mean = 1.831). No rotation was applied. Factor loadings ranged from .46 to .85, and communalities exceeded .40

for most items. The single factor explained 54.7% of the variance. Fit indices were RMSEA = 0.083, SRMR = 0.051, TLI = 0.887, and CFI = 0.897, indicating an acceptable model. One item ("I didn't take the lead in social activities") was removed for poor alignment with the factor solution (see Supplementary Material, Tables S6, S7, Figure F1). The final 24-item scale demonstrated excellent internal consistency (Cronbach's $\alpha = 0.96$). A composite sum score was computed for subsequent analyses.

Social Support. The Child and Adolescent Social Support Scale (CASSS; Malecki & Demaray, 2002) was administered to assess perceived social support. It consisted of 40 items in which participants rated the frequency of specific supportive behaviours (e.g., "My parents help me to solve my problems"). It comprised four subscales: support from parents; support from teachers; support from classmates, and support from close friends. Items were rated on a 6-point Likert (1 = *never*, 6 = *always*). Subscale scores were aggregated to compute a composite sum score, with higher scores indicating greater perceived social support. In the present study, the internal consistency for the full scale was excellent, with Cronbach's $\alpha = 0.94$.

Paradigm Features. Participants' involvement, presence, immersion, and perception of realism were assessed after each experimental condition. Four items, constructed based on existing measures (Witmer et al., 2005; Wiebe et al., 2014; Will et al., 2016; Bodzin et al., 2021), were administered at the end of both paradigms. An exploratory factor analysis (EFA) was conducted to examine the scale's structure. Sampling adequacy was acceptable (KMO = 0.731), and Bartlett's Test of Sphericity was significant, $\chi^2(6) = 269.285$, $p < .001$. Maximum Likelihood extraction supported a one-factor solution, as indicated by an eigenvalue > 1 ($\lambda = 2.630$), scree plot inspection, and parallel analysis (2.630 vs. 1.193). No rotation was applied. Communalities were high for immersion ($h^2 = 0.901$), perception of realism ($h^2 = 0.651$), and presence ($h^2 = 0.560$). Involvement

showed lower communality ($h^2 = 0.167$), but was retained for theoretical relevance. The factor explained 57.3% of the variance. Fit indices suggested an overall acceptable model: RMSEA = 0.155, SRMR = 0.046, TLI = 0.918, and CFI = 0.973 (the high RMSEA likely reflecting the low item number and low degrees of freedom). Factor loadings ranged from 0.40 to 0.94 (Supplementary Material, Tables S8, S9, Figure F2). Internal consistency was acceptable, Cronbach's $\alpha = 0.78$. A composite sum score was computed and used in subsequent analyses.

Statistical Analyses

We used IBM SPSS Statistics (Version 27, IBM Corp., 2020) for all our analyses. As a preliminary step, the internal consistency of all scales was verified using Cronbach's alpha (cf. supra), and assumptions of normality were assessed through skewness, kurtosis, and visual inspection of histograms and Q–Q plots. Reliability indices across all measures in the present study ranged from $\alpha = .78$ (minimum, *Paradigm Features*) to $\alpha = .96$ (maximum, *Previous Rejection Experiences*), indicating overall acceptable to excellent internal consistency. Tests of normality indicated no significant deviations from a normal distribution for any of the variables. All participants provided complete data on all measures, except for one participant who was excluded from the analyses because he did not attend the second pre-to-post assessment; therefore, no imputation due to missing data was necessary. Finally, for each hypothesis, we conducted a sensitivity analysis to control for potential bias introduced by students who had received information about the peer exclusion manipulation or were aware of the deception. However, the results remained unchanged after excluding these cases, supporting the robustness of our findings. To account for the nested structure of the data (i.e., students within classes and schools), we tested for clustering effects by computing intraclass correlation coefficients (ICCs) for pre-to-post difference scores of the outcome variables. All ICCs fell within an acceptable range (Hox et al.,

2017), with the highest reaching 0.13, indicating moderate clustering. Therefore, the variance structure did not warrant the use of multilevel modelling, and standard analyses were retained.

To test hypotheses H1 and H2a, that both the 2D Cyberball and the 3D VR paradigm reduce positive mood and psychological needs while increasing negative mood from baseline to post-measurement, and that the 3D VR paradigm exerts stronger effects than the 2D Cyberball paradigm, we conducted three 2 × 2 repeated-measures ANOVA *(Time × Paradigm)*. Paradigm (i.e., 2D Cyberball vs. 3D VR) served as the independent variable and positive mood, negative mood, and psychological needs as the dependent variables. Post-hoc pairwise comparisons compared post-paradigm outcomes between the two conditions and time-points.

To test the hypothesis H2b, which expected that the 3D VR paradigm would yield higher ratings of immersion, presence, involvement, and realism, we conducted a 2 × 2 × 2 repeated-measures ANOVA (*Time* × *Paradigm* × *Paradigm Features*). Paradigm (i.e., 2D Cyberball vs. 3D VR) served as the independent variable and positive mood, negative mood, and psychological needs as the dependent variables. Paradigm features (i.e., immersion, presence, involvement, realism) was included as within-subject moderator. Post-hoc analyses of parameter estimates assessed the extent to which these features influenced mood and psychological needs.

To test the third set of hypotheses (H3a–b), we conducted two sets of analyses. For H3a, which expected that adolescents would show stronger responses to exclusion than children, three 2 × 2 × 2 repeated-measures ANOVAs (*Time* × *Paradigm* × *Age Group*) were performed with Time (baseline vs. post), Paradigm (2D Cyberball vs. 3D VR), and Age Group (children vs. adolescents) as factors. Paradigm served as the within-subject factor, and positive mood, negative mood, and psychological needs as the dependent variables, with Age Group as the between-subject moderator. Significant interactions were followed up with Bonferroni-adjusted post-hoc

comparisons. For H3b, which expected age-related differences in perceived exclusion and paradigm features, two 2 × 2 repeated-measures ANOVAs (*Paradigm × Age Group)* were conducted with Paradigm (i.e., 2D Cyberball vs. 3D VR) as the within-subject factor and Age Group (children vs. adolescents) as the between-subject factor. The first ANOVA tested perceived exclusion across paradigms and age groups, and the second examined ratings of paradigm features (immersion, presence, involvement, realism). Significant main and interaction effects were further explored using Bonferroni-adjusted post-hoc comparisons.

To test the fourth hypothesis, that effects are stronger in females than in males, we conducted three 2 × 2 × 2 repeated-measures ANOVAs (*Gender × Time × Paradigm*). Paradigm served as the independent variable, and positive mood, negative mood, and psychological needs as the dependent variables. Gender (males vs. females) served as the between-subject moderator. Significant interactions were followed up with Bonferroni-adjusted post-hoc comparisons.

To test the fifth hypothesis, that received social support and previous rejection experiences moderate the effects of exclusion on positive mood, negative mood, and psychological needs, we conducted six 2 × 2 repeated-measures ANCOVAs *(Time × Paradigm × Moderator)*. Time (baseline vs. post) and Paradigm (2D Cyberball vs. 3D VR) served as within-subjects factors, and positive mood, negative mood, and psychological needs were entered as dependent variables. Received social support and previous rejection experiences were entered as covariates in separate sets of analyses. For significant interaction effects involving a covariate, parameter estimates were examined post hoc to determine how the covariate was associated with changes in outcomes across paradigms.

Results

Table 1 presents the descriptive statistics, intercorrelations, and distributions of the variables of interest. Age correlated negatively with positive mood and psychological needs at baseline, indicating that younger participants reported higher positive mood and psychological needs prior to the experiment. Previous rejection experiences correlated positively with negative mood and negatively with psychological needs measured at baseline. In contrast, social support was positively associated with positive mood and psychological needs measured at baseline.

Table 1

Descriptive Statistics, Distributions, and Correlations

Variable	*M*	*SD*	Min	Max	1	2	3	4	5	6	7	8	9
1. Age	12.54	2.14	8.33	16.08	—								
2. SES	35.03	5.20	23.00	46.00	–.08	—							
3. Previous Rejection Experiences	57.58	22.03	27.00	120.00	.05	–.04	—						
4. Total Social Support	206.94	33.68	128.00	278.00	**–.20**	.01	**–.32**	—					
5. Baseline Positive Mood	16.47	2.59	8.00	20.00	**–.40**	–.01	**–.25**	**.28**	—				
6. Baseline Negative Mood	6.15	2.33	4.00	15.00	**.22**	.07	**.22**	**–.18**	**–.51**	—			
7. Baseline Psychological Needs Satisfaction	95.16	14.07	62.00	121.00	**–.21**	.04	**–.54**	**.26**	**.47**	**–.44**	—		
8. Paradigm Features 2D	7.82	3.68	4.00	20.00	–.00	–.05	**.30**	–.06	–.03	.06	–.15	—	
9. Paradigm Features 3D VR	10.82	4.50	4.00	20.00	**–.45**	–.12	.09	.12	.16	–.03	.04	**.31**	—

Note. *M* = Mean; *SD* = Standard Deviation; Min = Minimum; Max = Maximum; SES = Socio-Economic Status; VR = Virtual Reality; Paradigm = 2D Cyberball vs. 3D VR; Paradigm Features = composite score of immersion, presence, involvement, and perceived realism. $p < .05$ marked bold.

Table 2 presents descriptive statistics for the full sample and for children, adolescents, males, and females across both the 2D Cyberball and 3D VR paradigms. Baseline and post-test scores for positive mood, negative mood, and psychological needs are reported alongside the corresponding *t*-test statistics. Across all groups, participants showed significant decreases in positive mood and psychological needs satisfaction, as well as significant increases in negative mood, following the exclusion manipulation in both paradigms. These patterns were consistent across age and gender subgroups, with all comparisons being statistically significance.

Table 3 presents the descriptive statistics and distributions for the child and adolescent groups, as well as for males and females. Additionally, the groups were tested for systematic differences in the variables of interest. Significant group differences emerged for adolescents. Specifically, adolescent males reported higher baseline positive mood than females and lower baseline negative mood. Adolescent males also reported higher psychological needs satisfaction than females and perceived the 3D VR paradigm as significantly more immersive and realistic. No significant gender differences were observed among children. Furthermore, Chi-square tests indicated that age group distribution (children vs. adolescents) and gender distribution (males vs. females) did not differ significantly, suggesting that the sample composition was balanced across these categories.

Table 2

Descriptive Statistics [mean ± SD] and Group Comparisons for the 2D Cyberball and the 3D VR Conditions

		2D Cyberball				3D VR			
		Baseline	Post-Test	*t*(df)	*p*	Baseline	Post-Test	*t*(df)	*P*
Positive Mood	Full sample (*n* =150)	16.47 ± 2.59	10.44 ± 4.37	14.54 (242.18)	< .001*	16.42 ± 2.55	12.16 ± 4.59	9.94 (232.98)	< .001*
	Children (*n* = 76)	17.62 ± 2.42	11.21 ± 4.59	10.77 (113.71)	< .001*	17.17 ± 2.42	13.70 ± 4.69	5.73 (112.29)	< .001*
	Adolescents (*n* = 74)	15.66 ± 2.53	9.65 ± 4.02	10.88 (122.99)	< .001*	15.66 ± 2.58	10.59 ± 3.94	9.26 (125.88)	< .001*
	Males (*n* = 79)	16.95 ± 2.38	11.16 ± 4.64	9.87 (116.39)	< .001*	16.91 ± 2.23	12.61 ± 4.56	7.53 (113.29)	< .001*
	Females (*n* = 71)	15.94 ± 2.73	9.63 ± 3.93	11.11 (124.80)	< .001*	15.89 ± 2.79	11.68 ± 4.61	6.58 (115.21)	< .001*
Negative Mood	Full sample (*n* =150)	6.15 ± 2.33	10.66 ± 4.17	–11.56 (233.77)	< *.001	6.28 ± 2.49	8.27 ± 4.00	–5.17 (249.40)	< .001*
	Children (*n* = 76)	5.61 ± 2.01	10.54 ± 4.61	–8.55 (102.52)	< .001*	5.80 ± 2.21	7.33 ± 3.85	–3.00 (119.59)	.003*
	Adolescents (*n* = 74)	6.72 ± 2.53	10.80 ± 3.70	–7.83 (129.02)	< .001*	6.77 ± 2.69	9.24 ± 3.96	–4.44 (128.54)	< .001*
	Males (*n* = 79)	5.81 ± 2.00	10.45 ± 4.22	–8.83 (111.36)	< .001*	5.86 ± 2.18	8.23 ± 4.12	–4.52 (118.50)	< .001*
	Females (*n* = 71)	6.42 ± 2.56	10.75 ± 3.79	–7.98 (122.87)	< .001*	6.40 ± 2.65	8.30 ± 4.05	–3.31 (120.65)	.001*
Psychological Needs	Full sample (*n* =150)	95.16 ± 14.07	55.55 ± 17.34	21.72 (285.87)	< .001*	95.76 ± 14.05	66.54 ± 22.66	13.42 (248.81)	< .001*
	Children (*n* = 76)	97.43 ± 13.32	56.29 ± 18.88	15.52 (134.84)	< .001*	98.16 ± 12.96	73.41 ± 24.92	7.68 (112.80)	< .001*
	Adolescents (*n* = 74)	92.84 ± 14.53	54.80 ± 15.70	15.30 (145.13)	< .001*	93.31 ± 14.78	59.50 ± 17.63	12.64 (141.68)	< .001*

Males (n = 79)	95.83 ± 13.75	56.02 ± 17.89	15.68 (146.31)	< .001*	96.12 ± 13.68	66.11 ± 23.65	9.76 (124.94)	< .001*
Females (n = 71)	94.51 ± 14.26	55.33 ± 16.92	14.92 (136.10)	< .001*	95.41 ± 13.82	66.90 ± 21.97	9.26 (117.90)	< .001*

Note. Group comparisons were conducted using paired-samples *t*-tests. t = *t*-value; df = degrees of freedom. *$p < .05$.

Table 3

Descriptive Statistics [mean ± SD] and Group Comparisons for Children vs. Adolescents and Males vs. Females

	Children				Adolescents			
	Male (n = 39)	Female (n = 37)	t(df)	p	Male (n = 40)	Female (n = 34)	t(df)	p
Age	9.37 (1.09)	9.29 (1.11)	0.32 (74)	.75	14.75 (1.21)	14.63 (1.17)	0.43 (72)	.67
SES	34.74 (5.38)	34.74 (5.38)	0.00 (74)	> .99	35.34 (5.03)	35.34 (5.03)	0.00 (72)	> .99
Received Social Support	202.00 (36.28)	212.45 (29.83)	1.15 (74)	.26	212.22 (38.68)	201.53 (26.83)	-0.63 (72)	.53
Previous Rejection Experiences	54.15 (21.78)	61.41 (21.84)	1.28 (74)	.20	60.00 (22.28)	58.87 (22.28)	-0.27 (72)	.79
Baseline Positive Mood	16.95 (2.38)	15.94 (2.73)	-0.75 (74)	.46	17.26 (2.42)	15.66 (2.53)	-2.47 (72)	.02*
Baseline Negative Mood	5.97 (2.47)	6.35 (2.19)	0.60 (74)	.55	5.61 (2.01)	6.72 (2.53)	1.87 (72)	.07
Baseline Psychological Needs	99.30 (11.95)	90.56 (14.88)	-1.79 (74)	.08	97.43 (13.32)	92.84 (14.53)	-1.74 (72)	.09
Paradigm Features 2D Cyberball	7.33 (3.76)	8.38 (3.53)	1.32 (74)	.19	7.68 (3.57)	7.97 (3.81)	0.50 (72)	.62
Paradigm Features 3D VR	11.14 (4.90)	10.48 (4.04)	-0.47 (74)	.64	12.80 (4.32)	8.80 (3.76)	-5.21 (72)	< .001*

Note. Paradigm = 2D Cyberball vs. 3D VR; Paradigm Features = composite score of immersion, presence, involvement, and perceived realism; SES = Socio-Economic Status. Follow-up comparisons were conducted using paired-samples t-tests. t = t-value; df = degrees of freedom. *$p < .05$.

Effects of the 2D Cyberball and the 3D VR Paradigm on Participants' Positive Mood, Negative Mood, and Psychological Needs

To test H1 and H2a, which expected that both paradigms would reduce positive mood and psychological needs while increasing negative mood, three 2 × 2 repeated-measures ANOVAs *(Time × Paradigm)* were conducted. Tables 4, 5, and 6 present the *F*-statistics and effect sizes for positive mood, negative mood, and psychological needs.

Positive Mood

As shown in Table 4, the results of a 2 × 2 repeated-measures ANOVA with positive mood as the dependent variable showed a significant main effect of *Time*, indicating a decrease from baseline (M = 16.45, SE = 0.20) to post-measurement (M = 11.30, SE = 0.31), $MDiff$ = 5.15, SE = 0.29, $p < .001$, 95% CI [4.57, 5.72]. A significant main effect of *Paradigm* indicated that, across both time points, positive mood differed between the 3D VR (M = 14.30, SE = 0.25) and 2D Cyberball (M = 13.46, SE = 0.24) paradigms, $MDiff$ = 0.84, SE = 0.22, $p < .001$, 95% CI [0.41, 1.26]. Moreover, the *Time × Paradigm* interaction was significant, indicating that the magnitude of decrease in positive mood differed by paradigm. Post-hoc pairwise comparisons showed a significant reduction in positive mood from baseline to post-measurement in both paradigms, with a less pronounced decrease for the 3D VR paradigm compared to the 2D Cyberball paradigm, $MDiff$ = 1.73, SE = 0.39, $p < .001$, 95% CI [0.96, 2.49]. Therefore, the significant *Time × Paradigm* interaction revealed that the 2D Cyberball paradigm led to a stronger average decline in positive mood. Baseline scores of positive mood did not differ significantly between the 2D Cyberball (M = 16.47, SE = 0.21) and the 3D VR paradigm (M = 16.43, SE = 0.21), indicating that post-exposure differences cannot be attributed to initial disparities.

Table 4

ANOVA Results: Main and Interaction Effects of Time and Paradigm on Positive Mood

	$F(1,149)$	p	ηp^2
Time	315.02*	< .001	0.679
Paradigm	15.01*	< .001	0.092
Time × Paradigm	19.46*	< .001	0.116

Note. All factors were within-subject factors. Paradigm = 2D Cyberball vs. 3D VR; Time = baseline vs. post. Paradigm features = composite score of immersion, presence, involvement, and perceived realism. ηp^2 = partial eta squared. Effect size interpretation for ηp^2 is as follows: small (≈ .01), medium (≈ .06), and large (≈ .14; Cohen, 1988). *$p < .05$.

Negative Mood

As shown in Table 5, the results of a 2 × 2 repeated-measures ANOVA with negative mood as the dependent variable showed a significant main effect of *Time*, indicating an increase from baseline (M = 6.22, SE = 0.18) to post-measurement (M = 9.47, SE = 0.28) across both paradigms, *MDiff* = -3.25, SE = 0.218, $p < .001$, 95% CI [-3.80, -2.71]. A significant main effect of *Paradigm* was also found, indicating that, across both time points, negative mood differed between the 2D Cyberball (M = 8.41, SE = 0.21) and the 3D VR paradigm (M = 7.28, SE = 0.22), *MDiff* = 1.13, SE = 0.21, $p < .001$, 95% CI [0.73, 1.43]. Importantly, the *Time* × *Paradigm* interaction was significant, indicating that the magnitude of increase differed by paradigm. Post-hoc pairwise comparisons supported a significant increase in negative mood in both paradigms, with a more pronounced increase following the 2D Cyberball paradigm than the 3D VR paradigm, *MDiff* = 2.39, SE = 0.37, $p < .001$, 95% CI [1.66, 3.12]. Therefore, the 2D Cyberball paradigm elicited stronger overall increases in negative mood. Baseline negative mood scores did not differ between the 2D Cyberball (M = 6.15, SE = 0.19) and the 3D VR paradigm (M = 6.28, SE = 0.20), ruling out pre-existing differences as an explanation for post-test differences.

Table 5

ANOVA Results: Main and Interaction Effects of Time and Paradigm on Negative Mood

	F(1,149)	*p*	ηp^2
Time	138.96*	< .001	0.483
Paradigm	30.33*	< .001	0.169
Time × Paradigm	37.51*	< .001	0.201

Note. All factors were within-subject factors. Paradigm = 2D Cyberball vs. 3D VR; Time = baseline vs. post. Paradigm features = composite score of immersion, presence, involvement, and perceived realism. ηp^2 = partial eta squared. Effect size interpretation for ηp^2 is as follows: small (≈ .01), medium (≈ .06), and large (≈ .14; Cohen, 1988). *$p < .05$.

Psychological Needs

As shown in Table 6, the results of a 2 × 2 repeated-measures ANOVA with psychological needs as the dependent variable indicated a significant main effect of *Time*, indicating a decrease in needs satisfaction from baseline (M = 95.47, SE = 1.12) to post-measurement (M = 61.05, SE = 1.39) across paradigms, *MDiff* = 34.42, SE = 1.35, $p < .001$, 95% CI [31.74, 37.09]. A significant main effect of *Paradigm* was also found, suggesting that participants reported differential effects for the 3D VR paradigm (M = 81.16, SE = 1.24) compared to the 2D Cyberball paradigm (M = 75.36, SE = 1.09), *MDiff* = 5.80, SE = 0.95, $p <$ .001, 95% CI [3.91, 7.68]. The *Time* × *Paradigm* interaction was significant, indicating that the magnitude of reduction differed by paradigm. Post-hoc pairwise comparisons indicated a significant decrease in psychological needs from baseline to post-measurement in both paradigms, with a more pronounced reduction following the 2D Cyberball paradigm compared to the 3D VR paradigm, *MDiff* = 10.99, SE = 1.76, $p < .001$, 95% CI [7.52, 14.47]. Therefore, the 2D Cyberball paradigm produced a stronger overall decline. Baseline psychological needs scores were comparable across the 2D Cyberball (M = 95.17, SE = 1.15) and the 3D VR paradigm (M = 95.77, SE = 1.15), ruling out pre-existing differences as an explanation for post-test effects.

Table 6

ANOVA Results: Main and Interaction Effects of Time and Paradigm on Psychological Needs

	F(1,149)	*p*	*ηp²*
Time	646.96*	< .001	0.813
Paradigm	36.81*	< .001	0.198
Time × Paradigm	34.28*	< .001	0.187

Note. All factors were within-subject factors. Paradigm = 2D Cyberball vs. 3D VR; Time = baseline vs. post. Paradigm features = composite score of immersion, presence, involvement, and perceived realism. *ηp²* = partial eta squared. Effect size interpretation for *ηp²* is as follows: small (≈ .01), medium (≈ .06), and large (≈ .14; Cohen, 1988). **p* < .05.

Effects of the 2D Cyberball and 3D VR Paradigms Moderated by Paradigm Features

To test the hypothesis that paradigm features would moderate the effects of the 2D Cyberball and 3D VR paradigms on positive mood, negative mood, and psychological needs, three 2 × 2 × 2 repeated-measures ANOVAs (*Time* × *Paradigm* × *Paradigm Features*) were conducted. The components of immersion, presence, involvement, and perceived realism were combined into a single composite variable labelled *Paradigm Features*. The analysis examined whether this composite variable moderated the effects of the two paradigms. The main and interaction effects on positive mood are reported in Table 7, on negative mood in Table 8, and on psychological needs in Table 9.

Positive Mood

As shown in Table 7, the results of a 2 × 2 × 2 repeated-measures ANOVA with positive mood as the dependent variable showed a significant main effect of *Time*, indicating that positive mood decreased from baseline (M = 16.45, SE = 0.19) to post-measurement (M = 11.30, SE = 0.30) across conditions, $MDiff$ = 5.15, SE = 0.29, $p < .001$, 95% CI [4.57, 5.72]. The main effect of *Paradigm* was not significant. There was a significant main effect of *Paradigm Features*, indicating that higher paradigm feature scores were, on average, associated with higher positive mood. The *Time* × *Paradigm* interaction was not significant. Both the *Time* × *Paradigm Features* and *Paradigm* × *Paradigm Features* interactions were significant, suggesting that the relation between paradigm features and positive mood varied from the baseline to the post-measurement and between paradigms. The *Time* × *Paradigm* × *Paradigm Features* interaction was significant, suggesting that changes from baseline to post-measurement differed between paradigms as a function of paradigm features. Follow-up parameter estimates for this three-way interaction showed that, in the 3D VR condition, paradigm features were significantly associated with post-test positive mood, B = 0.36, SE = 0.07, $p < .001$, but not baseline scores, B = 0.08, SE = 0.04, p = .064. In the 2D Cyberball

condition, paradigm features were not significantly associated with baseline, $B = 0.09$, $SE = 0.04$, $p = .051$, or post-test positive mood scores, $B = 0.09$, $SE = 0.08$, $p = .240$).

Table 7

ANOVA Results: Main and Interaction Effects of Time, Paradigm, and Paradigm Features on Positive Mood

	$F(1,148)$	p	ηp^2
Time	80.32*	< .001	.352
Paradigm	1.25	.264	.008
Paradigm Features	12.03*	<.001	.075
Time × Paradigm	1.57	.211	.011
Time × Paradigm Features	5.01*	.027	.033
Paradigm × Paradigm Features	8.18*	.005	.052
Time × Paradigm × Paradigm Features	10.55*	.001	.067

Note. All factors were within-subject factors. Paradigm = 2D Cyberball vs. 3D VR; Time = baseline vs. post. Paradigm features = composite score of immersion, presence, involvement, and perceived realism. ηp^2 = partial eta squared. Effect size interpretation for ηp^2 is as follows: small (≈ .01), medium (≈ .06), and large (≈ .14; Cohen, 1988). *$p < .05$.

Negative Mood

As shown in Table 8, the results of a 2 × 2 × 2 repeated-measures ANOVA with negative mood as the dependent variable indicated a significant main effect of *Time*, with negative mood increasing from baseline (M = 6.22, SE = 0.18) to post-measurement (M = 9.47, SE = 0.28) across paradigms, *MDiff* = -3.25, SE = 0.218, $p < .001$, 95% CI [-3.80, -2.71]. The main effect of *Paradigm* was also significant, indicating that negative mood differed overall between the 2D Cyberball (M = 8.41, SE = 0.21) and the 3D VR paradigm (M = 7.28, SE = 0.22), *MDiff* = 1.13, SE = 0.21, $p < .001$, 95% CI [0.73, 1.43]. The main effect of *Paradigm Features* was not significant, indicating that the association between paradigm features and changes in negative mood did not differ between the 3D VR and 2D Cyberball paradigms. The *Time* × *Paradigm*, *Time* × *Paradigm Features*, and *Paradigm* × *Paradigm Features* interactions were not significant. However, the *Time* × *Paradigm* × *Paradigm Features* interaction was significant, indicating that the association between paradigm features and changes in negative mood differed between the 3D VR and 2D Cyberball paradigms. Follow-up parameter estimates indicated that paradigm features were associated with post-test negative mood in the 3D VR condition but not in the 2D Cyberball condition. In the 3D VR condition, higher paradigm features were associated with lower post-test negative mood, B = –0.20, SE = 0.07, p = .005, but not baseline negative mood, B = -0.05, SE = 0.07, p = .444. In the 2D Cyberball condition, paradigm features were not significantly associated with negative mood at either baseline, B = -0.01, SE = 0.04, p = .665, or post-test, B = 0.00, SE = 0.07, p = .992.

Table 8

ANOVA Results: Main and Interaction Effects of Time, Paradigm, and Paradigm Features on Negative Mood

	$F(1,148)$	p	ηp^2
Time	40.48*	< .001	.215
Paradigm	0.53*	.046	.004
Paradigm Features	1.07	.302	.007
Time × Paradigm	0.20	.656	.001
Time × Paradigm Features	3.82	.053	.025
Paradigm × Paradigm Features	2.25	.136	.015
Time × Paradigm × Paradigm Features	9.60*	.002	.062

Note. All factors were within-subject factors. Paradigm = 2D Cyberball vs. 3D VR; Time = baseline vs. post. Paradigm features = composite score of immersion, presence, involvement, and perceived realism. ηp^2 = partial eta squared. Effect size interpretation for ηp^2 is as follows: small (≈ .01), medium (≈ .06), and large (≈ .14; Cohen, 1988). *$p < .05$.

Psychological Needs

As presented in Table 9, the results of a 2 × 2 × 2 repeated-measures ANOVA with psychological needs as the dependent variable reflected a main effect of *Time*, indicating a decline in needs satisfaction from baseline (M = 95-47, SE = 1.12) to post-measurement (M = 61.05, SE = 1.39), *MDiff* = 34.42, SE = 1.35, $p < .001$, 95% CI [31.74, 37.09]. The main effect of *Paradigm* was not significant. A significant main effect of *Paradigm Features* was found, indicating that, on average, higher feature scores were associated with greater psychological needs satisfaction. The *Time* × *Paradigm* interaction was not significant. However, the *Time* × *Paradigm Features* and *Paradigm* × *Paradigm Features* interactions were significant, indicating that the association between paradigm features and psychological needs varied across time and across paradigms., The *Time* × *Paradigm* × *Paradigm Features* interaction effect was significant, indicating that the association between paradigm features and changes in psychological needs differed between the two paradigms. Follow-up parameter estimates for the three-way interaction showed that paradigm features were associated with higher post-test psychological needs only in the 3D VR condition, B = 1.96, SE = 0.38, $p < .001$, but not baseline levels, B = 0.12, SE = 0.25, p = .623. In the 2D Cyberball condition, paradigm features were not significantly associated with psychological needs at either baseline, B = 0.13, SE = 0.25, p = .595, or post-test, B = 0.12, SE = 0.31, p = .688.

Table 9

ANOVA Results: Main and Interaction Effects of Time, Paradigm, and Paradigm Features on Psychological Needs

	F (1,148)	*p*	*ηp²*
Time	167.00*	< .001	.530
Paradigm	3.06	.082	.020
Paradigm Features	4.21*	.042	.028
Time × Paradigm	5.02	.026	.033
Time × Paradigm Features	9.78*	.002	.062
Paradigm × Paradigm Features	20.96*	< .001	.124
Time × Paradigm × Paradigm Features	25.50*	<.001	.147

Note. All factors were within-subject factors. Paradigm = 2D Cyberball vs. 3D VR; Time = baseline vs. post. Paradigm features = composite score of immersion, presence, involvement, and perceived realism. *ηp²* = partial eta squared. Effect size interpretation for *ηp²* is as follows: small (≈ .01), medium (≈ .06), and large (≈ .14; Cohen, 1988). *$p < .05$.

Age-Related Variations in Effects

To test the third hypothesis, which expected that adolescents would show larger effects in response to exclusion than children, particularly in the 3D VR paradigm, three 2 × 2 × 2 repeated-measures ANOVAs *(Time × Paradigm × Age Group)* were conducted. The analysis examined age-related differences in positive mood, negative mood, and psychological needs, before and after exposure to peer exclusion in the two paradigms. To further examine age-related differences in perceived exclusion and paradigm features, two 2 × 2 repeated-measures ANOVAs (*Paradigm × Age Group*) were conducted. Results are summarised in Table 10 for positive mood, in Table 11 for negative mood, in Table 12 for psychological needs, in Table 13 for perceived exclusion, and in Table 14 for paradigm features.

Positive Mood

As presented in Table 10, the results of a 2 × 2 × 2 repeated-measures ANOVA with positive mood as the dependent variable reflected a significant main effect of *Time* , indicating that positive mood decreased from baseline (M = 16.44, SE = 0.19) to post-measurement (M = 11.29, SE = 0.30), *MDiff* = 5.15, SE = 0.29, $p < .001$, 95% CI [4.58, 5.72]. A significant main effect of *Paradigm* was also observed, showing that, across both time points, positive mood was overall higher in the 3D VR (M = 14.28, SE = 0.23) than in the 2D Cyberball paradigm (M = 13.45, SE = 0.23), *MDiff* = 0.84, SE = 0.22, $p < .001$, 95% CI [0.41, 1.26]. A significant main effect of *Age Group* emerged, with children reporting higher positive mood (M = 14.84, SE = 0.28) than adolescents (M = 12.89, SD = 0.29), *MDiff* = 1.94, SE = 0.40, $p < .001$, 95% CI [1.15, 2.73]. Neither the *Time × Age Group* nor the *Paradigm × Age Group* interaction was significant. However, the *Time × Paradigm* interaction was significant. Post-hoc analyses showed that the magnitude of decline differed between the 2D Cyberball and 3D VR paradigms, with the decline being more pronounced in the 2D Cyberball paradigm compared to the 3D VR paradigm, *MDiff* = 1.71, SE = 0.38, $p < .001$, 95% *CI* [0.96, 2.48]. The *Time ×*

Paradigm × *Age Group* interaction was also significant. Bonferroni-corrected post-hoc comparisons showed that adolescents in the 3D VR condition showed a greater decline compared to children, *MDiff* = -3.10, *SE* = 0.71, $p < .001$, 95% CI [-4.50, -1.70].

Table 10

ANOVA Results: Main and Interaction Effects of Time, Paradigm, and Age Group on Positive Mood

	$F(1,148)$	p	ηp^2
Time	317.31*	< .001	.682
Paradigm	15.02*	< .001	.092
Age Group	23.52*	< .001	.137
Time × Paradigm	19.64*	< .001	.117
Time × Age Group	1.81	.181	.012
Paradigm × Age Group	2.82	.095	.019
Time × Paradigm × Age Group	4.22*	.042	.028

Note. Time and Paradigm were within-subject factors. Age Group was a between-subjects factor. Paradigm = 2D Cyberball vs. 3D VR; Time = baseline vs. post. Age group = children vs. adolescents. ηp^2 = partial eta squared. Effect size interpretation for ηp^2 is as follows: small (≈ .01), medium (≈ .06), and large (≈ .14; Cohen, 1988). * $p < .05$.

Negative Mood

As shown in Table 11, the results of a 2 × 2 × 2 repeated-measures ANOVA with negative mood as the dependent variable reflected a significant main effect of *Time*, with negative mood increasing from baseline (M = 6.22, SE = 0.17) to post-measurement (M = 9.48, SE = 0.28), *MDiff* = -3.25, SE = 0.28, $p < .001$, 95% CI [-3.80, -2.71]. A significant main effect of *Paradigm* also emerged, indicating that across both time points, negative mood was higher in the 2D Cyberball (M = 8.42, SE = 0.21) than in the 3D VR paradigm (M = 7.29, SE = 0.21), *MDiff* = 1.13, SE = 0.20, $p < .001$, 95% CI [0.72, 1.53]. A significant main effect of *Age Group* indicated that adolescents (M = 8.38, SE = 0.26) reported higher negative mood than children (M = 7.32, SE = 0.26) , *MDiff* = 1.06, SE = 0.36, p = .004, 95% CI [0.34, 1.78]. Neither the *Time* × *Age Group* nor the *Paradigm* × *Age Group* interaction was significant. However, the *Time* × *Paradigm* interaction was significant, indicating that increases in negative mood varied by paradigm. Post-hoc analyses showed that the magnitude of increase differed between the 2D Cyberball and 3D VR paradigms, with the increase being more pronounced in the 2D Cyberball paradigm compared to the 3D VR paradigm, *MDiff* = 2.38, SE = 0.36, $p < .001$, 95% CI [1.66, 3.10]. The *Time* × *Paradigm* × *Age Group* interaction was also significant. Post-hoc analyses showed that adolescents experienced a stronger increase in negative mood than children following the 3D VR paradigm, *MDiff* = 1.91, SE = 0.63, p = .003, 95% CI [0.65, 3.17], whereas the 2D Cyberball paradigm produced comparable effects across age groups, *MDiff* = 0.26, SE = 0.68, p = .706, 95% CI [-1.09, 1.61].

Table 11

ANOVA Results: Main and Interaction Effects of Time, Paradigm, and Age Group on Negative Mood

	$F(1,148)$	p	ηp^2
Time	138.03*	< .001	.483
Paradigm	30.55*	< .001	.171
Age Group	8.46*	.004	.054
Time × Paradigm	38.12*	< .001	.205
Time × Age Group	0.08	.933	.000
Paradigm × Age Group	3.43	.066	.023
Time × Paradigm × Age Group	4.91*	.028	.032

Note. Time and Paradigm were within-subject factors. Age Group was a between-subject factor. Paradigm = 2D Cyberball vs. 3D VR; Time = baseline vs. post. Age group = children vs. adolescents. ηp^2 = partial eta squared. Effect size interpretation for ηp^2 is as follows: small (≈ .01), medium (≈ .06), and large (≈ .14; Cohen, 1988). *$p < .05$.

Psychological Needs

As presented in Table 12, the results of a 2 × 2 × 2 repeated-measures ANOVA with psychological needs as the dependent variable indicated a significant main effect of *Time*, with psychological needs decreasing from baseline (M = 95.44, SE = 1.10) to post-measurement (M = 60.99, SE = 1.36), *MDiff* = 34.44, SE = 1.35, $p < .001$, 95% CI [31.76, 37.11]. A significant main effect of *Paradigm* also emerged, indicating that the magnitude of decline differed between the 2D Cyberball (M = 75.34, SE = 1.09) and 3D VR paradigm (M = 81.09, SE = 1.18), *MDiff* = -5.75, SE = 9.23, $p < .001$, 95% CI [-7.58, -3.93]. A significant main effect of *Age Group* was found as well, with children reporting greater needs satisfaction (M = 81.32, SE = 1.46) than adolescents (M = 75.11, SE = 1.48), *MDiff* = 6.21, SE = 2.07, p = .003, 95% *CI* [2.11, 10.31]. A significant *Time* × *Paradigm* interaction emerged, showing that decreases in psychological needs varied by paradigm. Post-hoc analyses indicated that the decrease was more pronounced in the 2D Cyberball compared to the 3D VR paradigm, *MDiff* = -10.91, SE = 1.69, $p < .001$, 95% CI [-14.25, -7.57]. The *Time* × *Age Group* was not significant, while the *Paradigm* × *Age Group* was. The *Time* × *Paradigm* × *Age Group* interaction was also significant. Bonferroni-corrected post-hoc comparisons indicated that adolescents in the 3D VR paradigm experienced a stronger decrease in psychological needs than children, *MDiff* = -9.38, SE = 2.36, $p < .001$, 95% CI [-14.05, -4.70], whereas the 2D Cyberball paradigm resulted in comparable decreases across age groups, *MDiff* = 3.04, SE = 2.17, p = .163, 95% CI [-1.25, 7.34].

Table 12

ANOVA Results: Main and Interaction Effects of Time, Paradigm, and Age Group on Psychological Needs

	$F(1,148)$	p	ηp^2
Time	648.51*	< .001	.814
Paradigm	38.90*	< .001	.208
Age Group	8.96*	.003	.057
Time × Paradigm	36.38*	< .001	.197
Time × Age Group	1.21	.273	.008
Paradigm × Age Group	11.78*	< .001	.071
Time × Paradigm × Age Group	12.66*	< .001	.079

Note. Time and Paradigm were within-subject factors. Age Group was a between-subject factor. Paradigm = 2D Cyberball vs. 3D VR; Time = baseline vs. post. Age group = children vs. adolescents. ηp^2 = partial eta squared. Effect size interpretation for ηp^2 is as follows: small (≈ .01), medium (≈ .06), and large (≈ .14; Cohen, 1988). * $p < .05$.

Perceived Exclusion

As shown in Table 13, the results of a 2 × 2 ANOVA with perceived exclusion as the dependent variable indicated a significant main effect of *Paradigm*, with higher perceived exclusion in the 2D Cyberball (M = 8.83, SE = 0.16) compared to the 3D VR paradigm (M = 7.42, SE = 0.22). A significant main effect of *Age Group* also emerged, with adolescents reporting higher perceived exclusion (M = 8.59, SE = 0.22) than children (M = 7.66, SE = 0.21), *MDiff* = 0.92, SE = 0.30, p = .003, 95% CI [0.32, 1.53]. In addition, the *Paradigm* × *Age Group* interaction was significant. Bonferroni-adjusted post-hoc comparisons indicated that in the 3D VR paradigm, adolescents reported higher perceived exclusion than children, *MDiff* = 1.43, SE = 0.41, p = .001, 95% *CI* [0.62, 2.25]. In contrast, in the 2D Cyberball paradigm, the difference between adolescents and children was not significant, *MDiff* = 0.30, SE = 0.22, p = .178, 95% CI [-0.14, 0.74].

Table 13

ANOVA Results: Main and Interaction Effects of Paradigm and Age Group on Perceived Exclusion

	$F(1,148)$	p	ηp^2
Paradigm	39.68*	< .001	.211
Age Group	7.91*	.006	.051
Paradigm × Age Group	5.04*	.026	.033

Note. Paradigm was the within-subject factor. Age Group was a between-subject factor. Paradigm = 2D Cyberball vs. 3D VR; Age group = children vs. adolescents. ηp² = partial eta squared. Effect size interpretation for ηp^2 is as follows: small (≈ .01), medium (≈ .06), and large (≈ .14; Cohen, 1988). *$p < .05$.

Paradigm Features

As shown in Table 14, the results of a 2 × 2 ANOVA with paradigm features as the dependent variable indicated a significant main effect of *Paradigm*, with higher ratings for the 3D VR paradigm (M = 10.80, SE = 0.33) than for the 2D Cyberball paradigm (M = 7.83, SE = 0.30), $MDiff$ = 2.971, SE = 0.36, $p < .001$, 95% CI [2.27, 3.68]. A significant main effect of *Age Group* also emerged, with children (M = 10.24, SE = 0.37) rating paradigm features higher than adolescents (M = 8.39, SE = 0.37), $MDiff$ = 1.86, SE = 0.52, $p < .001$, 95% CI [0.82, 2.89]. Moreover, the *Paradigm* × *Age Group* interaction was significant. Bonferroni-adjusted post-hoc comparisons revealed that children rated the paradigm features of the 3D VR paradigm higher than those of the 2D Cyberball paradigm, $MDiff$ = 5.12, SE = 0.52, $p < .001$, 95% CI [4.10, 6.15]. Adolescents also reported higher ratings for the 3D VR paradigm compared to the 2D Cyberball paradigm, $MDiff$ = 0.83, SE = 0.27, p = .003, 95% CI [0.29, 1.38].

Table 14

ANOVA Results: Main and Interaction Effects of Paradigm and Age Group on Paradigm Features

	$F(1,148)$	p	ηp^2
Paradigm	69.48*	< .001	.319
Age Group	12.63*	< .001	.079
Paradigm × Age Group	36.28*	< .001	.197

Note. Paradigm was the within-subject factor. Age Group was a between-subject factor. Paradigm = 2D Cyberball vs. 3D VR; Age group = children vs. adolescents. Paradigm features represent the combined score of immersion, presence, involvement, and realism. ηp² = partial eta squared. Effect size interpretation for ηp^2 is as follows: small (≈ .01), medium (≈ .06), and large (≈ .14; Cohen, 1988). *$p < .05$.

Gender-Related Differences in Effects

To test H4, which assumed gender differences in sensitivity to peer exclusion, with females expected to show stronger negative effects, three 2 × 2 × 2 repeated-measures ANOVAs (*Time* × *Paradigm* × *Gender*) were conducted on positive mood, negative mood, and psychological needs. Results are summarised in Table 15 for positive mood, Table 16 for negative mood, and Table 17 for psychological needs.

Positive Mood

As presented in Table 15, the results of a 2 × 2 × 2 repeated-measures ANOVA with positive mood as the dependent variable indicated a significant main effect of *Time*, indicating decreases from baseline (M = 16.42, SE = 0.19) to post-measurement (M = 11.27, SE = 0.31), *MDiff* = 5.15, SE = 0.29, $p < .001$, 95% CI [4.58, 5.73]. A significant main effect of *Paradigm* also emerged with overall higher positive mood in the 3D VR paradigm (M = 14.27, SE = 0.24) compared to the 2D Cyberball paradigm (M = 13.42, SE = 0.23) , *MDiff* = 0.85, SE = 0.22, $p < .001$, 95% CI [0.42, 1.28]. A significant main effect of *Gender* indicated that males (M = 14.41, SE = 0.29) reported higher positive mood than females (M = 13.29, SE = 0.31) across paradigms, *MDiff* = 1.12, SE = 0.42, p = .009, 95% CI [0.29, 1.96]. The *Time* × *Paradigm* interaction was significant, indicating that decreases were more pronounced in the 2D Cyberball paradigm compared to the 3D VR paradigm, *MDiff* = -1.74, SE = 0.39, $p < .001$, 95% CI [-2.51, -0.97]. Neither the *Time* × *Gender* interaction, the *Paradigm* × *Gender*, nor the *Time* × *Paradigm* × *Gender* interaction reached significance.

Table 15

ANOVA Results: Main and Interaction Effects of Time, Paradigm, and Gender on Positive Mood

	$F(1,148)$	p	ηp^2
Time	313.01	< .001*	.679
Paradigm	15.19	< .001*	.093
Gender	7.08	.009*	.046
Time × Paradigm	19.72	< .001*	.118
Time × Gender	0.14	.711	.001
Paradigm × Gender	0.45	.505	.003
Time × Paradigm × Gender	0.59	.445	.004

Note. Time and Paradigm were within-subject factors. Gender was a between-subject factor. Paradigm = 2D Cyberball vs. 3D VR; Time = baseline vs. post. Gender = male vs. female. ηp^2 = partial eta squared. Effect size interpretation for ηp^2 is as follows: small (≈ .01), medium (≈ .06), and large (≈ .14; Cohen, 1988). * $p < .05$.

Negative Mood

As presented in Table 16, the results of a 2 × 2 × 2 repeated-measures ANOVA with negative mood as the dependent variable indicated a significant main effect of *Time*, indicating overall increases from baseline (*M* = 6.22, *SE* = 0.18) to post-measurement (*M* = 9.47, *SE* = 0.28), *MDiff* = -3.25, *SE* = 0.28, $p < .001$, 95% CI [-3.80, -2.70]. A significant main effect of *Paradigm* was also found, with higher negative mood in the 2D Cyberball (*M* = 8.42, *SE* = 0.21) compared to the 3D VR paradigm (*M* = 7.27, *SE* = X0.22), *MDiff* = 1.15, *SE* = 0.21, $p < .001$, 95% CI [0.74, 1.55]. No significant main effect of *Gender* emerged. The *Time* × *Paradigm* interaction was significant, indicating that increases in negative mood varied by paradigm. Post-hoc analyses showed that the magnitude of increase differed between the 2D Cyberball and 3D VR paradigms, with the increase being more pronounced in the 2D Cyberball paradigm compared to the 3D VR paradigm, *MDiff* = 2.41, *SE* = 0.37, $p < .001$, 95% CI [1.68, 3.15]. The *Time* × *Gender*, the *Paradigm* × *Gender,* and the *Time* × *Paradigm* × *Gender* interactions were not significant.

Table 16

ANOVA Results: Main and Interaction Effects of Time, Paradigm, and Gender on Negative Mood

	$F(1,148)$	p	ηp^2
Time	137.30*	< .001	.481
Paradigm	31.09*	< .001	.174
Gender	0.12	.729	.001
Time × Paradigm	37.56*	< .001	.202
Time × Gender	0.13	.719	.001
Paradigm × Gender	1.53	.218	.010
Time × Paradigm × Gender	0.27	.603	.002

Note. Time and Paradigm were within-subject factors. Gender was a between-subject factor. Paradigm = 2D Cyberball vs. 3D VR; Time = baseline vs. post. Gender = male vs. female. ηp^2 = partial eta squared. Effect size interpretation for ηp^2 is as follows: small (≈ .01), medium (≈ .06), and large (≈ .14; Cohen, 1988). *$p < .05$.

Psychological Needs

As presented in Table 17, the results of a 2 × 2 × 2 repeated-measures ANOVA with psychological needs as the dependent variable indicated a significant main effect of *Time*, indicating an overall decrease from baseline (M = 95.25, SE = 1.07) to post-measurement (M = 60.89, SE = 1.38), *MDiff* = 34.36, SE = 1.36, $p < .001$, 95% CI [31.68, 37.04]. A significant main effect of *Paradigm* also emerged, with higher needs satisfaction in the 3D VR (M = 80.96, SE = 1.21) compared to the 2D Cyberball paradigm (M = 75.17, SE = 1.06), *MDiff* = 5.79, SE = 0.96, $p < .001$, 95% CI [3.89, 7.68]. A significant main effect of *Gender* indicated that, on average, males reported higher needs satisfaction (M = 81.64, SE = 1.42) than females (M = 74.50, SE = 1.49), *MDiff* = 7.14, SE = 2.06, $p < .001$, 95% CI [3.08, 11.21]. The *Time* × *Paradigm* interaction was significant, whereas the *Time* × *Gender*, the *Paradigm* × *Gender*, and the *Time* × *Paradigm* × *Gender* interactions were not. Bonferroni-corrected post-hoc comparisons showed that the decline from baseline to post-measurement was greater in the 2D Cyberball than in the 3D VR paradigm, *MDiff* = -10.94, SE = 1.77, $p < .001$, 95% CI [-14.43, -7.45].

Table 17

ANOVA Results: Main and Interaction Effects of Time, Paradigm, and Gender on Psychological Needs

	$F(1,148)$	p	ηp^2
Time	641.16*	< .001	.812
Paradigm	36.35*	< .001	.197
Gender	12.05*	< .001	.075
Time × Paradigm	33.59*	< .001	.185
Time × Gender	0.55	.461	.004
Paradigm × Gender	0.03	.856	.000
Time × Paradigm × Gender	0.75	.389	.005

Note. Time and Paradigm were within-subject factors. Gender was a between-subject factor. Paradigm = 2D Cyberball vs. 3D VR; Time = baseline vs. post. Gender = male vs. female. ηp^2 = partial eta squared. Effect size interpretation for ηp^2 is as follows: small (≈ .01), medium (≈ .06), and large (≈ .14; Cohen, 1988). *$p < .05$.

Moderating Roles of Social Support and Previous Rejection Experiences

To test H5, which expected that higher social support would buffer against the effects of peer exclusion, whereas previous rejection would exacerbate them, a total of six 2 × 2 repeated-measures ANCOVAs were conducted with *Time* (baseline vs. post-measurement) and *Paradigm* (2D Cyberball vs. 3D VR) as *within-subjects factors. Social Support* and *Previous Rejection Experiences* were entered as covariates in separate sets of analyses to examine whether they were associated with changes in positive mood, negative mood, and psychological needs, and whether these associations differed between paradigms. For social support, results are summarised in Table 18 for positive mood, Table 19 for negative mood, and Table 20 for psychological needs. For previous rejection experiences, results are summarised in Table 21 for positive mood, Table 22 for negative mood, and Table 23 for psychological needs.

Social Support

Positive Mood. As presented in Table 18, the results of a 2 × 2 repeated-measures ANCOVA with positive mood as the dependent variable revealed a significant main effect of *Time*, with decreases from baseline (M = 16.45, SE = 0.19) to post-measurement (M = 11.30, SE = 0.31), $MDiff$ = 5.15, SE = 0.29, $p < .001$, 95% CI [4.58, 5.73]. The main effect of *Paradigm* was not significant (3D VR: M = 14.30, SE = 0.24; 2D Cyberball: M = 13.46, SE = 0.23). A significant main effect of *Social Support* indicated that higher levels of perceived support were associated with higher positive mood overall. Parameter estimates indicated that in the 2D Cyberball paradigm, social support was associated with higher positive mood at both baseline, B = 0.02, SE = 0.00, $p < .001$, and post-measurement, B = 0.02, SE = 0.01, p = .031. In the 3D VR paradigm, social support was associated with higher positive mood at baseline, B = 0.02, SE = 0.00, $p < .001$, but not at post-measurement, B = 0.01, SE = 0.01, p = .118. No significant *Time* × *Paradigm*, *Time* × *Social Support*, *Paradigm* × *Social Support,* or *Time* × *Paradigm* × *Social Support* interaction effects were found.

Table 18

ANCOVA Results: Main and Interaction Effects of Time, Paradigm, and Received Social Support on Positive Mood

	$F(1,148)$	p	ηp^2
Time	5.84*	.017	.038
Paradigm	0.51	.478	.003
Social Support	12.75*	< .001	.079
Time × Paradigm	2.26	.135	.015
Time × Social Support	0.18	.673	.001
Paradigm × Social Support	0.01	.925	.000
Time × Paradigm × Social Support	0.65	.420	.004

Note. Time and Paradigm were within-subject factors. Social Support was included as a covariate. Paradigm = 2D Cyberball vs. 3D VR; Time = baseline vs. post. ηp^2 = partial eta squared. Effect size interpretation for ηp^2 is as follows: small (≈ .01), medium (≈ .06), and large (≈ .14; Cohen, 1988). *p< .05.

Negative Mood. As presented in Table 19, the results of a 2 × 2 repeated-measures ANCOVA with negative mood as the dependent variable revealed a significant main effect of *Time*, indicating an increase from baseline (M = 6.22, SE = 0.17) to post-measurement (M = 0.47, SE = 0.27) across both paradigms, *MDiff* = -3.25, SE = 0.218, p < .001, 95% CI [-3.80, -2.71]. The main effect of *Paradigm* was not significant (3D VR: M = 7.28, SE = 0.21; 2D Cyberball: M = 8.41, SE = 0.20). A significant main effect of *Social Support* was found, with higher support associated with lower negative mood. Parameter estimates showed that in the 2D Cyberball paradigm, social support was associated with lower negative mood at both baseline, B = –0.01, SE = 0.00, p = .023, and post-measurement, B = –0.02, SE = 0.01, p = .034. In the 3D VR paradigm, social support was associated with lower negative mood at baseline, B = –0.01, SE = 0.00, p = .009, but not at post-measurement, B = –0.01, SE = 0.01, p = .564. No significant *Time* × *Paradigm*, *Time* × *Social Support*, *Paradigm* × *Social Support*, or *Time* × *Paradigm* × *Social Support* interactions emerged.

Table 19

ANCOVA Results: Main and Interaction Effects of Time, Paradigm, and Received Social Support on Negative Mood

	$F(1,148)$	p	ηp^2
Time	6.02	.015*	.039
Paradigm	1.103	.312	.007
Social Support	9.62	.002*	.061
Time × Paradigm	2.58	.110	.017
Time × Social Support	0.33	.564	.002
Paradigm × Social Support	0.02	.891	.000
Time × Paradigm × Social Support	0.40	.526	.003

Note. Time and Paradigm were within-subjects factors. Social Support was included as a covariate. Paradigm = 2D Cyberball vs. 3D VR; Time = baseline vs. post. ηp^2 = partial eta squared. Effect size interpretation for ηp^2 is as follows: small (≈ .01), medium (≈ .06), and large (≈ .14; Cohen, 1988). *$p < .05$.

Psychological Needs. As presented in Table 20, the results of a 2 × 2 repeated-measures ANCOVA with psychological needs as the dependent variable revealed a significant main effect of *Time*, indicating a decrease in needs satisfaction from baseline (M = 95.47, SE = 1.07) to post-measurement (M = 61.05, SE = 1.39) across paradigms, $MDiff$ = 34.42, SE = 1.35, $p <$ .001, 95% CI [31.75, 37.08]. The main effect of *Paradigm* was not significant (3D VR: M = 81.16, SE = 1.21; 2D Cyberball: M = 75.36, SE = 1.07). The significant main effect of *Social Support* showed that higher support was associated with greater needs satisfaction. Parameter estimates showed that in the 2D Cyberball paradigm, social support was associated with higher baseline needs satisfaction, B = 0.11, SE = 0.03, p = .001, but not post-measurement, B = 0.06, SE = 0.04, p = .138. Similarly, in the 3D VR paradigm, social support was associated with higher baseline needs satisfaction, B = 0.13, SE = 0.03, $p <$ .001, but not post-measurement, B = 0.07, SE = 0.05, p = .201. No significant *Time* × *Paradigm*, *Time* × *Social Support*, *Paradigm* × *Social Support*, or *Time* × *Paradigm* × *Social Support* interactions emerged.

Table 20

ANCOVA Results: Main and Interaction Effects of Time, Paradigm, and Received Social Support on Psychological Needs

	$F(1,148)$	p	ηp^2
Time	7.56*	.007	.049
Paradigm	0.23	.635	.002
Social Support	9.20*	.003	.059
Time × Paradigm	1.48	.225	.010
Time × Social Support	1.83	.179	.012
Paradigm × Social Support	0.25	.618	.002
Time × Paradigm × Social Support	0.83	.774	.001

Note. Time and Paradigm were within-subject factors. Social Support was included as a covariate. Paradigm = 2D Cyberball vs. 3D VR; Time = baseline vs. post. ηp^2 = partial eta squared. Effect size interpretation for ηp^2 is as follows: small (≈ .01), medium (≈ .06), and large (≈ .14; Cohen, 1988). *$p < .05$.

Previous Rejection Experiences

Positive Mood. As presented in Table 21, the results of a 2 × 2 repeated-measures ANCOVA with positive mood as the dependent variable revealed a significant main effect of *Time*, indicating a decrease from baseline (M = 16.45, SE = 0.19) to post-measurement (M = 11.03, SE = 0.31) in positive mood, $MDiff$ = 5.15, SE = 0.29, $p < .001$, 95% CI [4.58, 5.73]. The main effect of *Paradigm* was not significant (3D VR: M = 14.30, SE = 0.25; 2D Cyberball: M = 13.46, SE = 0.23). A significant main effect of *Previous Rejection Experiences* emerged, showing that higher rejection history was associated with lower positive mood. Parameter estimates indicated that in the 2D Cyberball paradigm, previous rejection experiences were associated to lower baseline positive mood, B = –0.02, SE = 0.00, p = .003, but not post-measurement, B = –0.02, SE = 0.01, p = .071. In the 3D VR paradigm, previous rejection experiences were associated to lower baseline positive mood, B = –0.03, SE = 0.00, p = .002, but not post-measurement, B = –0.07, SE = 0.01, p = .684. No significant *Time* × *Paradigm*, *Time* × *Previous Rejection Experiences*, *Paradigm* × *Previous Rejection Experiences*, or *Time* × *Paradigm* × *Previous Rejection Experiences* interactions were observed.

Table 21

ANCOVA Results: Main and Interaction Effects of Time, Paradigm, and Previous Rejection Experiences on Positive Mood

	$F(1,148)$	p	ηp^2
Time	50.76*	< .001	.255
Paradigm	0.11	.735	.001
Previous Rejection Experiences	6.13*	.014	.040
Time × Paradigm	0.177	.676	.001
Time × Previous Rejection Experiences	0.74	.390	.005
Paradigm × Previous Rejection Experiences	1.24	.266	.008
Time × Paradigm × Previous Rejection Experiences	1.53	.218	.010

Note. Time and Paradigm were within-subject factors. Previous Rejection Experiences was the covariate. Paradigm = 2D Cyberball vs. 3D VR; Time = baseline vs. post. ηp^2 = partial eta squared. Effect size interpretation for ηp^2 is as follows: small (≈ .01), medium (≈ .06), and large (≈ .14; Cohen, 1988). * $p < .05$.

Negative Mood. As presented in Table 22, the results of a 2 × 2 repeated-measures ANCOVA with negative mood as the dependent variable revealed a significant main effect of *Time*, showing an increase from baseline ($M = 6.22$, $SE = 0.17$) to post-measurement ($M = 9.47$, $SE = 0.28$) in negative mood, $MDiff = -3.25$, $SE = 0.28$, $p < .001$, 95% CI [-3.80, -2.71]. A significant main effect of *Paradigm* also emerged with overall higher negative mood in the 2D Cyberball ($M = 8.41$, $SE = 0.21$) than in the 3D VR paradigm ($M = 7.28$, $SE = 0.21$), $MDiff = 1.13$, $SE = 0.21$, $p < .001$, 95% *CI* [0.73, 1.43]. The *Time* × *Paradigm* interaction was significant, with greater increases in the 2D Cyberball paradigm compared to the 3D VR paradigm, $MDiff = 2.39$, $SE = 0.37$, $p < .001$, 95% *CI* [1.66, 3.13]. A significant main effect of *Previous Rejection Experiences* also emerged, indicating that higher rejection history was associated with greater negative mood. Parameter estimates showed that previous rejection experiences were associated with higher baseline negative mood in both the 2D Cyberball paradigm, $B = 0.02$, $SE = 0.01$, $p = .005$, and the 3D VR paradigm, $B = 0.03$, $SE = 0.00$, $p < .001$. No significant *Time* × *Previous Rejection Experiences*, *Paradigm* × *Previous Rejection Experiences,* or *Time* × *Paradigm* × *Previous Rejection Experiences* interactions were found.

Table 22

ANCOVA Results: Main and Interaction Effects of Time, Paradigm, and Previous Rejection Experiences on Negative Mood

	$F(1,148)$	p	ηp^2
Time	23.45*	< .001	.137
Paradigm	9.68*	.002	.061
Previous Rejection Experiences	8.71*	.004	.056
Time × Paradigm	5.75*	.018	.037
Time × Previous Rejection Experiences	0.48	.448	.003
Paradigm × Previous Rejection Experiences	1.50	.222	.010
Paradigm × Time × Previous Rejection Experiences	0.05	.812	.000

Note. Time and Paradigm were within-subject factors. Previous Rejection Experiences was included as a covariate. Paradigm = 2D Cyberball vs. 3D VR; Time = baseline vs. post. ηp^2 = partial eta squared. Effect size interpretation for ηp^2 is as follows: small (≈ .01), medium (≈ .06), and large (≈ .14; Cohen, 1988). *$p < .05$.

Psychological Needs. As presented in Table 23, the results of a 2 × 2 repeated-measures ANCOVA with psychological needs as the dependent variable revealed a main effect of *Time*, indicating an overall decrease in needs satisfaction from baseline (M = 95.47, SE = 0.92) to post-measurement (M = 61.05, SE = 1.37), *MDiff* = 34.42, SE = 1.30, $p < .001$, 95% *CI* [31.84, 36.99]. The main effect of *Paradigm* was not significant (3D VR: M = 81.16, SE = 1.18; 2D Cyberball: M = 75.36, SE = 0.97). A significant Time × Previous Rejection Experiences interaction emerged, indicating that the association between previous rejection history and changes in needs satisfaction differed from baseline to post-measurement. A significant main effect of *Previous Rejection Experiences* also emerged, with higher rejection history associated with lower needs satisfaction overall. In addition, a significant *Time × Previous Rejection Experiences* interaction indicated that the association between previous rejection history and needs satisfaction differed from baseline to post-measurement. Parameter estimates showed that in the 2D Cyberball paradigm, previous rejection experiences were associated with lower needs satisfaction at both baseline, B = –0.35, SE = 0.04, $p < .001$, and post-measurement, B = –0.20, SE = 0.06, $p < .001$. In the 3D VR paradigm, previous rejection experiences were associated with lower baseline needs satisfaction, B = –0.38, SE = 0.04, $p < .001$, but not post-measurement, B = –0.08, SE = 0.08, p = .345. Neither the *Time × Paradigm* interaction nor the Paradigm × Previous Rejection Experiences or the *Time × Paradigm × Previous Rejection Experiences* interaction reached significance.

Table 23

ANCOVA Results: Main and Interaction Effects of Time, Paradigm, and Previous Rejection Experiences on Psychological Needs

	$F(1,148)$	p	ηp^2
Time	162.55*	< .001	.523
Paradigm	0.80	.371	.005
Previous Rejection Experiences	31.31*	< .001	.175
Time × Paradigm	0.36	.547	.002
Time × Previous Rejection Experiences	12.74*	< .001	.079
Paradigm × Previous Rejection Experiences	1.85	.176	.012
Time × Paradigm × Previous Rejection Experiences	2.55	.112	.017

Note. Time and Paradigm were within-subject factors. Previous Rejection Experiences was included as a covariate. Paradigm = 2D Cyberball vs. 3D VR; Time = baseline vs. post. ηp^2 = partial eta squared. Effect size interpretation for ηp^2 is as follows: small (≈ .01), medium (≈ .06), and large (≈ .14; Cohen, 1988). *$p < .05$.

Discussion

The primary objective of this study was to validate a newly developed 3D VR paradigm designed to assess peer exclusion in school settings. Specifically, we sought to determine whether the 3D VR paradigm produced effects on mood and psychological needs comparable to those elicited by the established 2D Cyberball paradigm (Williams, 2001). In addition, we examined whether the 3D VR paradigm provided higher immersion, presence, involvement, and realism, thereby establishing a stronger basis for ecological validity.

To this end, we first developed a novel VR-based exclusion scenario situated in a classroom context. We then compared its effects to those of the 2D Cyberball paradigm in a within-subject design. A total of 76 children (aged 8–12) and 74 adolescents (aged 13–16), completed baseline and post-assessments of positive and negative mood and psychological needs, as well as evaluations of immersion, presence, involvement, and realism following the participation in both paradigms.

Effects of the 2D Cyberball Paradigm and the 3D VR paradigm on Mood and Psychological Needs

The initial hypothesis was that experiencing either paradigm would demonstrate a comparable effect of peer exclusion on positive and negative mood and psychological needs. Consistent with earlier evidence on the robustness of the 2D Cyberball paradigm in eliciting social exclusion (Williams et al., 2000; Zadro et al., 2004; Hartgerink et al., 2015), the findings demonstrated that both paradigms induced decreases in positive mood and psychological needs and increases in negative mood. Importantly, these effects emerged in the same direction across paradigms, albeit with differences in magnitude. Specifically, the absolute baseline to-post changes in mood and needs were greater in the 2D Cyberball paradigm, whereas the effect sizes derived from within-paradigm repeated-measures ANOVAs were larger in the 3D VR paradigm. This pattern indicates that the 2D Cyberball paradigm elicited stronger score

changes, while the VR paradigm might be viewed to have elicited more uniform effects across participants. These findings suggest that being excluded and ignored during a 3D VR conversation with virtual peers elicits a comparable sense of exclusion in terms of outcome direction, resulting in reduced positive mood and psychological needs and heightened negative mood. They further highlight that the 2D Cyberball paradigm may amplify exclusion cues through its simplicity, whereas the 3D VR paradigm induced somewhat smaller absolute score changes. Overall, these outcomes support our initial hypothesis and are align with prior literature emphasising both the reliability of the 2D Cyberball paradigm as a strong exclusion paradigm and the effectiveness of 3D VR technology as a method for assessing peer exclusion (Abrams et al., 2011; Prendergast & Schubert, 2020).

The second hypothesis posited that the 3D VR paradigm would prove more effective than the 2D Cyberball paradigm due to its superior immersion, presence, involvement, and perception of realism. In line with expectations, the 3D VR paradigm elicited higher ratings on paradigm features compared to the 2D Cyberball paradigm. However, the outcome patterns regarding mood and psychological needs were more nuanced. Baseline to post-measurement changes were more pronounced in the 2D Cyberball condition, with participants showing stronger decreases in positive mood and psychological needs and stronger increases in negative mood. Indeed, the traditional 2D Cyberball paradigm was more effective in intensifying declines in positive mood and psychological needs and increases in negative mood than the novel 3D VR paradigm. A possible explanation lies in the qualitative differences between the two exclusion situations. The 2D Cyberball paradigm is a structured ball-tossing game, where exclusion is operationalised as a clear violation of participants' expectations about fair play. Not receiving the ball directly signals rejection, eliciting frustration and exclusion-related distress (Schuck et al., 2018). In contrast, the 3D VR paradigm required participants to engage in conversations with unfamiliar peers, which may have introduced an additional psychological

challenge—such as discomfort in initiating and maintaining interactions with strangers—that could partially overshadow the exclusion manipulation. Consequently, participants may have attributed their discomfort more to the demands of the social task than to the exclusion itself, potentially weakening the perceived impact of exclusion in the VR setting (Quintana et al., 2023).

The second hypothesis further posited that higher perception of immersion, presence, involvement, and realism would amplify the effects of the 3D VR paradigm on mood and psychological needs, resulting in stronger peer exclusion effects. Results indicated that the 2D Cyberball paradigm elicited stronger negative outcomes than the 3D VR paradigm. At the same time, the 3D VR paradigm was rated higher in immersion, presence, involvement, and realism, consistent with expectations regarding its potential ecological validity. At the overall sample level, higher immersion, presence, involvement, and realism in the 3D VR paradigm was associated with a weaker decline in mood and psychological needs. This suggests that the paradigm features of 3D VR moderated the impact of exclusion, such that the more authentic and naturalistic the environment was perceived to be, the less strongly participants experienced its social consequences.

Taken together, these findings suggest that the 2D Cyberball paradigm, by virtue of its simple and overt exclusion cue (not receiving the ball), may exaggerate exclusion effects, whereas the attenuated effects observed in 3D VR may more closely approximate real-life social interactions, which are often more ambiguous and emotionally regulated (Pfundmair et al., 2015). A further explanation could be the novelty effect, particularly salient for younger participants: the novelty of being immersed in a 3D VR environment may have drawn attention away from the exclusion manipulation itself and toward the technological experience, thereby dampening the perceived strength of exclusion (Southgate et al., 2019).

Age and Gender-Related Effects

The third hypothesis posited that adolescents would demonstrate heightened sensitivity to peer exclusion compared to children in both paradigms, leading to stronger negative effects, including reduced positive mood and psychological needs and elevated negative mood. Results partially supported this assumption. The 3D VR paradigm elicited stronger negative effects in adolescents than in children, whereas responses to the 2D Cyberball paradigm did not differ between age groups. Children, however, reported higher immersion, presence, involvement, and realism than adolescents, which was associated with a diminished sense of exclusion in children. One explanation for adolescents' heightened reactivity in the 3D VR condition may be that they spend a greater proportion of their daily interactions in verbal than physical activities with peers (Rubin et al., 2015). As conversational exchanges become more central to peer relationships during adolescence; therefore, peer exclusion in this context is likely to be experienced as more personally significant and thus more detrimental to mood and psychological needs (Ladd et al., 2021). Accordingly, adolescents may be more prone than children to experiencing negative emotions when excluded and ignored in a peer conversation, whereas exclusion during a virtual ball game may be perceived as less threatening to their social self.

The fourth hypothesis assumed that, consistent with previous evidence (e.g., Fuhrmann et al., 2019), female participants would exhibit greater sensitivity to peer exclusion, reflected in stronger declines in positive mood and psychological needs and stronger increases in negative mood compared to males. Contrary to expectations, no significant interactions involving Gender emerged, suggesting that the effects of exclusion (i.e., changes from baseline to post) were comparable for males and females in both paradigms. Although males reported higher overall positive mood and needs satisfaction than females, these level differences did not translate into differential reactivity to exclusion. One possible explanation is that gender

disparities in responses to exclusion may attenuate with age, as individual coping styles and previous social experiences become more influential than generalised gender norms (La Greca & Harrison, 2005). Moreover, recent findings suggest that gender effects are highly context-dependent: while girls often report stronger distress in naturalistic settings that involve relational or reputational threats, experimental paradigms such as Cyberball or VR simulations might evoke more uniform responses across genders (e.g., Masten et al., 2013; van Beest & Williams, 2006). Cultural shifts in norms surrounding emotional expressiveness may also play a role, with boys increasingly socialised to acknowledge and report negative emotions in peer contexts (Chaplin & Aldao, 2013). Finally, it is possible that subtle gender differences manifest more strongly at the neural or physiological level than in self-reports, as shown in neuroimaging studies of social exclusion (Masten et al., 2009). Together, these considerations suggest that while gendered patterns of peer exclusion sensitivity are well-documented, they may not reliably emerge in all paradigms or measures, underscoring the importance of considering contextual and developmental moderators.

Moderating Role of Social Support and Previous Rejection Experiences

The fifth hypothesis expected that higher levels of received social support from parents, teachers, and friends would buffer, and previous rejection would exacerbate, the effects of exclusion. This assumption was based on prior findings that social support is associated with reduced vulnerability to exclusion (Arslan, 2018), whereas previous rejection is associated with stronger negative reactions (Will et al., 2016). Across both paradigms, higher social support was consistently associated with more favourable profiles of positive mood, negative mood, and psychological needs, while higher levels of previous rejection experiences were associated with less favourable profiles. Evidence that these variables moderated changes from baseline to post-measurement was more limited. For psychological needs, previous rejection experiences were associated with steeper declines over time, suggesting that a history of rejection may be

linked to stronger need frustration following exclusion. However, interactions with Paradigm were not significant, indicating that these associations did not reliably differ between the 2D Cyberball and 3D VR paradigms. Overall, the findings provide partial support for H5 by highlighting robust associations of social support and prior rejection with mood and needs, but only limited evidence that they systematically moderated exclusion effects, and no clear indication that such moderation differed between paradigms.

Strengths and Implications

The principal strength of this work lies in the introduction of a novel 3D VR paradigm to simulate and assess peer exclusion in naturalistic school settings. This paradigm represents a promising complement to traditional exclusion methods, as it enables participants to engage in lifelike social interactions and was rated higher in immersion, presence, involvement, and realism. These features are important for narrowing the gap between controlled laboratory simulations and the complex realities of everyday school environments. The successful implementation of this paradigm demonstrates the feasibility and potential of VR-based tools in educational psychology research and practice, while also highlighting areas for further refinement.

A second strength is that the 3D VR paradigm opens new possibilities for investigating the effects of peer exclusion on variables central to educational contexts, such as cognitive and academic functioning in more naturalistic settings (Villena-Taranilla et al., 2022). Although exclusion effects were not consistently stronger in VR, the paradigm provides a methodological foundation for studying social processes in ecologically richer environments.

Third, the study's comprehensive and methodologically rigorous design represents a further strength. With a comparably large, age-diverse sample of school-aged students, a within-subjects design, and the integration of both quantitative and theoretically informed constructs (e.g., paradigm features, prior rejection experiences, and received social support),

the study provides a nuanced perspective on how different exclusion experiences may affect children and adolescents.

Limitations and Future Directions

Firstly, with regard to the assessment of immersion, presence, involvement, and realism, a key limitation was the absence of validated scales for school-aged students. Consequently, we employed a single item per construct, adapted from existing scales. Although items were carefully selected, age-appropriate, and subject to EFA to establish reliability, the use of single-item measures may have limited construct validity, as such items cannot fully capture the complexity of psychological constructs (Grassini & Laumann, 2020). Future research would benefit from the development and validation of a multi-item instrument specifically designed to assess immersion, presence, involvement, and realism in school-aged samples.

Secondly, the experimental procedure of did not incorporate techniques or measures to control for the novelty effect, that is, the tendency of VR to become more absorbed in the virtual environment itself than in the assigned task (Southgate et al., 2019). As novelty effects are typically stronger in younger participants, future studies using 3D VR paradigms should adopt more robust procedures to monitor and mitigate this issue. Techniques could include providing participants with time to familiarise themselves with the 3D VR environment immediately before the exclusion paradigm or exposing them to multiple practical sessions involving minor tasks to build familiarity and reduce novelty (Miguel-Alonso et al., 2024). Complementary measures might involve administering brief novelty/familiarity questionnaires assessing prior VR use and perceived newness of the environment (Makransky et al., 2021), or behavioral indices such as time on task and unnecessary interactions, which serve as proxies for distraction in VR research (Mousavi et al., 2023). Together, such procedures would enable researchers both to reduce novelty effects and verify their reduction, thereby strengthening the interpretability of 3D VR exclusion effects.

Finally, with regard to the implementation of the 3D VR paradigm, an important limitation concerns the design of the virtual environment and the exclusion scenario. Feedback collected during the final debriefing indicated that some participants perceived the 3D design as insufficiently realistic and the situation not as fully age-appropriate (De Luca et al., 2026) This may have led participants to recognise that the virtual peers were simulated rather than genuine, thereby reducing immersion and identification with the avatars and ultimately limiting the naturalistic character of the experience. For future research, it would be advisable to enhance both the graphical fidelity and the contextual design of the paradigm. One promising avenue would be the incorporation of actual recordings or avatars of real students to establish a more authentic conversational context, thereby increasing realism and strengthening the validity of VR-based exclusion manipulations (Lie et al., 2023).

Conclusion

This study provides evidence that both the traditional 2D Cyberball paradigm and the novel 3D VR paradigm elicit the expected patterns associated with peer exclusion, including decreases in positive mood and psychological needs and increases in negative mood. Although the 2D Cyberball paradigm was associated with larger absolute changes, the 3D VR paradigm produced significant emotional and psychological responses, with particularly pronounced effects among adolescents. These findings indicate that the 3D VR paradigm is capable of reproducing exclusion-related outcomes in a setting that is experienced as more school-like and socially relevant.

Rather than replacing established approaches, the 3D VR paradigm should be considered a complementary method. Its successful implementation demonstrates feasibility and highlights the potential of VR-based tools to enhance ecological validity in the study of peer exclusion. Taken together, these findings support continued use of the well-established 2D

Cyberball paradigm while underscoring the promise of VR for examining peer dynamics in educational contexts.

Looking ahead, the results suggest that VR-based paradigms may offer unique opportunities for simulating school-relevant experiences and could be extended to investigate related phenomena, such as inclusion, victimisation, and social support. Refining and expanding VR-based paradigms may ultimately contribute to research efforts aimed at understanding and supporting student well-being and classroom social processes.

References

Abrams, D., Weick, M., Thomas, D., Colbe, H., & Franklin, K. M. (2011). On-line ostracism affects children differently from adolescents and adults. *British Journal of Developmental Psychology*, *29*(1). https://doi.org/10.1348/026151010X494089

Achenbach, T. M. (1991). Child Behavior Checklist/4-18. *Journal of Abnormal Child Psychology*, *15*.

Arslan, G. (2018). Social Exclusion, Social Support and Psychological Wellbeing at School: A Study of Mediation and Moderation Effect. *Child Indicators Research*, *11*(3). https://doi.org/10.1007/s12187-017-9451-1

Asher, S. R., Hymel, S., & Renshaw, P. D. (1984). Loneliness in Children. *Child Development*, *55*(4), 1456–1464.

Asscheman, S. J., Koot, S., Ma, I., Marieke Buil, J., Krabbendam, L., Cillessen, A. H. N., & van Lier, P. A. C. (2020). Erratum: Heightened neural sensitivity to social exclusion in boys with a history of low peer preference during primary school (Developmental Cognitive Neuroscience (2019) 38, (S1878929318302676), (10.1016/j.dcn.2019.100673)). In *Developmental Cognitive Neuroscience* (Vol. 44). https://doi.org/10.1016/j.dcn.2020.100792

Bodzin, A., Araujo Junior, R., Hammond, T., & Anastasio, D. (2021). *Investigating Engagement and Flow With A Placed-based Immersive Virtual Reality Game*.

Bronfenbrenner, U. (2005). Making human beings human: Bioecological perspectives on human development. In *British Journal of Developmental Psychology* (Vol. 23, Issue 1).

Brown, B. B., & Larson, J. (2009). Peer Relationships in Adolescence. In *Handbook of Adolescent Psychology*. https://doi.org/10.1002/9780470479193.adlpsy002004

Brown, M., McCormack, M., Reeves, J., Brooks, C., & Grajek, S. (2020). OK 2023 EDUCAUSE Horizon Report. Teaching and Learning Edition. In *EDUCAUSE Horizon Report Review* (Vol. 55, Issue 1).

Buhs, E. S., Ladd, G. W., & Herald, S. L. (2006). Peer exclusion and victimization: Processes that mediate the relation between peer group rejection and children's classroom engagement and achievement? In *Journal of Educational Psychology* (Vol. 98, Issue 1). https://doi.org/10.1037/0022-0663.98.1.1

Campodifiori, E., Figura, E., Papini, M., & Ricci, R. (2010). *Istituto nazionale per la valutazione del sistema educativo di istruzione e di formazione Un indicatore di status socio-economico-culturale degli allievi della quinta primaria in Italia*.

Chaplin, T. M., & Aldao, A. (2013). Gender differences in emotion expression in children: a meta-analytic review. Psychological bulletin, 139(4), 735.

Chirico, A., Ferrise, F., Cordella, L., & Gaggioli, A. (2018). Designing awe in virtual reality: An experimental study. *Frontiers in Psychology*, *8*(JAN). https://doi.org/10.3389/fpsyg.2017.02351

Cohen, J. (1988). Statistical power analysis for the behavioral sciences (2nd ed.). Lawrence Erlbaum Associates.

Di Natale, A. F., Repetto, C., Riva, G., & Villani, D. (2020). Immersive virtual reality in K-12 and higher education: A 10-year systematic review of empirical research. In *British Journal of Educational Technology* (Vol. 51, Issue 6). https://doi.org/10.1111/bjet.13030

Fuhrmann, D., Casey, C. S., Speekenbrink, M., & Blakemore, S. J. (2019). Social exclusion affects working memory performance in young adolescent girls. *Developmental Cognitive Neuroscience*, *40*. https://doi.org/10.1016/j.dcn.2019.100718

Gini, G., Carli, G., & Pozzoli, T. (2009). Social support, peer victimisation, and somatic complaints: A mediational analysis. *Journal of Paediatrics and Child Health*, *45*(6). https://doi.org/10.1111/j.1440-1754.2009.01501.x

Grassini, S., & Laumann, K. (2020). Questionnaire Measures and Physiological Correlates of Presence: A Systematic Review. *Frontiers in Psychology*, *11*. https://doi.org/10.3389/fpsyg.2020.00349

Hartgerink, C. H. J., van Beest, I., Wicherts, J. M., & Williams, K. D. (2015). The ordinal effects of ostracism: A meta-analysis of 120 Cyberball studies. PLoS ONE, 10(5), e0127002. https://doi.org/10.1371/journal.pone.0127002

Horn, S. S. (2003). Adolescents' Reasoning about Exclusion from Social Groups. In *Developmental Psychology* (Vol. 39, Issue 1). https://doi.org/10.1037/0012-1649.39.1.71

Hox, J., Moerbeek, M., & Van de Schoot, R. (2017). Multilevel analysis: Techniques and applications. Routledge.

Hu, L. T., & Bentler, P. M. (1999). Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Structural Equation Modeling*, *6*(1). https://doi.org/10.1080/10705519909540118

IBM Corp. (2020). IBM SPSS Statistics for Windows (Version 27.0)

Kassner, M. P., Wesselmann, E. D., Law, A. T., & Williams, K. D. (2012). Virtually ostracized: Studying ostracism in immersive virtual environments. *Cyberpsychology, Behavior, and Social Networking*, *15*(8). https://doi.org/10.1089/cyber.2012.0113

Killen, M., & Rutland, A. (2011). Children and Social Exclusion: Morality, Prejudice, and Group Identity. In *Children and Social Exclusion: Morality, Prejudice, and Group Identity*. https://doi.org/10.1002/9781444396317

Kingery, J. N., Erdley, C. A., & Marshall, K. C. (2011). Peer acceptance and friendship as predictors of early adolescents' adjustment across the middle school transition. *Merrill-Palmer Quarterly*, *57*(3). https://doi.org/10.1353/mpq.2011.0012

Knickenberg, M., Zurbriggen, C. L. A., & Schwab, S. (2022). Validation of the Student Version of the Perceptions of Inclusion Questionnaire in Primary and Secondary Education Settings. *SAGE Open*, *12*(1). https://doi.org/10.1177/21582440221079896

Kothgassner, O. D., Goreis, A., Glenk, L. M., Kafka, J. X., Beutl, L., Kryspin-Exner, I., Hlavacs, H., Palme, R., & Felnhofer, A. (2021). Virtual and real-life ostracism and its

impact on a subsequent acute stressor. *Physiology and Behavior*, *228*. https://doi.org/10.1016/j.physbeh.2020.113205

Ladd, G. W., Herald-Brown, S. L., & Andrews, R. K. (2009). The Child Behavior Scale (CBS) Revisited: A Longitudinal Evaluation of CBS Subscales With Children, Preadolescents, and Adolescents. *Psychological Assessment*, *21*(3). https://doi.org/10.1037/a0016205

Ladd, G. W., Kochenderfer-Ladd, B., Ettekal, I., & Clifford, B. N. (2021). Manifestations of Solitude in Interpersonal Contexts and Negative Peer Experiences. In *The Handbook of Solitude* (pp. 117–132). Wiley. https://doi.org/10.1002/9781119576457.ch9

La Greca, A. M., & Harrison, H. M. (2005). Adolescent peer relations, friendships, and romantic relationships: Do they predict social anxiety and depression?. Journal of clinical child and adolescent psychology, 34(1), 49-61.

Lie, S. S., Røykenes, K., Sæheim, A., & Groven, K. S. (2023). Developing a Virtual Reality Educational Tool to Stimulate Emotions for Learning: Focus Group Study. *JMIR Formative Research*, *7*. https://doi.org/10.2196/41829

Lila, M., Van Aken, M., Musitu, G., & Buelga, S. (2020). Peer relations in adolescence. In *Handbook of Adolescent Development*. https://doi.org/10.4324/9780203969861-10

Makransky, G., Andreasen, N. K., Baceviciute, S., & Mayer, R. E. (2021). Immersive virtual reality increases liking but not learning with a science simulation and generative learning strategies promote learning in immersive virtual reality. Journal of Educational Psychology, 113(4), 719.

Malecki, C. K., & Demaray, M. K. (2002). Measuring perceived social support: Development of the Child and Adolescent Social Support Scale (CASSS). *Psychology in the Schools*, *39*(1). https://doi.org/10.1002/pits.10004

Malti, T., Killen, M., & Gasser, L. (2012). Social Judgments and Emotion Attributions About Exclusion in Switzerland. *Child Development*, *83*(2). https://doi.org/10.1111/j.1467-8624.2011.01705.x

Marcoen, A., Goossens, L., & Caes, P. (1987). Lonelines in pre-through late adolescence: Exploring the contributions of a multidimensional approach. *Journal of Youth and Adolescence*, *16*(6). https://doi.org/10.1007/BF02138821

Masten, C. L., Eisenberger, N. I., Borofsky, L. A., Pfeifer, J. H., McNealy, K., Mazziotta, J. C., & Dapretto, M. (2009). Neural correlates of social exclusion during adolescence: understanding the distress of peer rejection. Social cognitive and affective neuroscience, 4(2), 143-157.

Masten, C. L., Eisenberger, N. I., Pfeifer, J. H., & Dapretto, M. (2013). Neural responses to witnessing peer rejection after being socially excluded: fMRI as a window into adolescents' emotional processing. Developmental science, 16(5), 743-759.

Mavromihelaki, E., Eccles, J., Harrison, N., Critchley, H., & Mania, K. (2014). *Cyberball3D+ for fMRI*. https://doi.org/10.1145/2614217.2614278

Mousavi, S. A., Powell, W., Louwerse, M. M., & Hendrickson, A. T. (2023). Behavior and self-efficacy modulate learning in virtual reality simulations for training: a structural equation modeling approach. Frontiers in Virtual Reality, 4, 1250823.

Meta. (2020). Meta Quest 2 [Virtual reality headset].

Miguel-Alonso, I., Checa, D., Guillen-Sanz, H., & Bustillo, A. (2024). Evaluation of the novelty effect in immersive Virtual Reality learning experiences. *Virtual Reality*, *28*(1). https://doi.org/10.1007/s10055-023-00926-5

Nelson, E. E., Leibenluft, E., McClure, E. B., & Pine, D. S. (2005). The social re-orientation of adolescence: A neuroscience perspective on the process and its relation to psychopathology. In *Psychological Medicine* (Vol. 35, Issue 2). https://doi.org/10.1017/S0033291704003915

Parsons, T. D. (2015). Virtual reality for enhanced ecological validity and experimental control in the clinical, affective and social neurosciences. *Frontiers in Human Neuroscience*, *9*(DEC). https://doi.org/10.3389/fnhum.2015.00660

Pfundmair, M., Aydin, N., Du, H., Yeung, S., Frey, D., & Graupmann, V. (2015). Exclude Me If You Can: Cultural Effects on the Outcomes of Social Exclusion. *Journal of Cross-Cultural Psychology*, *46*(4). https://doi.org/10.1177/0022022115571203

Prendergast, C. N., & Schubert, T. (2020). Investigating Reflexive Responses to Explicit and Implicit Forms of Social Exclusion Using Immersive Virtual Environment Technology. *Frontiers in Psychology*, *11*. https://doi.org/10.3389/fpsyg.2020.575783

Qualtrics. (2023). Qualtrics XM Platform [Computer software]

Quintana, P., Bouchard, S., Botella, C., Robillard, G., Serrano, B., Rodriguez-Ortega, A., Torp Ernst, M., Rey, B., Berthiaume, M., & Corno, G. (2023). Engaging in Awkward Social Interactions in a Virtual Environment Designed for Exposure-Based Psychotherapy for People with Generalized Social Anxiety Disorder: An International Multisite Study. *Journal of Clinical Medicine*, *12*(13). https://doi.org/10.3390/jcm12134525

Riva, G., Mantovani, F., & Gaggioli, A. (2004). Presence and rehabilitation: Toward second-generation virtual reality applications in neuropsychology. In *Journal of NeuroEngineering and Rehabilitation* (Vol. 1). https://doi.org/10.1186/1743-0003-1-9

Riva, P., & Eck, J. (2016). Social exclusion: Psychological approaches to understanding and reducing its impact. In *Social Exclusion: Psychological Approaches to Understanding and Reducing Its Impact*. https://doi.org/10.1007/978-3-319-33033-4

Rubin, K. H., Bukowski, W. M., & Bowker, J. C. (2015). Children in Peer Groups. In *Handbook of Child Psychology and Developmental Science*. https://doi.org/10.1002/9781118963418.childpsy405

Scheithauer, H., Alsaker, F., Wölfer, R., & Ruggieri, S. (2013). Cyberball: A reasonable paradigm for research in developmental science? In *International Journal of Developmental Sciences* (Vol. 7, Issue 1). https://doi.org/10.3233/DEV-1300071

Schmidt, A., Dirk, J., & Schmiedek, F. (2019). The importance of peer relatedness at school for affective well-being in children: Between- and within-person associations. *Social Development*, *28*(4). https://doi.org/10.1111/sode.12379

Schuck, K., Niedeggen, M., & Kerschreiter, R. (2018). Violated expectations in the cyberball paradigm: Testing the expectancy account of social participation with ERP. *Frontiers in Psychology*, *9*(SEP). https://doi.org/10.3389/fpsyg.2018.01762

Sebastian, C., Viding, E., Williams, K. D., & Blakemore, S. J. (2010). Social brain development and the affective consequences of ostracism in adolescence. In *Brain and Cognition* (Vol. 72, Issue 1). https://doi.org/10.1016/j.bandc.2009.06.008

Secker, J., Hacking, S., Kent, L., Shenton, J., & Spandler, H. (2009). Development of a measure of social inclusion for arts and mental health project participants. *Journal of Mental Health*, *18*(1). https://doi.org/10.1080/09638230701677803

Skårbrevik, K. J. (2005). The quality of special education for students with special needs in ordinary classes. *European Journal of Special Needs Education*, *20*(4). https://doi.org/10.1080/08856250500268601

Southgate, E., Smith, S. P., Cividino, C., Saxby, S., Kilham, J., Eather, G., Scevak, J., Summerville, D., Buchanan, R., & Bergin, C. (2019). Embedding immersive virtual reality in classrooms: Ethical, organisational and educational lessons in bridging research and practice. *International Journal of Child-Computer Interaction*, *19*, 19–29. https://doi.org/10.1016/j.ijcci.2018.10.002

Steinberg, L., & Morris, A. S. (2025). *ADOLESCENT DEVELOPMENT* (Vol. 17). www.annualreviews.org.

Timeo, S., Riva, P., & Paladino, M. P. (2020). Being liked or not being liked: A study on social-media exclusion in a preadolescent population. *Journal of Adolescence*, *80*. https://doi.org/10.1016/j.adolescence.2020.02.010

Tuijnman, A., Kleinjan, M., Chen, S., Engels, R. C. M. E., & Granic, I. (2021). A Game-based Assessment of the Effects of Rejection on Young Adults. *Proceedings of the ACM on Human-Computer Interaction*, *5*(CHIPLAY). https://doi.org/10.1145/3474681

Van Beest, I., & Williams, K. D. (2006). When inclusion costs and ostracism pays, ostracism still hurts. Journal of personality and social psychology, 91(5), 918.

Villena-Taranilla, R., Tirado-Olivares, S., Cózar-Gutiérrez, R., & González-Calero, J. A. (2022). Effects of virtual reality on learning outcomes in K-6 education: A meta-analysis. *Educational Research Review*, *35*. https://doi.org/10.1016/j.edurev.2022.100434

Warrington, M., & Younger, M. (2011). 'Life is a tightrope': Reflections on peer group inclusion and exclusion amongst adolescent girls and boys. *Gender and Education*, *23*(2). https://doi.org/10.1080/09540251003674121

Wentzel, K. R. (1998). Social relationships and motivation in middle school: The role of parents, teachers, and peers. *Journal of Educational Psychology*, *90*(2). https://doi.org/10.1037/0022-0663.90.2.202

Wiebe, E. N., Lamb, A., Hardy, M., & Sharek, D. (2014). Measuring engagement in video game-based environments: Investigation of the User Engagement Scale. *Computers in Human Behavior*, *32*. https://doi.org/10.1016/j.chb.2013.12.001

Will, G. J., van Lier, P. A. C., Crone, E. A., & Güroğlu, B. (2016). Chronic Childhood Peer Rejection is Associated with Heightened Neural Responses to Social Exclusion During Adolescence. *Journal of Abnormal Child Psychology*, *44*(1). https://doi.org/10.1007/s10802-015-9983-0

Williams, K. D. (2001). *Ostracism: the power of silence. (Emotions and social behavior)*. Guilford.

Williams, K. D., Cheung, C. K. T., & Choi, W. (2000). Cyberostracism: Effects of being ignored over the internet. *Journal of Personality and Social Psychology*, *79*(5). https://doi.org/10.1037/0022-3514.79.5.748

Witmer, B. G., Jerome, C. J., & Singer, M. J. (2005). The factor structure of the Presence Questionnaire. In *Presence: Teleoperators and Virtual Environments* (Vol. 14, Issue 3). https://doi.org/10.1162/105474605323384654

Wölfer, R., & Scheithauer, H. (2013). Ostracism in childhood and adolescence: Emotional, cognitive, and behavioral effects of social exclusion. *Social Influence*, *8*(4). https://doi.org/10.1080/15534510.2012.706233

Zadro, L., Williams, K. D., & Richardson, R. (2004). How low can you go? Ostracism by a computer is sufficient to lower self-reported levels of belonging, control, self-esteem, and meaningful existence. Journal of Experimental Social Psychology, 40(4), 560–567. https://doi.org/10.1016/j.jesp.2003.11.006

Supplementary Material

Text of the Final Debriefing After Study Participation

"Our experiment is over, we thank you for participating. We want to take this moment to give you some important information about this experiment. The aim of the research was not to compare two video games with different technological modes, as was explained to you at the beginning, but actually, the aim was to see which of the two games was more able to let you feel excluded by other students of the same age as you. In order for the simulation to be as realistic as possible, we had to tell you at the beginning of each experiment that the other two online participants were students of your age who were carrying out the same experiment at the same time from two other schools in Emilia Romagna. Actually, the other two participants were two digital avatars that followed specific commands established before the experiment, and their actions towards you were the same for all of you, so you all interacted with the exact same avatars that behaved in the exact same way with all of you. This is the main reason why we asked you, at the end of each individual experiment, not to talk to your classroom and school mates about the experiment for any reason until the total experiment was over for all students in the school. Now, wanting to have the most reliable data possible, we would like to ask you to please be truthful and tell us if you heard any details or any information about the experiment from other mates before running the experiment yourself so that we can mark your participation code and add this information to the database. Finally, we would like to tell you that we remain at your disposal if you would like a one-to-one meeting for further clarifications or if you have any specific questions for us. If you need this, just ask your teachers and we, through them, will arrange a meeting with you here at school. Also, when we have analysed the data and obtained the results, we will organize, together with the headmaster, a meeting with you, your teachers and parents, to better explain what we have done and what we have achieved."

Instructions for the 2D Cyberball Paradigm (cf. Williams et al., 2000)

We will now let you enter an online platform where you will play with two other students of your age from two other schools in Emilia Romagna who are carrying out the same experiment at the same time. Before you enter, you will have the chance to enter your name and a picture of yourself taken through the computer's webcam, and the other two players will do the same, so that all three of you can see your names and pictures next to your avatar. The game consists of passing a ball between all players. Each time the ball comes to you, you will have to use the right arrow to pass it to the student on your right and, vice versa, the left arrow to pass it to the student on your left. Before you start the real game with the other two students, we'll give you a quick one-shot test to make sure you understand how the controls work. Then we'll quickly contact our colleagues in the other two schools to make sure the other two students are ready, and once all three of you are ready, we'll let you go ahead and you can start playing.

Instructions for the 3D Virtual Reality Paradigm

We will now take you into a three-dimensional environment built through virtual reality using a headset. Once you have put on the headset, you will find yourself sitting in a virtual classroom together with two other students of your age from two other schools in Emilia Romagna, who are carrying out the same experiment at the same time, and who will be seated on the other sides of the desk. The virtual environment is ready and set up, once we have quickly heard from our colleagues in the other two schools to make sure that the other two students are ready. We will let you enter the virtual environment through the headset and give you two minutes to orient yourself inside the virtual environment and look around. After two minutes you can start to interact. In the meantime, we ask you to think of an interesting activity that you have done at school recently or in the previous months, whether in school or out of school, because this will be the topic that we want you to talk about with the others: we want each of you to share a school activity that you find interesting and discuss it among yourselves. The only two recommendations we make to you is to try to intervene when the other two are not talking and when they deliberately ask you to speak or turn towards you, so as to avoid talking over each other in order for the conversation not to become chaotic, and to stay seated all the time avoiding to walk in the VR room, as you can risk falling in the real environment. To avoid any problems and provide you with more security, we will monitor you via computer during the entire time you are inside the virtual environment. When the time for talking is over, we will interrupt the connection with the virtual environment and notify you so that you know when you can take off the headset. We ask you to actively and attentively participate in the conversation with the other two students because once you have exited virtual reality, we will ask you again to fill out a questionnaire, this time containing information about your experience in the virtual environment and what you talked about inside.

Scripts for the 3D VR Paradigm

The following scripts were developed for the exclusion and inclusion conditions. The emotion labels in parentheses (e.g., *enthusiasm, curiosity*) indicate the emotional tone that the AI-generated voices were instructed to convey when reading each line aloud.

Exclusion – Children (8-10 years)

Child 1 (Luca): Hi! I am Luca. And what's your name? (Referred to participant) (*Enthusiasm, curiosity*) Participant: (avatars look at the participant who introduces himself)

Child 1 (Luca) Hi! What's your name (referring to the avatar)? Child 2 (Martina): Hi! I am Martina! (*Joy, enthusiasm*)

Child 1 (Luca): What's the last interesting thing you did at your school?

Child 2 (Martina): Mmh, I don't know... the first thing that comes to mind is a trip we took to nature to do a science project. We went to a forest and saw the trees and the animals there! (*Enthusiasm*)

Child 1 (Luca): Wow! What about you? (Referred to participant) Participant: (avatars look at the participant answering the question)

Child 1 (Luca): Aah, OK. Martina how lucky you are to have done this so interesting thing. I like nature so much and I like discovering new things about plants and animals. (*Admiration, interest*)

Child 2 (Martina): Yes! It was really great! We saw a beautiful forest. There were very tall trees and we saw lots of animals living there (*Enthusiasm, Wonder*)

Child 1 (Luca): And what did you do while visiting the forest? Did you see any particular animals? (*Curiosity, interest*)

Child 2 (Martina): Yes! We saw how different trees are from each other and how they have leaves and bark. It was wonderful to discover that each tree has its own history and its

own important role in the forest. We also saw many animals, like squirrels jumping and colourful birds in the trees (*Enthusiasm, Wonder*)

Child 1 (Luca): Wow! That sounds really a too good experience! My dream is to be able to see a forest like that one day. It must have been amazing to observe animals in nature. (*Admiration*)

Child 2 (Martina): Yes, it was a magical moment! We were surrounded by nature and didn't hear the noise of the city. I loved hearing the sound of the leaves and the birds singing. I felt like a real explorer!

(*Happiness, nostalgia*)

Child 1 (Luca): How nice! I also like nature and I like being outdoors. When I'm in nature, I feel immersed in the world around us. (*Sharing, reflection*)

Child 2 (Martina): True! Nature inspires us and makes us feel part of something bigger. Although at the beginning I was a bit afraid of soiling my clothes or tripping over tree roots, I learnt to be brave. Now I am no longer afraid and I have had a lot of fun. I realised that it's important to be in nature even if you can fall, because even if you get hurt it doesn't hurt forever! (*Sharing, Gratitude*)

Child 1 (Luca): What bravery, Martina! You are a real explorer! How nice that you were lucky enough to do something so special. (*Admiration, happiness*)

Child 2 (Martina): Thank you, Luca. And have you done anything nice at school lately? (*Curiosity, interest*)

Child 1 (Luca): Mmh... A while ago we did an art project in which we created paintings. We used a lot of colours and drew our landscapes, towns and typical things. It was like travelling through our region. (*Enthusiasm, pride*)

Child 2 (Martina): How nice, Luca! I love art too! I would like to see your little works to know the places and what you have drawn. Did you add anything special to your artwork? (*Curiosity, interest*)

Child 1 (Luca): Yes! In the paintings I drew the historical houses and buildings of the cities, such as medieval towers and Renaissance palaces. I also drew the typical things we eat, like tortellini and Parmesan cheese. I tried to draw everything precisely so that those who see my drawings can recognise our region. (*Enthusiasm, pride*)

Child 2 (Martina): How beautiful! Surely your drawings are beautiful and show the beautiful things of our region. It would be nice to see them up close. Maybe you can ask the teachers to organise an exhibition with your artwork! (*Enthusiasm, curiosity, reflection*)

Child 1 (Luca): What a great idea! It can be done to show how beautiful our drawings are, not only to our schools, but also to other people who might see how good we are. We have to talk to the teachers and see if it can be done! That would be really great! (*Enthusiasm, determination*)

Child 2 (Martina): You're right, Luca! You have to beg your teachers to do this. It will be a unique experience! (*Enthusiasm, determination*)

Child 1 (Luca): Yes! We should also ask all the other children and all the teachers at our school. We could do things together during the exhibition, like start painting all together. That way we can show the others how nice it is to paint too. (*Enthusiasm, sharing*)

Child 2 (Martina): What a fantastic idea, Luca! I'm sure many children will be happy to participate and try their hand at painting. (*Enthusiasm, desire to learn*)

Child 1 (Luca): True! We need to have an exhibition where not only the children from our school but

everyone can participate. We can get the families and the townspeople to come and invite them to see our handicrafts! (*Determination, Pride*)

Child 2 (Martina): I really like your idea! It would be too nice to see all the habitants looking at the school's handiworks and admiring what you have done. (*Appreciation*)

Exclusion – Pre-Adolescents (11-13 years)

Boy 1 (Sara): Hi! I'm Sara! (*Enthusiasm*)

Boy 2 (Angelo): Hi Sara! I'm Angelo, nice to meet you! And what's your name? (*Happiness*) Participant: (avatars turn to look at the participant introducing themselves)

Boy 1 (Sara): What was the last activity you did at school? (*Curiosity*)

Boy 2 (Angel): I don't know... I don't think it's interesting, but the last thing we did was a maths workshop. (*Emphasis and enthusiasm*)

Boy 1 (Sara): Ah, nice, what about you? (Referred to participant) Participant: (avatars turn to look at the responding participant)

Boy 1 (Sara): Ah, OK. Wow, Angelo, your lab sounds really interesting! I really like maths. What have you been up to? (*Curiosity*)

Boy 2 (Angel): We did fractions in a whole new way! We learnt how to add, subtract, multiply and divide fractions in ways I never imagined. (*Excitement*)

Boy 1 (Sara): Really! And how? I like solving problems, but fractions seem really interesting. How did you do it? (*Interest*)

Boy 2 (Angelo): It was a lot of fun! Our teacher proposed maths games where we had to divide food

between friends and divide spaces. We solved everyday problems using fractions and discovered how they can be useful in everyday life. It was really fun! (*Excitement*)

Boy 1 (Sara): Wow, that sounds really interesting! I guess it was a fun assignment! (*Admiration*)

Boy 2 (Angel): Absolutely, Sara! It was an incredible experience. I learnt that fractions are useful and can simplify our lives. I was really happy to discover all that! (*Enthusiasm*)

Boy 1 (Sara): I'm happy for your experience! It's great when we can learn while having fun and use the knowledge in real life. (*Satisfaction*)

Boy 2 (Angel): Yes, that's really great! And you, Sara, what was the last thing you did at your school? (*Curiosity*)

Boy 1 (Sara): Mmh, I can think of a science project on the human body. It was really interesting! (*Enthusiasm*)

Boy 2 (Angel): Wow, that sounds cool! I'd like to understand how our bodies work. What exactly did you do? (*Curiosity*)

Boy 1 (Sara): We studied the various systems of the human body, such as the digestive system, the

circulatory system and the respiratory system. We also built a three-dimensional model of the human body to better understand what each organ does. It was a really great experience! (*Wonder*)

Boy 2 (Angelo): That must have been really exciting! I like the idea of studying the human body and understanding how it works. Our body is incredible! (*Admiration*)

Boy 1 (Sara): That's right, I really agree! It was a great way to learn! (*Enthusiasm*)
Boy 2 (Angel): It sounds really incredible! What did you like the most? (*Curiosity*)

Boy 1 (Sara): The brain and the nervous system. It was amazing to discover that the brain receives

information and sends signals through the nervous system to make us move and think. (*Wonder and excitement*)

Boy 2 (Angel): Wow, I can't even imagine how much fun that was! I didn't know that the brain influences our thinking and behaviour. Did you also do any hands-on activities? (*Interest*)

Boy 1 (Sara): Yes. We were divided into groups and each of us was able to investigate a specific system of the human body. My group focused on the skeletal system. (*Interest*)

Boy 2 (Angel): Ah, beautiful! And what exactly did you do? (*Curiosity*)

Boy 1 (Sara): We examined the bones, learning their names and functions. We also looked at the importance of the joints and muscles that enable us to move. But the most interesting part was when we created a model of the skeletal system with recycled materials. (*Enthusiasm*)

Boy 2 (Angel): What a great idea! I'm sure it was a lot of fun. How did you make the model? (*Curiosity*)

Boy 1 (Sara): We used various materials, such as cardboard, toothpicks and paint. We built the skeleton so that it stood straight and we could see all the parts, such as the skull, vertebrae, ribs and limb bones. It was fascinating to see how all these bones connect and form the structure of our body. (*Wonder and excitement*)

Boy 2 (Angel): It must have been really nice to see your finished model. (*Admiration*)

Boy 1 (Sara): Absolutely! Every time we looked at our model, we thought our body looked like that. Also, they explained to us how important it is to eat well and exercise. (*Satisfaction*)

Boy 2 (Angelo): I'm sure this experience has made you learn a lot of new things. This is really great! (*Pride*)

Boy 1 (Sara): Thank you, Angelo! It was a very important project. Now I'm even more interested in the human body and science. (*Enthusiasm*)

Exclusion –Adolescents (14-16 years)

Boy 1 (Alessandra): Hey, hi! My name is Alessandra. And you?

Boy 2 (Davide): Hi Alessandra! I'm Davide, nice to meet you! And you? (*Happiness*)

Participant: (avatars look at the participant who introduces himself)

Boy 1 (Alessandra): How are you? Have you done anything interesting at school lately? (*Curiosity*)

Boy 2 (Davide): Mmh, I don't know. The last thing I can think of is a scientific lab project on the effect of sunlight on plants. We looked at how light affects the growth and development of plants. It was an interesting topic to explore! (*Enthusiasm*)

Boy 1 (Alessandra): Hmm, got it. How about you? Participant: (avatars look at the responding participant)

Boy 1 (Alessandra): Ah, OK. Wow, Davide! Your project sounds really interesting! How did you structure your experiment? (*Curiosity*)

Boy 2 (Davide): We created suitable conditions for sunlight exposure for a group of identical plants. Some plants were placed in full sunlight, while others were placed in a shaded area. We left some plants indoors, away from direct sunlight. During the experiment, we measured the plants' growth, number of leaves, height and general health. We wanted to understand the effects of sunlight on plants.

Boy 1 (Alessandra): Wow, that sounds like a really good experiment! And what were your discoveries? What did you learn? (*Curiosity*)

Boy 2 (Davide): It was really interesting! We noticed that the plants exposed to direct sunlight grew more than the plants in the shade. The plants exposed to sunlight had stronger stems and bigger, greener leaves. In contrast, the plants in the shade showed slower growth and the leaves were paler. We also observed that the indoor plants grew very weak and had yellow leaves. (*Thrill of discovery*)

Boy 1 (Alessandra): Wow! So, direct sunlight makes plants grow and develop better. I never thought about how important sunlight is. (*Wonder*)

Boy 2 (Davide): Exactly! It is amazing how light, which we often take for granted, plays such an important role in plant life. This experiment gave us a better understanding of

the relationship between plants and the environment. It is as if we have unlocked a little secret of nature! (*Wonder*)

Boy 1 (Alessandra): I am really happy that you shared this experience with me, Davide. It's great to see how science allows us to discover the world. (*Satisfaction*)

Boy 2 (Davide): I too am happy that I was able to share my project with you, Alessandra. I discovered how exciting science can be. (*Pride*)

Boy 1 (Alessandra): I totally agree! We did an equally interesting science workshop. We focused on sets and graphs. (*Interest*)

Boy 2 (Davide): Ah cool! And how did you feel about doing sets and graphs? (*Curiosity*)

Boy 1 (Alessandra): It was difficult but at the same time exciting. In each set, we entered data. Afterwards, we used software to analyse the data and create the graphs. It was amazing to discover that data can be represented with graphs, which allowed us to discover new things about the phenomenon we were observing. (*Enthusiasm*)

Boy 2 (Davide): Interesting! I like the idea of working with graphic designers. It would be great if we could exchange our work to see what we've done! (*Enthusiasm*)

Boy 1 (Alessandra): Yes, that would be really interesting! Then between us we could share our experiences, discuss our discoveries and learn even more from each other. (*Curiosity*)

Boy 2 (Davide): Wow cool! I guess you enjoyed it. It's important to compare and take cues from each other. (*Enthusiasm*)

Boy 1 (Alessandra): I agree! Science is very interesting and we should appreciate it more because it allows us to know ourselves and the world. (*Passion*)

Boy 2 (Davide): You're right, Alessandra. It's wonderful to see how science can help us to learn new things. (*Marvel*)

Boy 1 (Alessandra): Exactly! There are so many situations where you can use science (*Enthusiasm*)

Boy 2 (Davide): I'm sure the projects we've done are incredible. It's interesting to see how each time you get a different result. (*Interest*)

Inclusion – Children (8-10 years)

(Child 1 - Andrea): Hello! My name is Andrea (*enthusiasm*). I am really curious to meet you.

(Child 2 - Clara): Hi Andrea! I'm Clara (*happiness*). I'm happy to meet you too. And what's your name? Participant: (avatars look at the participant who introduces himself)

(Child 1 - Andrea): Did you do something interesting at school? Something that really excited you? (*curiosity*)

(Child 2 - Clara): Well, actually yes! I can think of a really exciting little science project. We built a volcano and made it erupt using special ingredients. It was spectacular! (*enthusiasm*)

(Child 1 - Andrea): Wow! What about you?

Participant: (avatars look at the participant answering and continue to look at him referring to him in subsequent questions)

(Child 1 - Andrea): Wow, that sounds really interesting! Can I ask you what you did specifically? (*curiosity*) Participant: (avatars look at the responding participant)

(Child 2 -Clara): How nice! And how was it for you? (*Curiosity*)

Participant: (avatars look at the responding participant)

(Child 1 - Andrea): I guess. Clara, what did you do specifically? (*Curiosity*)

(Child 2 - Clara): We mixed liquids and substances that the teachers gave us and explained how to mix, what to put before and after inside the volcano, and at the end we

poured hot water to make the lava come out. It was amazing to see the smoke and fake lava coming out of the volcano! (*enthusiasm*)

(Child 1 - Andrea): That sounds really exciting! It must have been a lot of fun. How did you feel when you saw the lava coming out of the volcano? (*Curiosity*)

(Child 2 - Clara): I felt so excited and happy! It was like I was a real scientist doing experiments. I like it when we can do practical things instead of just listening to the teachers. (*joy*)

(Child 1 - Andrea): I'm so glad you had such a good time. And have you ever done a science project like that? Would you like to build a volcano? (Addressed to participant)

Participant: (avatars look at the responding participant)

Child 1 - Andrea): Understood. Clara, did you have any difficulty building the volcano? (*interest*)

(Child 2 - Clara): At first, I was a bit confused about how to do it and how to put together all the materials the teachers had given us. I felt a bit down because I wanted everything to go well. But then I asked the teacher for help and she slowly explained how to do it. I felt better when I understood how to do it. (*initial confusion, relief*)

(Child 1 - Andrea): Good thing you asked for help and your teacher helped you. (*approval*)

(Child 2 - Clara): Yes, at first I was a bit shy and didn't want to ask for help, but then I realised it was really necessary. After I did it, I felt much better! (*realisation, relief*) What would you have done in my place? (addressed to participant)

Participant: (avatars look at the responding participant)

(Child 2 - Clara): I guess. What about you, Andrea? Did you do anything interesting at school? (*Curiosity*)

(Child 1 - Andrea): Mmh, the last interesting thing I remember was a nature trip last week. We went to a park and saw lots of plants and animals. It was wonderful! I felt happy and amazed the whole day. (*happiness, wonder*)

(Child 2 - Clara): Wow, that sounds really good! I would love to do something like that. That must have been really interesting. (*admiration*)

(Child 1 - Andrea): It was fantastic! I was fascinated by the beauty of nature. It was like entering a new world! (*admiration, wonder*) It was like there were so many new things to see that I had never seen before. I felt really lucky to see that park. (*Gratitude*)

(Child 2 - Clara): You make me too curious. Have you ever done a similar trip with the school to a park? (Addressed to participant)

Participant: (avatars look at the responding participant)

(Child 2 - Clara): I see. Andrea, what kind of animals did you see on the trip? (*Curiosity*)

(Child 1 - Andrea): We saw so many different animals! There were colourful birds, squirrels hopping around in the trees and even a family of fawns running around in the middle of the park. It was exciting to be able to observe the animals so closely. (*enthusiasm*)

(Child 2 - Clara): Wow, you made me want to take a trip to the park too! How did you feel while observing the animals? (*Curiosity*)

(Child 1 - Andrea): I felt incredibly lucky and fascinated. Every time I saw an animal and could approach it without fear I felt a wonderful and mysterious world. It was a day all about nature. (*wonder, connection*)

(Child 2 - Clara): It sounds like a magical experience! I would love to have the chance to watch the animals so closely. It's like living inside nature. (*enthusiasm*)

(Child 1 - Andrea): It really is an amazing adventure! I discovered that it's wonderful to spend so much time inside a park where there are only plants and animals. I felt so lucky, don't you agree? (*appreciation*)

Participant: (avatars look at the responding participant)

(Child 2 - Clara): It's really true, they are wonderful experiences, and I'm so glad we told each other these stories! (*Gratitude*)

(Child 1 - Andrea): I too am happy to have talked to you. It's nice to talk about our experiences and see how curious we are about the world around us. (*satisfaction*)

Inclusion – Pre-Adolescents (11-13 years)

Boy 1 (Giulia): Hi! I'm Giulia, and you? (*enthusiasm*)

Boy 2 (Eugenio): Hi! I'm Eugenio, pleased to meet you! And you? (*enthusiasm*) Participant: (avatars look at the participant who introduces himself)

Boy 1 (Giulia): Nice to meet you! What have you been up to at school? Participant: (avatars look at the responding participant)

Boy 1 (Giulia): That sounds very interesting! And what exactly did you do? Participant: (avatars look at the responding participant)

Boy 2 (Eugenio): Cool! And how did it feel?

Participant: (avatars look at the responding participant) Boy 1 (Giulia): I can imagine. And you, Eugenio?

Boy 2 (Eugenio): I don't know, it occurs to me that we took a trip to the natural science museum last year. We were able to see and learn new things about plants, animals and rocks. It was a lot of fun! (*enthusiasm*)

Boy 1 (Giulia): Wow, that sounds really interesting! I'd like to be able to go to a natural science museum too. Have you ever seen a natural science museum? (Addressed to participant)

Participant: (avatars look at the responding participant)

Boy 1 (Giulia): Understood. What was the best part of the visit for you, Eugenio? (*Curiosity*)

Boy 2 (Eugenio): Well, one of the most beautiful things was seeing the fossils and learning more about our planet. It's amazing how many things there are in nature and how many animals exist. Do you like nature? (*admiration*)

Participant: (avatars look at the responding participant)

Boy 1 (Giulia): I really like looking at animals and plants. Nature is beautiful! We took a trip to the cookery workshop. We learnt how to make homemade pasta, gnocchi and many other dishes. It was fun kneading and then eating what we had made! (*enthusiasm*)

Boy 2 (Eugenio): How nice! I like the idea of learning to cook something good to eat. How about you? Do you like the idea of cooking? Have you ever done a cooking workshop?

Participant: (avatars look at the responding participant) Boy 2 (Eugenio): OK, did you have fun?

Boy 1 (Giulia): Yes! I had a really good time. It was a different trip from the others, and everything we ate tasted even better knowing that we had prepared it ourselves! (*enthusiasm*)

Boy 2 (Eugenio): Wow, that sounds really fun! Cooking will definitely be a unique experience and I would like to go on this trip too. What have you prepared? (*curiosity*)

Boy 1 (Giulia): We learnt how to make homemade pasta, gnocchi and much more. We used fresh ingredients such as mushrooms and spinach, but the most fun part was making the gnocchi! (*enthusiasm*) We were helped by a very good chef who explained how we had to move our hands to give the gnocchi a perfect shape. It was so much fun! (*enthusiasm*)

Boy 2 (Eugenio): I envy you. We've never been taken to a cookery workshop. Did you eat the things you prepared? (*curiosity*)

Boy 1 (Giulia): Of course! After we finished cooking, we ate everything. It was like a reward for our work. Maybe they looked even better to us because we had made them. (*satisfaction*) It was a really incredible experience and, in particular, my companions and I laughed a lot. The chef also explained to us that cooking is part of every region's culture and that a simple dish of pasta can unite even the most diverse people. (*satisfaction*)

Boy 2 (Eugenio): You're right, thinking about it, cooking is also important because it's part of the tradition. What do you think?

Participant: (avatars look at the responding participant)

Boy 2 (Eugenio): OK, it's nice that you were able to share this experience with your classmates. (*appreciation*). The most beautiful part must have been kneading with your hands! Did you find it difficult?

Boy 1 (Giulia): Some things were a bit complicated, but the chef had a lot of patience and was always behind us. In the end, we all managed to prepare delicious dishes! (*satisfaction*)

Boy 2 (Eugenio): How nice to learn this way. Maybe one day you and your mates could all cook dinner together. (*enthusiasm*)

Boy 1 (Giulia): Yeah, that would be really fun! I'm looking forward! (*enthusiasm*)

Inclusion – Adolescents (14-16 years)

Boy 1 (Nicola): Hi! I'm Nicola. What are your names?

Boy 2 (Caterina): Hi! I'm Caterina, nice to meet you! And you?

Participant: (avatars turn to look at the participant introducing themselves)

Boy 1 (Nicola): Nice to meet you! What's the last interesting thing you two did at school?

Boy 2 (Caterina): Well, I think the most interesting one was a science project where we explored the environment of our city. It was very cool! (*enthusiasm*)

Boy 1 (Nicola): Nice! We did a cool project too, but in technology, where we programmed and developed a little game. What did you do? (*Curiosity*)

Participant: (avatars look at the participant answering and continue to look at him referring to him in subsequent questions)

Boy 1 (Nicola): That sounds very interesting, what did you do specifically? (*Curiosity*) Participant: (avatars look at the participant while responding)

Boy 2 (Caterina): I see. Did you enjoy it? What did you feel at that moment? (*Curiosity*) Participant: (avatars look at the participant while responding)

Boy 1 (Nicola): I can imagine. And you, Caterina, what exactly did you do in your project? (*Curiosity*)

Boy 2 (Caterina): We learnt to recognise the species of plants and animals in our city. We also visited a nature park to directly observe the environment. It was really interesting to discover how each species performs a specific function! (*enthusiasm*)

Boy 1 (Nicola): Wow, that sounds really interesting! I like the idea of exploring the environment and seeing what it's like. Have you ever done anything similar with the school?

Participant: (avatars look at the responding participant)

Boy 1 (Nicola): Understood. How did you feel during the project? (*Curiosity*)

Boy 2 (Caterina): I felt very involved. It was like being a real scientist, observing nature, collecting data and doing experiments. I also liked it when we reconstructed the environment ourselves to better understand how it works! (*enthusiasm*)

Boy 1 (Nicola): Nice! The technology project we did was interesting as well. We created a little game using computer algorithms. (*enthusiasm*)

Boy 2 (Caterina): Top that cool! They never made us use algorithms. Did you guys ever do anything about computer science at school?

Participant: (avatars look at the responding participant)

Boy 2 (Caterina): OK, Nicola, did you find it difficult? (*Curiosity*)

Boy 1 (Nicola): A little bit, to be honest, but then I had fun. It was fun to create characters, levels and challenges. I also enjoyed solving the problems that arose and improving the game! (*enthusiasm*)

Boy 2 (Caterina): That's really interesting! I like the idea of developing a game using programming. It would be great if they made us do it too. (*enthusiasm*)

Boy 1 (Nicola): Yes, it would be really useful, even as an alternative activity to the usual school lessons. What do you think? (*satisfaction*)

Participant: (avatars look at the responding participant)

Boy 1 (Nicola): I see, in the meanwhile I was thinking, Caterina, have you ever thought of proposing this project to your teachers? It could be a fun way to learn and put digital knowledge into practice! (*Curiosity*)

Boy 2 (Caterina): Good idea! We should definitely talk to them and see if there is a possibility of introducing a similar project in our school. I'm convinced that many of our classmates would love to participate! Wouldn't you be happy if they asked you? (*enthusiasm*)

Participant: (avatars look at the responding participant)

Boy 1 (Nicola): I'm sure that if you can present your project convincingly, your teachers will be happy to give you this opportunity. You just have to make sure you are convincing (*determination*) Do you have any ideas for being convincing?

Participant: (avatars look at the responding participant)

Boy 2 (Caterina): Exactly! We have to show them how motivated we are. I think we could also involve the other kids from the school, forming a small team to develop the game together. (*enthusiasm*)

Boy1 (Nicola): Yes, it would be great to work together with other students. You could exchange ideas, collaborate and learn even more. Maybe you could even enter a competition. (*enthusiasm*)

Boy 2 (Caterina): I like how you're thinking big! I'm looking forward to start organising. (*determination*)

Confirmatory Factor Analysis for Positive and Negative Mood

A two-factor model, distinguishing between Positive Mood and Negative Mood, was specified and tested.

Table S1

Model Fit

Statistics	Value
$\chi^2(12)$	18.207
p	.110
CFI	.983
TLI	.960
RMSEA	.059
RMSEA 90% CI	[.000, .110]
RMSEA p-close	.352
SRMR	.039
Hoelter's N (α = .05)	174.226
Hoelter's N (α = .01)	216.992

Note: The estimator is ML. Abbreviations: CFA = confirmatory factor analysis; RMSEA = root mean square error of approximation; SRMR = standardised root mean square residual; CFI = comparative fit index; TLI = Tucker–Lewis index.

Table S2

Factor Loadings

Latent factor	Item/Mood dimension	Estimate	*SE*	*z*	*p*	95% *CI*
	Bad	.137	.096	1.434	.152	[-.050, .325]
Negative mood	Sad	.542	.075	7.241	< .001	[.395, .689]
	Unfriendly	.376	.052	7.244	< .001	[.274, .478]
	Angry	.666	.089	7.455	< .001	[.491, .842]
	Good	.442	.058	7.660	< .001	[.329, .556]
Positive mood	Happy	.719	.075	9.549	< .001	[.571, .866]
	Friendly	.468	.057	8.158	< .001	[.356, .580]
	Pleasant	.663	.069	9.575	< .001	[.527, .798]

Note. Parameter estimates are standardized. The two-factor confirmatory factor analysis (CFA) was specified with positive mood (good, happy, friendly, pleasant) and negative mood (bad, sad, unfriendly, angry) as correlated latent variables. SE = standard error; CI = confidence interval.

Confirmatory Factor Analysis (CFA) for Psychological Needs

A confirmatory factor analysis was conducted to test the hypothesised measurement model of psychological needs, with belongingness, self-esteem, meaningful existence, control, and certainty specified as correlated latent variables.

Table S3

Model Fit

Statistic	Value
$\chi^2(224)$	247.143
p	.138
CFI	.985
TLI	.980
RMSEA	.026
RMSEA 90% CI	[.000, .044]
RMSEA p-close	.989
SRMR	.064
Hoelter's N (α = .05)	138.378
Hoelter's N (α = .01)	147.177

Note: The estimator is ML. Abbreviations: CFA = confirmatory factor analysis; RMSEA = root mean square error of approximation; SRMR = standardized root mean square residual; CFI = comparative fit index; TLI = Tucker–Lewis index.

Table S5

Factor Loadings

Factor	Item	Need dimension	Estimate	SE	z	p	95% CI
Belongingness	I feel "disconnected"	Belongingness	.516	.089	5.832	< .001	[.343, .690]
	I feel rejected	Belongingness	.332	.055	6.075	< .001	[.225, .440]
	I feel like an outsider	Belongingness	.368	.061	6.021	< .001	[.248, .488]
	I feel I belong to the group	Belongingness	.410	.073	5.627	< .001	[.267, .552]
	I feel the others interact with me a lot	Belongingness	.418	.077	5.453	< .001	[.268, .568]
Self-esteem	I feel good about myself	Self-esteem	.815	.078	10.505	< .001	[.663, .967]
	My self-esteem is high	Self-esteem	.911	.079	11.526	< .001	[.756, 1.066]
	I feel liked	Self-esteem	.625	.069	9.088	< .001	[.490, .760]
	I feel insecure	Self-esteem	.763	.087	8.743	< .001	[.592, .934]
	I feel satisfied	Self-esteem	.705	.080	8.824	< .001	[.548, .861]
Meaningful existence	I feel invisible	Meaningful existence	.509	.063	8.044	< .001	[.385, .633]
	I feel meaningless	Meaningful existence	.452	.066	6.835	< .001	[.323, .582]
	I feel non-existent	Meaningful existence	.395	.061	6.481	< .001	[.275, .514]
	I feel important	Meaningful existence	.634	.070	9.057	< .001	[.497, .772]
	I feel useful	Meaningful existence	.526	.066	7.918	< .001	[.396, .656]
Control	I feel powerful	Control	.527	.083	6.335	< .001	[.364, .690]
	I feel I have control	Control	.524	.085	6.150	< .001	[.357, .692]
	I feel I have the ability to significantly alter events	Control	.411	.084	4.881	< .001	[.246, .576]
	I feel I am unable to influence the action of others	Control	.182	.089	2.049	.040	[.008, .356]
	I feel others decide everything	Control	.443	.090	4.938	< .001	[.267, .618]
Certainty	I feel uncertain about myself	Certainty	.676	.076	8.923	< .001	[.527, .824]
	I feel confident about who I am	Certainty	.697	.091	7.666	< .001	[.519, .875]
	I feel unsure of what makes me who I am	Certainty	.240	.108	2.214	.027	[.028, .452]
	I am certain about what to do	Certainty	.650	.089	7.319	< .001	[.476, .824]
	I do not know what I should be doing	Certainty	.381	.101	3.773	< .001	[.183, .579]

Note. The five-factor confirmatory factor analysis (CFA) was specified with belongingness, self-esteem, meaningful existence, control, and certainty as correlated latent factors. Reported estimates are standardized factor loadings. SE = standard error; CI = confidence interval.

Previous Rejection Experiences Scale

Instruction: Think about your experiences at school from the beginning of primary school to this point, and select the frequency with which you experienced the following situations from 1 (*never*) to 5 (*always*).

Exclusion from activities

1. I've been excluded from peers' activities (CBS**,** Ladd et al., 2009)
2. Other students didn't invite me to parties (Skårbrevik, 2005)
3. I didn't take the lead in social activities (Skårbrevik, 2005)

Exclusion from play

4. I didn't have anyone to play with (LSDQ, Asher et al., 1984).
5. Peers refused to let me play (CBS, Ladd, et al., 2009)
6. I was not chosen as playmate (CBS**,** Ladd et al., 2009)

Exclusion from talking or discussions

7. I've had nobody to talk to (LSDQ, Asher et al., 1984)
8. There was nobody I could go to when I needed help (LSDQ**,** Asher et al., 1984).

Emotionally excluded

9. Other kids in my class have been mean to me (Schmidt et al., 2019)
10. Others got me hurt a lot (YSR**,** Achenbach, 1991)

Indirectly excluded

11. I felt isolated from others (LLSCA, Marcoen et al., 1987)
12. I felt excluded by my classmates (LLSCA, Marcoen et al., 1987)
13. Other students didn't want I participated in activities (Skårbrevik, 2005)

Implicitly excluded

14. Peers avoided me (CBS**,** Ladd et al., 2009)
15. I've been ignored by peers (CBS, Ladd et al., 2009)
16. I've been inconsiderate from others (CBS, Ladd et al., 2009)

Short-term impact (negative mood and frustration)

17. I felt left out of things (LSDQ**,** Asher et al., 1984).

18. I felt sad because nobody wanted to join in with me (LLSCA, Marcoen et al., 1987)

19. I've been afraid the others wouldn't let me join in (LLSCA, Marcoen et al., 1987)

Long-term impact (Loneliness)

20. I have felt terribly alone and isolated (SIS, Secker et al., 2009)

21. I felt alone in my class (PIQ**,** Knickemberg et al., 2022)

22. I feel alone at school (LLSCA, Marcoen et al., 1987)

Lack of feedback

23. I didn't get along with other kids (YSR, Achenbach, 1991)

24. I wanted to be better integrated in the class group (LLSCA**,** Marcoen et al., 1987)

25. I have felt some people look down on me because of how I am (SIS, Secker et al., 2009)

Exploratory Factor Analysis (EFA)

To examine the factor structure of the Previous Rejection Experiences Scale (PRES), an exploratory factor analysis (EFA) with maximum likelihood extraction was conducted. Factor retention was evaluated using eigenvalues greater than one, scree plot inspection, and parallel analysis. Results supported a one-factor solution. One item from the original scale ("I didn't take the lead in social activities") was removed because it did not load on the factor. The final sum score of the remaining items was used in subsequent analyses.

Table S6

Model Fit

Statistics	Value
Extraction method	Maximum likelihood
Rotation	None (unrotated)
KMO (overall MSA)	.953
Bartlett's test	$\chi^2(276) = 2839.266$, $p < .001$
Eigenvalue (factor 1)	13.552
% variance explained	54.7%
Cronbach's α (final scale)	.96

Note. EFA = exploratory factor analysis; KMO = Kaiser–Meyer–Olkin; MSA = measure of sampling adequacy.

Figure F1

Scree plot

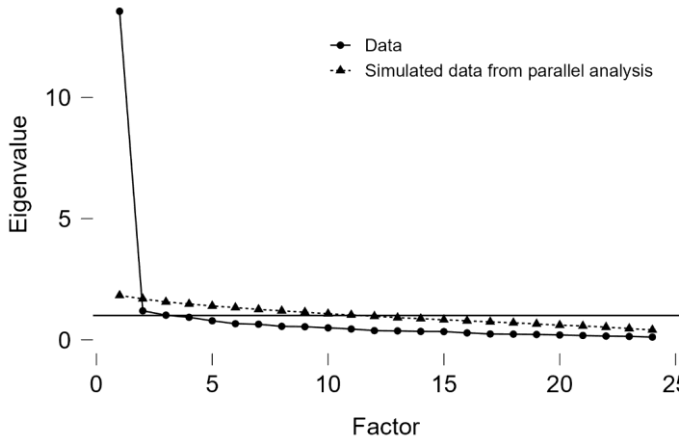


Table S7

Factor Loadings and Uniqueness

Item	Factor loading	Uniqueness
I felt isolated from others	.861	.258
I felt left out of things	.851	.276
I felt excluded by my classmates	.847	.282
I've been ignored by peers	.839	.297
Peers avoided me	.814	.337
I have felt terribly alone and isolated	.812	.341
I've been inconsiderate from others	.799	.361
I feel alone at school	.791	.375
I felt sad because nobody wanted to join in with me	.787	.381
I felt alone in my class	.786	.382
I've had nobody to talk to	.784	.386
Others got me hurt a lot	.774	.400
I didn't have anyone to play with	.765	.415
Other students didn't want I participated in activities	.738	.455
Peers refused to let me play	.720	.481
I was not chosen as playmate	.712	.493
I've been excluded from peers' activities	.709	.497
There was nobody I could go to when I needed help	.702	.507
Other kids in my class have been mean to me	.672	.549
I have felt some people look down on me because of how I am	.612	.626
Other students didn't invite me to parties	.583	.660
I've been afraid the others wouldn't let me join in	.582	.662
I wanted to be better integrated in the class group	.580	.664
I didn't get along with other kids	.467	.782

Note. All values are factor loadings for the single extracted factor and the uniqueness of each item. Loadings represent the correlation between the item and the factor, while uniqueness indicates the variance not explained by the factor. Loadings ≥ .40 are generally considered acceptable.

Paradigm Features Scale

For the next questions, please mark the number that best represents the thoughts you had during the game.	**Not at all**				**Totally**
Immersion					
I felt like I was experiencing that situation in a real environment	1	2	3	4	5
Presence					
I felt like I was actually present inside the virtual/digital environment	1	2	3	4	5
Involvement					
I felt fully/totally involved in the situation	1	2	3	4	5
Perception of Realism					
Interaction with other players/students felt natural to me	1	2	3	4	5

Exploratory Factor Analysis

An exploratory factor analysis (EFA) with maximum likelihood extraction was conducted to examine the factor structure of the Paradigm Features Scale. A single-factor solution was retained based on eigenvalue greater than one, scree plot inspection, and parallel analysis. Although RMSEA values were relatively high, this likely reflected the small number of items rather than poor model fit. Other indices (CFI, TLI, SRMR) indicated adequate fit, supporting the one-factor solution.

Table S8

Model Fit

Statistic	Value
Extraction method	Maximum likelihood
Rotation	None (unrotated)
KMO (overall MSA)	.731
Bartlett's test	$\chi^2(6) = 269.285$, $p < .001$
Eigenvalue (factor 1)	2.630
% variance explained	57.3%
Cronbach's α (final scale)	.78

Note. EFA = exploratory factor analysis; KMO = Kaiser–Meyer–Olkin; MSA = measure of sampling adequacy.

Figure F2

Scree plot

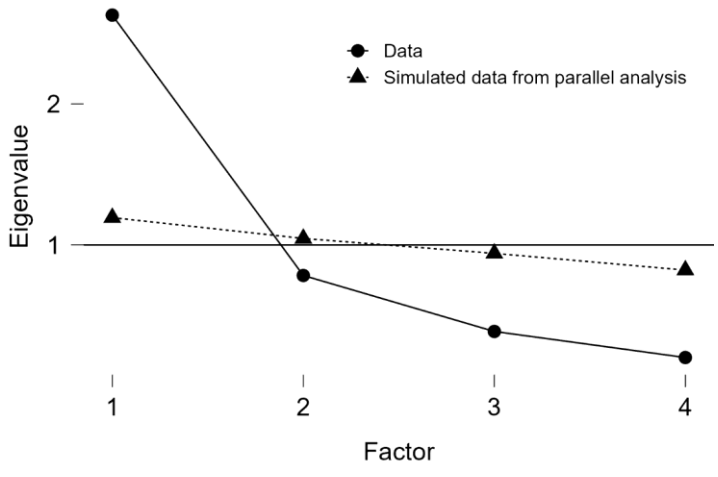


Table S9

Factor Loadings and Uniqueness

Item	Factor loading	Uniqueness
I felt like I was experiencing that situation in a real environment	.949	.099
Interaction with other players/students felt natural to me	.807	.349
I felt like I was actually present inside the virtual/digital environment	.748	.440
I felt fully/totally involved in the situation	.409	.833

Note. All values are factor loadings for the single extracted factor and the uniqueness of each item. Loadings represent the correlation between the item and the factor, while uniqueness indicates the variance not explained by the factor. Loadings ≥ .40 are generally considered acceptable.

References

Achenbach, T. M. (1991). Manual for the Child Behavior Checklist/4-18 and 1991 profile. University of Vermont, Department of Psychiatry.

Asher, S.R.; Hymel. S.; Renshaw, P. (1984) Loneliness in children. Child Development; 55:1456–1464.10.2307/1130015

Knickenberg, M., Zurbriggen, C. L., & Schwab, S. (2022). Validation of the Student Version of the Perceptions of Inclusion Questionnaire in Primary and Secondary Education Settings. SAGE Open, 12(1), 21582440221079896.

Ladd, G. W., Herald-Brown, S. L., & Andrews, R. K. (2009). The Child Behavior Scale (CBS) revisited: a longitudinal evaluation of CBS subscales with children, preadolescents, and adolescents. Psychological Assessment, 21(3), 325.

Marcoen, A., Goossens, L., & Caes, P. (1987). Loneliness in pre-through late adolescence: Exploring the contributions of a multidimensional approach. Journal of Youth and Adolescence, 16(6), 561-577.

Schmidt, A., Dirk, J., & Schmiedek, F. (2019). The importance of peer relatedness at school for affective well-being in children: Between- and within-person associations. Social Development, 28(4), 873–892. https://doi.org/10.1111/sode.12379

Secker, J., Hacking, S., Kent, L., Shenton, J., & Spandler, H. (2009). Development of a measure of social inclusion for arts and mental health project participants. Journal of Mental Health, 18(1), 65-72.

Skårbrevik, K. J. (2005). The quality of special education for students with special needs in ordinary classes. European Journal of Special Needs Education, 20(4), 387-401.

CHAPTER 5

The Cognitive Cost of Being Left Out: Immediate Effects of Peer Exclusion on Working Memory in Children and Adolescents Using Immersive Virtual Reality

Giuseppe De Luca[1,2], Elvis Mazzoni[1], Martina Benvenuti[1], Friederike Blume[3,4], Gerrit Meixner[5], Tung Khau[5], Dieter Baeyens[2]

[1] University of Bologna, Department of Psychology, Italy

[2] KU Leuven, Parenting and Special Education Research Unit, Belgium

[3] DIPF | Leibniz Institute for Research and Information in Education, Frankfurt/Main, Germany

[4] IDeA Research Centre for Individual Development and Adaptive Education of Children at Risk, Frankfurt/Main, Germany

[5] Heilbronn University, Usability and Interaction Technology Laboratory, Germany

Abstract

Executive functions (EFs)—including working memory (WM), inhibition, and cognitive flexibility—are foundational for learning and sensitive to emotional and social contexts during development. Peer exclusion is a salient social stressor that can undermine emotional well-being and cognitive functioning in school-aged youth. Using a developmentally sensitive, immersive virtual reality (VR) paradigm, this study examined how peer exclusion affects mood and WM among children and adolescents. A sample of 170 students aged 8–16 years completed pre- and post-exclusion measures of mood (positive and negative) and WM (verbal and visuospatial). Peer exclusion was experimentally manipulated via a standardised VR scenario simulating a realistic school conversation. Exclusion led to significant decreases in positive mood and increases in negative mood. No main effects emerged for WM, but age moderated outcomes. Younger children exhibited declines in visuospatial WM after social exclusion, whereas adolescents showed improvements. Mediation analyses revealed that specific emotional responses influenced WM performance in the full sample. Reductions in happiness and increases in anger had differential effects—with lower happiness predicting poorer WM performance and higher anger associated with enhanced performance, suggesting distinct emotion-specific pathways. Contextual and individual factors also moderated the impact of peer exclusion on WM, including VR presence, socioeconomic status, teacher support, and behavioural difficulties. Findings highlight that both individual resources (e.g., baseline WM, socioeconomic background, teacher support, and VR presence) and individual challenges (e.g., behavioural difficulties) shape how children and adolescents cope with social exclusion. The study advances the use of ecologically valid VR paradigms in educational psychology and underscores the need to foster emotional and cognitive supports in schools to reduce negative consequences of peer exclusion.

Keywords: Peer exclusion, Working Memory, Mood, Virtual Reality, Experimental Design

Introduction

As extensively documented in the educational psychology literature, the most proximal developmental contexts—such as family, classroom, and peer groups—play a pivotal role in shaping children's cognitive development and academic outcomes. Parents who provide positive care have been shown to promote better future academic achievement (Popov & Ilesanm, 2015). In contrast, lower levels of parental sensitivity and engagement have been found to negatively affect socio-cognitive development (Zarrella et al., 2018). Similarly, teachers are assumed to play a fundamental role in enhancing students' cognitive processes. They can lead to higher academic achievement by providing a cognitively structured and stimulating environment (Vandenbroucke et al., 2018b). However, the role of peers, particularly concerning cognitive outcomes in children, has received far less attention.

Peer relationships can be regarded as a proximal developmental context as children and adolescents interact daily with peers. Similar to caregivers in their proximal contexts (i.e., parents and teachers), peers influence developmental outcomes of children and adolescents (Moore et al., 2018). The extant literature on peer relationships has emphasised their role in school-related functioning, especially focusing on school wellbeing and engagement (Long et al., 2021). However, relatively little research has been conducted on the relationship between peer relationships and the cognitive processes children and adolescents use in the school setting to complete tasks and achieve academic goals.

Given that students cognitively engage (referring to the extent to which students invest mental effort, attention, and persistence in learning activities; Fredricks et al., 2004) daily in the classroom (and are expected to demonstrate high levels of performance to achieve optimal learning outcomes), it is important to examine how peer relationships may shape these cognitive processes. Within cognitive processes, working memory (WM) has been found to be particularly susceptible

to environmental influences (for systematic review, see for parent-child relationship: Valcan et al., 2018; for teacher-student interactions: Vandenbroucke et al., 2018b) while also demonstrating a pivotal predictive function for academic achievement and learning outcomes (Vandenbroucke et al., 2017). The present study thus aimed to examine the impact of short-term experiences of peer exclusion on students' WM performance.

Working Memory

WM is a core executive function (EF) which enables the storage, updating, and monitoring of relevant information during task performance, allowing individuals to memorise specific data and manipulate it as needed (Miyake et al., 2000). Among the various theoretical models of WM, Baddeley's multicomponent model is the most widely adopted and influential in the literature. This model posits a system comprising a central executive that coordinates three subsystems: the phonological loop, the visuospatial sketchpad, and the episodic buffer (Baddeley, 2000). Although alternative models exist, for example Cowan's embedded-processes model, which emphasises the role of attention in activating information from long-term memory (Cowan, 2012), Baddeley model's detailed specification of domain-specific components and the available empirical support across developmental and neuropsychological studies make it particularly suitable for research on EF.

High levels of WM have consistently been linked to positive developmental outcomes across multiple domains, including academic performance (for meta-analysis, see Carretti et al., 2009; Friso-van den Bos et al., 2013) and social interactions (for review, see Meyer & Lieberman, 2012; Riggs et al., 2006). Notably, WM performance measured at the beginning of kindergarten predicted later academic outcomes at the end of that period (Welsh et al., 2010). Similar results are found when WM was measured at the start of primary school (Judd et al., 2021) and when it was measured during adolescence (Söderqvist & Nutley, 2015). Regarding social interactions, evidence

has shown that individuals with lower WM resources are more prone to emotional dysregulation when confronted with socially stressful situations (Ouimet et al., 2009). Limited WM has been identified as a potential risk factor for poor emotional control, particularly under social pressure, which may, in turn, amplify the cognitive cost of negative social experiences (Petkus et al., 2017).

Compared to other EFs, WM exhibits the most protracted and linear developmental course, extending well into late adolescence and early adulthood (Satterthwaite et al., 2014). During the preschool years (ages 3–6), WM gradually emerges (Zelazo & Carlson, 2012). During primary school, WM development has been shown to accelerate in both verbal and visuospatial domains, reflecting increased demands of formal schooling; evidence indicated marked gains in WM capacity between ages 6 and 10 (Dirk & Schmiedek, 2016; Oberer et al., 2018). The idea of a discrete growth spurt in WM around early adolescence is debated: while certain EFs, such as inhibition, show spurt-like changes, WM development appears more gradual, though still marked by acceleration during the transition into adolescence (Luna et al., 2010). WM development is assumed to continue steadily into young adulthood (Crone & Dahl, 2012).

The development of WM is closely intertwined with age-related structural and functional changes in the brain. WM relies heavily on both cortical and subcortical brain systems, which mature along distinct yet overlapping trajectories. During childhood, subcortical regions such as the basal ganglia and thalamus show heightened activity and developmental changes, supporting early WM performance (Tamnes et al., 2013). In parallel, cortical regions critical for WM, especially the dorsolateral prefrontal cortex (dlPFC) and the anterior cingulate cortex (ACC), undergo a prolonged period of maturation characterised by cortical thinning and synaptic reorganisation (Lynch et al., 2023). The prefrontal cortex (PFC)—a hub for WM and other executive processes—begins its major developmental trajectory in late childhood (around ages 9–11), with continued refinement well into adolescence (Tervo-Clemmens et al., 2023). This

extended developmental window allows for increasing efficiency and specialisation of WM-related neural circuits, particularly in the dlPFC, which plays a central role in maintaining and manipulating information. As brain connectivity and structural differentiation advance, WM performance improves, reflecting the gradual integration of distributed neural networks (for review, see Luna et al., 2015). Importantly, these neurodevelopmental changes persist through adolescence and even into early adulthood, highlighting the protracted and plastic nature of WM development. The ongoing maturation of fronto-striatal and fronto-parietal circuits during this period underscores WM's sensitivity to developmental influences and environmental input (for review, see Larsen & Luna, 2018). This neural plasticity underpins the rationale for studying WM during the transition from childhood to adolescence, as it remains a dynamic and malleable cognitive function that continues to evolve alongside the maturing brain.

Environmental factors, both proximal and distal, significantly affect these developmental processes. According to Bronfenbrenner's ecological systems theory (2005), children's development is shaped by interactions within nested environmental systems, with distal contexts (e.g., socioeconomic conditions, culture) exerting more indirect influence, and proximal contexts (e.g., family, teachers, peers) having a direct, daily impact. Nevertheless, distal influences like socioeconomic status (SES) play a clear role: lower SES relates to reduced cognitive abilities in early childhood. At the same time, SES improvements correspond with WM performance gains (Hackman et al., 2010). Within the proximal contexts, parent-child relationships (PCRs) are strongly associated with WM. Here, warm parental behaviours (e.g., responsive caregiving, cognitive stimulation, consistent emotional availability), socio-emotional responsiveness, and cognitive stimulation are linked to better WM outcomes, also highlighting WM as the most malleable EF in response to environmental input (for meta-analysis, see Valcan et al., 2018). Similarly, teacher-student relationships (TSRs; i.e., the quality of the relational bond between a

teacher and a student, including emotional closeness, support, and absence of conflict) and teacher–student interactions (TSIs i.e., the observable behaviours and practices in the classroom such as emotional support, instructional feedback, and classroom organisation) play a pivotal role in predicting higher WM outcomes, particularly teachers' emotional support (for review, see Sankalaite et al., 2021) and closeness (for meta-analysis, see Xu et al., 2024). At the dyadic level, teachers' emotional support and closeness have been shown to enhance WM performance (Sankalaite et al., 2021). At the classroom level, aspects such as emotional support and classroom management have been found to contribute to improved WM outcomes (Xu et al., 2024). PCRs, TSRs, and TSIs appear to exert their influence through shared underlying mechanisms, including principles from attachment theory (Bowlby, 1982), developmental systems theory (DST; Gottlieb & Lickliter, 2007), cognitive load theory (Sweller, 1994), and Vygotsky's zone of proximal development (Vygotsky et al., 1979). These frameworks suggest that emotionally and cognitively supportive environments reduce stress, foster self-regulation, and provide appropriate scaffolding—conditions that are especially conducive to WM development (Sweller et al., 2019).

The dominant interest of existing research lies in family and teacher influences on WM performance and development, while underexploring the contributions of peer relationships. However, the limited available findings suggest that the level of peers' EFs within a classroom may have predictive value for students' own individual WM development. More specifically, classroom WM performance has been shown to improve more rapidly when students are embedded in classrooms where peers show greater EF task efficiency (Finch et al., 2019). While the direct influence of peers' levels of EF on WM specifically has yet to be fully clarified, these findings collectively underscore that peer dynamics—both social and cognitive—may be an important lever for supporting WM development across key developmental periods. The specific mechanisms through which peer dynamics influence WM generally remain poorly understood. This gap is

particularly striking considering the increasing developmental importance of peer interactions in late childhood and adolescence, precisely when peer influence and close peer relationships become central socialisation forces (Laursen & Veenstra, 2021; Prinstein & Giletta, 2020) and WM continues to exhibit marked neuroplasticity across adolescence (Larsen & Luna, 2018; Murty et al., 2016).

Peer Relationships as a Developmental Context

As mentioned before, peer relationships play a fundamental role in the broader development of children and adolescents (Weyns et al., 2018). Together with parent-child and teacher-student relationships, peer relationships form part of the microsystem and thus exert a direct influence on development (Bronfenbrenner, 2005). Attachment theory posits that, as children develop, their primary social focus gradually shifts from parents to peers. This process of social transition results in the establishment of attachment bonds with the peer group, which become increasingly significant as children progress from childhood to adolescence (Lila et al., 2020). In this way, peers become role models and essential sources of emotional and cognitive support (Telzer et al., 2013). Social support from parents, teachers, peers, and close friends has been identified as a significant predictor of children's and adolescents' well-being and psychological adjustment, serving as a protective buffer against adverse emotional events and promoting resilience in social functioning (Arslan, 2018; Cohen, 2004).

It is widely acknowledged that developing adequate peer relationships is pivotal during childhood and adolescence. As such, the experience of being excluded by one's peers or peer group has been shown to engender significant internal distress, manifesting in a range of adverse emotions, including unhappiness and anger (Williams, 2009). Peer exclusion can be defined as the experience of being kept apart from others physically (e.g., social isolation) or emotionally (e.g., being ignored or told one is not wanted; Riva & Eck, 2016). Research indicates that excluded

children and adolescents are more prone to the development of internalising problems, such as anxiety, social withdrawal, loneliness, isolation, and depression (Ladd et al., 2021). These symptoms may, in turn, manifest in behaviours characterised by shyness, unsociability, and social avoidance (Rytioja et al., 2019). Peer exclusion is a profoundly distressing emotional experience for students (Abrams et al., 2011). This is especially true for adolescents, who place a higher value on peer evaluations than younger children do (Sebastian et al., 2010). This heightened susceptibility during adolescence is characterised by an increased emotional reactivity in situations where exclusion is observed (Will et al., 2016). Nonetheless, extant literature and theoretical frameworks posit that social support from parents, teachers and friends may serve to mitigate the adverse effects of peer exclusion on the psychological well-being of children and adolescents (Nezlek et al., 2015). In the context of this distressing event in the school environment, such support may act as a protective factor.

Research has indicated that peer experiences are not uniformly perceived or processed across genders. It has been demonstrated that females appear to demonstrate a heightened emotional response to episodes of social exclusion, exhibiting elevated levels of distress and frustration in comparison to male subjects (Horn, 2003). This heightened sensitivity may be rooted in the greater emphasis placed on interpersonal relationships during female social development, potentially making negative peer experiences more emotionally salient (Warrington & Younger, 2011).

Next to socio-emotional outcomes, peer exclusion has also been shown to affect school functioning. Regarding academic performance, few studies suggest that the most excluded students at school may show poorer cognitive outcomes than the most popular ones, particularly in areas such as attention and logical reasoning skills (Tobia et al., 2017). More broadly, negative peer relationships have been associated with lower academic achievement in terms of school grades and

learning outcomes (Caemmerer & Keith, 2015). Students excluded from their peers show lower school engagement than accepted students; they tend to display less interest in school, more boredom, and disengagement from classroom activities, and they are more likely to drop out of school compared to their peers (Buhs et al., 2006). Nevertheless, the potential detrimental effects of peer relationships on cognitive performance remain less thoroughly investigated than those of parent-child and teacher-student relationships, especially concerning WM.

Peer Exclusion and Working Memory

Few studies have so far attempted to establish a causal link between peer exclusion and WM performance. Current efforts are characterised by several methodological limitations and contrasting results.

First, the few experimental studies which have specifically examined the effects of peer exclusion on WM performance in an experimental setting all used the Cyberball paradigm (Williams et al., 2000) to simulate exclusion experiences. Cyberball is an experimental paradigm consisting of an online ball-tossing game, where children and adolescents assume they are playing with other real peers, while actually interacting only with standardised computer players. The classical version of this online game involves three players passing a ball among each other. In the peer exclusion condition, children and adolescents never or rarely receive the ball. In contrast, in the neutral or inclusion condition, they regularly receive it. The Cyberball paradigm has proven to be effective in simulating peer exclusion by showing a decrease in positive mood and an increase in negative mood and frustration. However, as a two-dimensional (2D) paradigm, this paradigm suffers from limited ecological validity. Enhanced ecological validity can potentially amplify or refine existing findings by providing a more realistic and immersive experience, allowing students to perceive the simulated exclusion as more similar to an everyday real-life situation (Prendergast & Schubert, 2020). Consequently, students' emotional and cognitive responses—including

feelings and thoughts—may be closer to those experienced during genuine exclusion scenarios. To this end, a three-dimensional (3D) paradigm using a virtual reality (VR) environment has been developed to better replicate real-life situations, thereby achieving higher ecological validity (De Luca et al., 2026). Preliminary evidence from direct comparisons with the traditional 2D Cyberball paradigm suggested that the newly developed 3D VR paradigm effectively simulates peer exclusion, with stronger effects observed in adolescents than in children (De Luca et al., *in prep.*). Thus, we expect that our newly developed 3D VR paradigm can fill this methodological gap in the research on peer exclusion and WM.

Second, in addition to ecological validity, methodological design represents another major category of limitations in this line of research. The aforementioned experimental studies have shown that peer exclusion can impair both verbal and visuospatial WM performance in both primary and secondary school students (Fuhrmann et al., 2019; Hawes et al., 2012; Vandenbroucke et al., 2018a). Furthermore, the detrimental effect on WM performance has been found to be stronger in females than in males, suggesting that gender plays a moderating role in how peer dynamics influence cognitive functioning (Fuhrmann et al., 2019; Hawes et al., 2012). However, the majority of experimental studies have derived these results by only comparing an exclusion condition with a neutral condition (i.e., between-subject designs). Although this approach facilitates the comparison of experimental and control groups, it does not permit consideration of within-person change or the influence of pre-existing individual differences in cognitive performance, emotional reactivity, or sensitivity to social stress. Between-subject designs cannot disentangle the effects of peer exclusion from pre-existing individual differences in cognitive performance, emotional reactivity, or sensitivity to social stress. Therefore, between-subject designs cannot disentangle the effects of peer exclusion from pre-existing individual differences. Within-subject (pre-to-post) designs overcome this limitation by allowing each participant to serve

as their own control, thereby reducing error variance due to stable individual characteristics (e.g., baseline WM, emotional reactivity) and increasing statistical power and sensitivity to detect change following exclusion (Bolger & Laurenceau, 2013; Dimitrov & Rumrill, 2003).These designs also provide a more precise estimate of the immediate impact of peer exclusion on WM performance because they control for baseline differences and focus on intraindividual change, thereby improving internal validity and capturing the immediate cognitive cost of social exclusion (Dimitrov & Rumrill, 2003; Seltman, 2018). Building on these within-subject pre-to-post designs, it is also important to consider how peer dynamics relate to WM over longer timescales. A limited number of longitudinal studies have further examined peer relationships and WM development across childhood and adolescence, showing that peer acceptance predicts better subsequent WM performance, whereas peer exclusion or peer-related difficulties are associated with poorer outcomes, particularly in late childhood (de Wilde et al., 2016; Holmes et al., 2016; Lecce et al., 2020). Pre-to-post and longitudinal designs, therefore, complement each other by capturing both the immediate and long-term effects of peer exclusion on WM. Although longitudinal evidence was beyond the scope of this study, our approach focused on capturing the short-term, situational effects of peer exclusion on WM, thereby complementing prior correlational and longitudinal research.

Third, a common limitation is the way peer relationships have usually been operationalised. Two studies (de Wilde et al., 2016; Lecce et al., 2020) assessed peer acceptance and rejection based on social status in the classroom using sociometric techniques (i.e., peer nominations; Coie et al., 1982). Another one (Holmes et al., 2016) assessed peer problems through self-reports and evaluations provided by friends, parents, and teachers. These approaches are predicated on the perceptions of exclusion held by peers, neglecting the subjective perspective of the excluded children and adolescents themselves, and their own perception of being excluded by peers. This is

a limitation of the methodology, as it measures only the effects of social status, rather than the outcomes experienced by students after a peer exclusion experience (Ladd, 2005; Rubin et al., 2015). This gap can be addressed by employing a 3D VR paradigm, as it facilitates direct investigation of the immediate impact of peer exclusion experiences on students' subjective emotions and cognitive performance within an experimental design.

Fourth, the studies above did not explore potential differences between age groups. In light of the extensively documented developmental disparities outlined in psychological literature, it is imperative to recognise the growing salience of peer relationships during adolescence as compared to childhood (Lila et al., 2020). This developmental trend is further accentuated by the ongoing maturation of the prefrontal cortex and refinement of WM networks during adolescence, which support more complex cognitive processing and greater integration of emotional and social information (Luna et al., 2010). As a result, adolescents may experience peer exclusion more intensely than children, both cognitively and emotionally, making it a particularly critical period for examining intraindividual responses to social stress. More specifically, no study has yet experimentally investigated how the immediate effects of peer exclusion on WM may differ between children and adolescents, based on their personal experience of being excluded.

Fifth, empirical evidence indicated that social exclusion triggers immediate affective disturbances, most notably decreases in positive affect and increases in negative affect, such as sadness, anger, and anxiety (Eisenberger et al., 2003). These mood fluctuations may, in turn, affect cognitive functioning. In particular, WM performance is sensitive to affective states. Positive mood has been associated with enhanced WM performance, facilitating flexibility and information updating (Yang et al., 2013). In contrast, negative mood—especially high arousal negative states like anxiety—has been linked to WM impairments due to increased cognitive load and attentional capture by emotional stimuli (Oaksford et al., 1996; Shackman et al., 2006). The rationale

underpinning the association between social exclusion and diminished WM via mood is that recuperation from an exclusionary occurrence demands a substantial allocation of cognitive resources (Buelow et al., 2015). Therefore, after an episode of social exclusion, cognitive resources are allocated to recovering from this social stressor, which consequently diminishes the availability of these resources for other cognitive tasks (Sweller, 1994). Despite these converging findings, the mediating role of mood in the relationship between peer exclusion and WM remains underexplored.

To conclude, while prior research has established the critical role of developmental contexts in shaping stable aspects of WM, the situational manifestations of WM performance in response to their developmental contexts remain insufficiently studied. Therefore, there is a pressing need for research investigating situational WM changes within developmental contexts using rigorous experimental designs (i.e., the newly developed 3D VR paradigm). Furthermore, the intraindividual and subjective nature of peer exclusion as a personal experience has been largely overlooked, as well as the immediate effect of such experiences on children's and adolescents' emotions and cognition. The scarcity of intraindividual data makes it impossible to adequately capture or understand the immediate impact of exclusion on children's emotional states and cognitive performance. Thus, the understanding of how peer exclusion affects WM within the school environment is still emerging and incomplete.

The Present Study

The present study aimed to investigate the immediate effects of experiencing peer exclusion on students' mood and WM performance using an experimental design. The primary research question guiding this study was whether experiences of peer exclusion result in a decline in the WM performance of children and adolescents. Peer exclusion was operationalised in an immersive 3D VR scenario in which other virtual peers ignored the participant during a simulated conversation.

The following hypotheses were derived:

H1) The experience of peer exclusion will result in a decrease in positive mood and an increase in negative mood, as demonstrated in previous studies (Abrams et al., 2011).

H2) Based on the limited available literature, peer exclusion is expected to negatively affect cognitive functioning by reducing the ability to effectively use cognitive resources during cognitive tasks due to the stress experienced (Buhs & Ladd, 2001). Consequently, students are assumed to exhibit reduced WM performance following the peer exclusion experience (Hawes et al., 2012).

H3) Previous evidence indicated that females experience higher levels of frustration following peer exclusion than males (Horn, 2003), and that exclusion has a stronger negative effect on WM performance for females compared to males (Hawes et al., 2012). Thus, detrimental effects of peer exclusion on mood and WM performance are assumed to be more pronounced in females than in males.

H4) Adolescence is a critical period due to the social focus shift from parents to peers (Lila et al., 2020), as well as the maturation of brain regions crucial for WM, which makes the adolescent brain particularly sensitive to functional changes triggered by social experiences (Larsen & Luna, 2018). Negative effects of peer exclusion on mood and WM performance will therefore be greater in adolescents aged 13–16 years compared to children aged 8–12 years.

H5) Based on previous research showing that exclusion experiences negatively affect mood (Williams, 2009) and that mood states, in turn, potentially influence WM performance (Yang et al., 2013), we expected that mood changes will mediate the effect of perceived exclusion on WM performance. Specifically, it was expected that a decrease in positive mood and an increase in negative mood following perceived peer exclusion will mediate a corresponding decline in WM performance (Oaksford et al., 1996; Shackman et al., 2006), irrespective of whether the mediation is partial or full. If significant changes in WM performance are observed only in specific subgroups

(e.g., by gender or age), we will explore whether mood mediates the relationship between perceived peer exclusion and WM performance within these subgroups.

H6) Prior research indicated that social support from parents, teachers, peers, and friends can buffer the adverse effects of social exclusion (Arslan, 2018), whereas children and adolescents with previous experiences of rejection were more sensitive to new exclusion experiences (Will et al., 2016). Accordingly, it was expected that students who report higher levels of support from parents, teachers, and friends will experience improved WM performance following exclusion, while those with prior rejection experiences show reduced WM performance after a social exclusion episode in this experiment.

H7) Previous research suggested that VR features such as presence, involvement, and realism can enhance the perceived authenticity and emotional intensity of social interactions, thereby amplifying users' psychological responses to social experiences, including exclusion (Prendergast & Schubert, 2020). Accordingly, it was expected that students reporting higher levels of presence, involvement, and realism during the VR task will achieve lower WM performance following peer exclusion compared to those reporting lower levels of these VR features.

H8) Previous findings suggested that students from lower socioeconomic status (SES) backgrounds are more sensitive to peer exclusion compared to those from higher SES backgrounds (Gönül et al., 2023). Additionally, lower SES has been associated with poorer cognitive performance (Mooney et al., 2021). Treating SES as a continuous variable, we expected that the adverse effects of peer exclusion on WM performance are more pronounced as SES decreases.

H9) Previous research suggested that individuals with lower cognitive capacity experience stronger negative emotional effects following exclusion (Ouimet et al., 2009). Limited WM may serve as a risk factor for mood dysregulation (Petkus et al., 2017). Therefore, we expected that baseline WM performance predicts lower WM performance following peer exclusion.

H10) Prior evidence has linked externalising behaviours (e.g., hyperactivity) and internalising problems (e.g., peer difficulties) to cognitive impairment (Donati et al., 2021). Therefore, we assumed that these behavioural problems influence cognition by showing lower WM performance scores after peer exclusion.

Methods

Participants

One hundred seventy students were recruited from three different schools (a total of nine classrooms participated): 80 children (8–12 years; 47.1%) and 90 adolescents (13–16 years; 52.9%). The mean participant age was 13.26 years (*SD* = 2.03). Students self-reported their gender by selecting from three options (male, female, diverse); however, none selected the third option, resulting in the classification of students into 87 males (51.2%) and 83 females (48.8%). Students were eligible for study entry when they met the following inclusion criteria: 1) students were aged between 8 and 16 years, and 2) they were attending regular schools that were invited for study participation. Exclusion criteria included teacher-reported intellectual disabilities or significant physical/emotional impairments, as defined by the International Classification of Diseases (ICD) classifications. These exclusion criteria ensured that all students would understand instructions, have the necessary motor and visual skills to complete the tasks, and/or would not be excessively affected by the social exclusion manipulation (e.g., students with anxiety disorders). In total, six students were excluded from participation based on these criteria: one due to a physical impairment, two due to emotional impairments, and three due to intellectual disabilities.

Procedure

The study was pre-registered in OSF (https://osf.io/j2h4c/overview?view_only=42c85ea3ac7647dda88675731fdd1417) and received approval from the University Institutional Ethical Committee Board of the University of Bologna

(Protocol No. 0151020). Students were recruited by contacting the principals of three schools in Italy that had previously collaborated with the research institution. Each school was asked to provide at least one class per grade (Grades 4–10, approximately ages 8–16), with a target of at least 22 students per class to meet the minimum sample size determined by an a priori power analysis. Upon approval from principals and teachers, anonymised lists of eligible students were provided, and parental consent was obtained. Teachers also identified students meeting exclusion criteria, based on official certifications reported by families, using a secure coding system to protect privacy. Students did not receive any remuneration for their participation.

Once parental consent was granted, the study consisted of three phases: pre-experimental, experimental, and post-experimental.

Pre-experimental phase. Parents completed an online questionnaire via Qualtrics (2023) providing demographic information (e.g., child's gender, age, grade, school type) and SES data using the Italian National SES indicator (Campodifiori et al., 2010). One week prior to the experimental sessions, students completed questionnaires assessing moderating influences in the classroom, including previous peer rejection experiences and perceived social support from parents, teachers, and friends (CASSS; Gini et al., 2009). Data pseudonymization was ensured through unique coding procedures.

Experimental phase. Each student participated individually in a 60-minute experimental session using the VR exclusion paradigm, conducted in a quiet room within their school. The session included pre- and post-manipulation measures of mood and WM. Every participant experienced a peer exclusion condition using a 3D VR paradigm. This paradigm was designed according to Cyberball's main mechanism (Williams, 2001), with the key difference being its interactive conversational nature. Participants were told they would interact with two unknown

peers, who were actually preset avatars, discussing school activities or experiences they enjoyed (De Luca et al., 2026).

Three exclusion scenarios were tailored to grade levels: primary (up to Grade 5; see Figure 1), lower high school (Grades 6–8; see Figure 2), and upper high school (Grades 9+; see Figure 3). Each version adjusted avatars, voice, language, and conversation topics to the age group, while maintaining the same experimental structure centred on a conversational task in a virtual classroom.

Figure 1: VR scenario for primary school

Figure 2: VR scenario for lower high school

Figure 3: VR scenario for upper high school

Before entering the VR environment, students were informed that they would engage in a virtual conversation with two peers from other schools and were instructed to listen carefully and participate actively. The virtual classroom contained two avatars (one male, one female) discussing a school-related topic. After a five-minute familiarisation period, the interaction began, with one avatar initiating the conversation and prompting responses from both the participant and the second avatar.

Peer exclusion was manipulated by having avatars invite the participant to contribute but then ignore their input, continuing to address only each other. The questions were adapted by grade: primary school students were asked about a pleasant school activity; lower high school students about favourite school-time activities; upper high school students about an interesting school trip. The exclusion interaction lasted five minutes, in addition to the familiarisation period, and the VR scenario was delivered using the Oculus Meta Quest 2 system (Meta, 2020). The paradigm has been validated against Cyberball (Williams, 2001), showing comparable decreases in positive mood and increases in negative mood (De Luca et al., *in prep.*). Effects were developmentally differentiated: adolescents exhibited stronger exclusion-related responses than children.

Qualitative analyses indicated that participants perceived the VR paradigm as more immersive and realistic, eliciting stronger social presence and authentic appraisals of exclusion (De Luca et al., 2026). Participants in the validation study also offered constructive feedback to enhance ecological fidelity, including more naturalistic dialogue, improved facial animations, and context-appropriate conversational topics (De Luca et al., 2026). This feedback was subsequently incorporated into the refinement of these specific elements of the VR paradigm, which was then employed in the current study.

To maintain the experimental deception, students were told the study evaluated psychological responses to a VR situation. Teachers were not blind to the research aims but communicated only the cover story to students. Sessions were conducted individually, and students were asked not to discuss the experiment afterwards. Information exchange was monitored through a single closed-ended item, and sensitivity analyses excluded participants who indicated exposure to details of the manipulation, VR design, or mood deception.

Mood and WM performance were assessed before and after the experimental manipulation using standardised questionnaires and performance-based tasks. This pre-to-post within-subject design allowed us to measure the immediate, intraindividual effects of peer exclusion while controlling for baseline differences. Although the procedure was necessarily extensive due to the variety of dependent variables assessed, we considered all the previously listed hypotheses to be valid as previous studies have shown that negative emotions induced by exclusion lead to sustained frustration and prolonged cognitive disruption (Buelow et al., 2015). Given the limited number of studies examining the effects of peer exclusion on WM performance (Hawes et al., 2012; Vandenbroucke et al., 2018a), we adopted the same WM tasks as these studies. These tasks have shown a strong balance between reliability and sensitivity to change, making them well-suited for capturing pre-to-post differences within an experimental design. Pre- and post-exclusion

assessments of mood and WM were conducted using online software (Qualtrics, 2023; Stoet, 2017) and standardised test materials (Digit Backwards test in paper format).

To address ethical concerns, an inclusion condition was implemented at the end of the session, in which students engaged in a lively discussion with different avatars under the same VR conditions.

Post-experimental phase. After data collection, students were debriefed in group discussions, during which the true purpose and methodology of the study were explained.

Measures

Descriptive Variables

To provide a comprehensive profile of the sample and control for relevant background factors, we collected information on participants' demographic characteristics, socioeconomic status, and behavioural adjustment.

Demographic Variables. Information regarding students' gender and age was collected through a parent-reported questionnaire administered at the beginning of the study. Gender was assessed via a single question offering three response options: male, female, and diverse. Age was reported by asking parents to specify the child's exact age in years and months.

Socioeconomic Status (SES). SES was measured following the guidelines of the Italian National Institute for the Evaluation of the Education and Training System (INVALSI; Campodifiori et al., 2010). The SES questionnaire included three components: (a) parental employment status (one item with nine response options), (b) parental educational level (one item with six response options), and (c) possession of specific household items (seven dichotomous items regarding possessions such as rooms and books). For the first two components, responses were scored from 0 to 5, while possession items were scored as 0 (absence) or 1 (presence). The

total SES score was computed by summing these item scores, with higher scores indicating higher socioeconomic status.

Strengths and Difficulties Questionnaire (SDQ). Prosocial behaviour and problem behaviours were assessed using the Italian version of the SDQ (Goodman, 1997; Tobia & Marzocchi, 2018). The SDQ consists of 25 items divided into five subscales: Emotional Symptoms, Conduct Problems, Hyperactivity, Peer Problems, and Prosocial Behaviour (five items each). Parents rated how well each item described their child's behaviour on a 3-point Likert scale ranging from 1 (not true) to 3 (certainly true). Higher scores on the problem subscales reflect greater difficulties. The total difficulties score was used in the analyses. In this study, the total scale reliability was α = .82, while the reliability of the individual subscales was lower but still acceptable.

Dependent Variables

The main outcomes of interest in this study were mood and WM performance, as these are the processes hypothesised to be directly affected by peer exclusion.

Mood. Mood and perceived exclusion were assessed using the Italian version of the Need-Threat Scale (Timeo et al., 2020; Williams et al., 2000), a widely adopted instrument in Cyberball studies. The scale consists of eight mood-related items measuring various affective states experienced during the exclusion manipulation (e.g., good, bad, happy, sad, friendly, unfriendly, pleasant, angry) and two manipulation check items assessing perceived exclusion ("I was excluded" and "I was ignored"). Responses were recorded on a 5-point Likert scale from 1 (not at all) to 5 (extremely).

A confirmatory factor analysis (CFA) conducted on this scale in a previous work of our research team (De Luca et al., *in prep.*) supported a two-factor model distinguishing *Positive Mood* (good, happy, pleasant, friendly) from *Negative Mood* (bad, sad, angry, unfriendly), in line with

Hu and Bentler's (1999) criteria. Therefore, as in our previous study (De Luca et al., *in prep.*), the two mood dimensions will be used in this study, rather than the separate mood items. Manipulation Check items formed a separate subscale. For each subscale, total scores were computed by summing the corresponding items. Higher scores indicated higher levels of the specific mood or perceived exclusion. Reliability indices in the present study were satisfactory: Positive Mood (α = .88), Negative Mood (α = .82), and Manipulation Check (α = .78).

Verbal Working Memory Performance. Verbal WM performance was measured using the Digit Backwards subtest (Taylor, 2013), a standard task for assessing verbal WM performance. Students listened to sequences of digits read aloud to them and were asked to repeat them in reverse order. Sequence length increased progressively from two to nine digits, with two trials per sequence length. The task continued until the participant failed both trials at a given sequence length.

Two outcome measures were derived: (a) backwards span score (the maximum sequence length correctly recalled), and (b) item score (the total number of correctly recalled sequences across the task). In this study, the Digits Backwards subtest demonstrated acceptable internal consistency (α = .71).

Visuospatial Working Memory Performance. Visuospatial WM performance was assessed using the Corsi Block Tapping Task - Backwards subtest (Berch et al., 1998), adapted and administered via the PsyToolKit platform (Stoet, 2017) on a standard computer screen. Students viewed a board with nine blocks displayed in a specific spatial configuration. On each trial, blocks were illuminated in a particular sequence, and students were required to reproduce the sequence in reverse order by clicking the corresponding blocks. Sequence length ranged from two to nine blocks, with four trials per sequence length.

As with the verbal WM performance task, two scores were computed: (a) backwards span score (the longest correctly recalled sequence length) and (b) item score (the total number of

correctly reproduced sequences). The Corsi Backwards subtest showed acceptable reliability in the present sample (α = .79).

Moderator Variables

To examine which factors might buffer or exacerbate the impact of peer exclusion, we also assessed potential moderators, consisting of prior rejection experiences, perceived social support, and VR features.

Previous Rejection Experiences. Students' previous experiences of peer rejection were assessed with a self-report instrument developed explicitly for this study, based on items adapted from validated questionnaires on peer rejection experiences (Achenbach, 1991; Asher et al., 1984; Knickenberg et al., 2022; Ladd et al., 2009; Marcoen et al., 1987; Schmidt et al., 2019; Secker et al., 2009; Skårbrevik, 2005) and translated into Italian using a forward-backward translation method.

The scale consists of 25 items measuring various aspects of peer exclusion and associated emotional responses, distributed across nine theoretically determined subscales (De Luca et al., *in prep.*): exclusion from general school activities (3 items), exclusion from play (3 items), exclusion from talking and discussion (2 items), emotional and physical exclusion (2 items), direct and indirect exclusion (3 items), implicit and explicit exclusion (3 items), mood effects (3 items), loneliness (3 items), and lack of feedback(3 items). Responses were given on a 5-point Likert scale from 1 (completely disagree) to 5 (completely agree). Higher scores indicated more frequent and intense experiences of rejection.

Exploratory factor analysis (EFA) conducted on this scale (De Luca et al., *in prep.*) indicated a unidimensional structure with factor loadings between .46 and .85, supporting the use of a total rejection score. One item was removed following EFA suggestions. The final scale demonstrated excellent reliability (α = .97).

Social Support. Received social support was measured using the Italian version of the Child and Adolescent Social Support Scale (CASSS; Gini et al., 2009; Malecki & Demaray, 2002), which evaluates support received from four sources: parents, teachers, classmates, and close friends. The scale consists of 40 items; students rated the frequency of support behaviours on a 6-point scale ranging from 1 (never) to 6 (always). Scores for each subscale were summed to create a total support score, with higher scores indicating greater perceived support. In this study, internal consistency was excellent (α = .95).

VR Features

The Italian version of the Igroup Presence Questionnaire (IPQ; Iachini et al., 2019; Regenbrecht & Schubert, 2002) was administered to evaluate the extent to which students experienced a sense of being in the virtual environment, or a sense of presence. The IPQ consists of 14 items which investigate various aspects associated with the concept of presence and are grouped into three areas: 1) Spatial Presence is defined as the sense of being physically present and acting in a virtual space; 2) Involvement is measured as the degree of awareness of the virtual scenario while isolating the external world; and 3) Realism is regarded as the degree of realism attributed to the virtual scenario. students were presented with statements describing the virtual experience and were asked to indicate their agreement on a seven-point Likert scale ranging from "complete disagreement" (1) to "complete agreement" (7). The calculation of the sum of the subscales' scores resulted in the determination of the final scale's total score. It was established that higher scores indicated a higher level of overall spatial presence. In this study, internal consistency was good (α = .82).

Analyses Plan

The present study employed a within-subject experimental design with a single experimental condition (peer exclusion). The current sample exceeds the required sample of 128

participants suggested by power calculation in G*Power 3.1 (Faul et al., 2007). This number of participants would allow to detect effects of peer exclusion manipulation on mood and WM of modest effects size (f = 0.15; according to previous work by Fuhrmann et al., 2019) using main effects and two-way (within-between) interaction effects in a repeated measures Analysis of Variance (ANOVA), with a statistical power of .80 and an alpha level of .05.

All statistical analyses were conducted using IBM SPSS Statistics, version 29 and the PROCESS macro for SPSS (Hayes, 2019). The independent variable was the peer exclusion experimental condition. The dependent variables included students' mood (positive and negative mood), and verbal and visuospatial WM performance assessed before and immediately following the social exclusion experience.

As preliminary steps, the internal consistency of all scales was verified using Cronbach's alpha (cf. supra), and assumptions of normality were assessed through skewness, kurtosis, and visual inspection of histograms and Q–Q plots. Reliability indices across all measures in the present study ranged from α = .71 (minimum, Digits Backwards) to α = .97 (maximum, Previous Rejection Experiences), indicating overall acceptable to excellent reliability. Although some moderator variables (e.g., problem behaviours) did not fully meet the assumption of normality, repeated-measures ANOVA is considered robust against moderate deviations from normality (Blanca et al., 2017; Schmider et al., 2010). Missing data were handled using multiple imputation via the Fully Conditional Specification (FCS) method implemented in SPSS. In line with best practices in the literature (Jakobsen et al., 2017), imputation was applied only in cases where a single value (either pre- or post-test) was missing on pre–post measures, provided that the proportion of missing data did not exceed 20%. Cases with both pre- and post-test data missing, or with missing data on other continuous variables, were excluded from analyses. Only one student (0.6% of the total sample of 171 students) was excluded due to missing data. Finally, for each hypothesis, we conducted a

sensitivity analysis to control for potential bias introduced by students who had received information about the peer exclusion manipulation or were aware of the deception. However, the results remained unchanged after excluding these cases, supporting the robustness of our findings. To account for the nested structure of the data (i.e., students within classes and schools), we tested for clustering effects by computing intraclass correlation coefficients (ICCs) for pre-to-post difference scores of the outcome variables. All ICCs fell within an acceptable range (Hox et al., 2017), with the highest reaching 0.07, indicating moderate clustering. Therefore, the variance structure did not warrant the use of multilevel modelling, and standard analyses were retained.

To test the effect of the peer exclusion on mood and WM performance, a series of statistical analyses were conducted. First, we tested whether positive mood would decrease, and negative mood would increase following the exclusion experience (H1), and whether WM performance—both verbal (Digit Backwards) and visuospatial (Corsi Backwards)—would also decline as a consequence of exclusion (H2). These hypotheses were evaluated using paired-sample t-tests, comparing pre- and post-exclusion scores for each dependent variable.

To examine whether gender (males vs. females) and age group (children vs. adolescents) moderated the effects of exclusion on mood and WM performance (H3–H4), two repeated-measures ANOVAs were conducted. In each model, pre- and post-exclusion scores for positive mood, negative mood, verbal WM, and visuospatial WM served as within-subject dependent variables, with either gender or age group entered as a between-subject factor.

The hypothesis that mood would mediate the effect of peer exclusion on WM performance (H5) was tested using a mediation model implemented in the PROCESS macro for SPSS. Perceived peer exclusion (measured via the Manipulation Check variable) was entered as the predictor, mood change scores (pre-to-post differences in both positive and negative mood, with higher positive mood difference scores indicating a pre-to-post higher decrease in positive mood, and with higher

negative mood difference scores indicating a pre-to-post lower increase in negative mood) served as mediators, and WM performance difference scores (Digit Backwards and Corsi Backwards, with higher WM performance difference scores indicating a pre-to-post higher decrease in WM performance) were entered as outcome variables. Age and gender groups were added as between-variables in the mediation model.

Finally, a series of moderation analyses were conducted to explore whether several continuous variables influenced the effect of peer exclusion on WM performance (H6–H10). As the literature has consistently highlighted the role of individual and contextual factors in shaping cognitive responses to social stress, our primary theoretical focus was on moderation effects on WM performance, since WM represents the central cognitive outcome most directly affected by peer exclusion, whereas mood effects were considered primarily as mediators. Specifically, we tested the moderating roles of perceived social support, previous rejection experiences, VR features (i.e., presence, involvement, realism), SES, baseline WM performance, and problem behaviours. Each moderator was entered separately as continuous predictors in individual repeated-measures ANOVAs, with WM performance (pre- and post-exclusion scores) as the dependent variable.

Results

Table 1 reports descriptive statistics, distributions and interclass correlations related to the variables employed in this study. Notably, WM performance was positively associated with age and socioeconomic status, with verbal and visuospatial WM tasks strongly interrelated. While social support showed significant associations with mood (positively with positive mood and negatively with negative mood), it was not significantly correlated with WM performance.

Table 1: Descriptive statistics, Distributions and Interclass Correlations

Variable	*M*	*SD*	Min	Max	1	2	3	4	5	6	7	8	9
1. Age	13.26	2.31	10.17	16.29	-								
2. SES	34.80	5.79	19.00	45.00	**0.23**	-							
3. Problem Behaviours	27.25	5.28	20.00	45.00	**-0.20**	**-0.22**	-						
4. Previous Rejection Experiences	47.54	20.31	24.00	113.00	0.01	-0.07	**0.25**	-					
5. Total Social Support	211.50	34.20	115.00	279.00	**-0.21**	-0.01	**-0.20**	**-0.38**	-				
6. Positive Mood Baseline	15.93	2.36	10.00	20.00	**-0.31**	-0.12	0.04	**-0.16**	**0.37**	-			
7. Negative Mood Baseline	5.43	2.00	4.00	18.00	0.045	0.01	**0.20**	**0.21**	**-0.18**	**-0.30**	-		
8. Corsi Backwards Baseline	15.75	4.82	2.00	32.00	**0.33**	**0.21**	**-0.19**	**-0.18**	-0.05	-0.08	0.12	-	
9. Digit Backwards Baseline	7.95	2.25	1.00	15.00	**0.43**	**0.31**	-0.12	-0.02	-0.07	-0.11	0.04	**0.44**	-
10. Paradigm Features 3D VR	58.52	12.98	24.00	95.00	**-0.27**	-0.004	0.10	0.14	**0.17**	**0.30**	-0.01	-0.11	-0.04

Note. $p < .05$ marked bold.

Table 2 presents descriptive statistics and distributions for the child and adolescent groups, as well as for males and females. Independent-samples *t*-tests were conducted to examine gender differences separately for children and adolescents. Among children, no significant gender differences emerged for any of the baseline or moderator variables. Among adolescents, males reported higher baseline positive mood compared to females, and lower previous rejection experiences than females. No other gender differences reached significance in either age group. A Pearson's chi-square test indicated that the distribution of males and females did not differ significantly between children and adolescents, $\chi^2(1, N = 170) = 0.40$, $p = .53$, confirming that gender was evenly distributed across age groups.

Table 2: Descriptive Statistics [mean ± SD] and Group Comparisons for Children vs. Adolescents and Males vs. Females

Variable	Children				Adolescents			
	Male (n = 43)	Female (n = 37)	t(78)	p	Male (n = 44)	Female (n = 46)	t(88)	P
Age	11.33 (0.74)	11.30 (0.81)	0.15	.88	14.96 (0.99)	15.02 (0.96)	-0.26	.80
SES	33.26 (6.25)	34.03 (6.74)	-0.53	.60	35.48 (5.00)	36.22 (4.90)	-0.71	.48
Total Social Support	212.05 (32.08)	223.84 (39.60)	-1.45	.15	201.23 (30.95)	210.89 (32.15)	-1.45	.15
Problem Behaviours	28.60 (5.32)	27.51 (5.32)	0.92	.36	26.23 (4.65)	26.76 (5.65)	-0.49	.63
Previous Rejection Experiences	45.12 (22.36)	50.30 (21.91)	-1.04	.30	43.07 (18.80)	51.87 (17.59)	-2.29	.02*
Baseline Positive Mood	16.47 (1.65)	17.08 (2.29)	-1.39	.17	15.73 (2.25)	14.70 (2.51)	2.05	.04*
Baseline Negative Mood	5.26 (1.59)	5.32 (1.86)	-0.18	.86	5.64 (1.89)	5.48 (2.53)	0.34	.74
Baseline Corsi Backwards	15.28 (3.69)	14.05 (3.87)	1.45	.15	17.41 (6.10)	15.96 (4.66)	1.27	.21
Baseline Digit Backwards	6.93 (2.02)	7.16 (1.74)	-0.55	.59	9.00 (2.19)	8.52 (2.31)	1.01	.32
VR Features	61.46 (13.66)	60.65 (13.31)	0.27	.79	55.14 (11.98)	57.43 (12.50)	-0.89	.38

Note. SES = Socio-Economic Status VR Features = Virtual Reality Features (composite score of spatial presence, involvement, and perceived realism). Follow-up comparisons were conducted using independent-samples *t*-tests, reported with *t*(df). *$p < .05$.

H1 & H2: General Effects of Peer Exclusion on Mood and WM performance

Table 3 reports descriptive statistics and t-test scores for pre-to-post mood and WM performance measurements. To test the first and the second hypotheses regarding the general effect of peer exclusion on mood and WM performance, paired-sample *t*-tests were conducted comparing pre- and post-exclusion scores. Results revealed that students experienced a significant decrease in positive mood after experiencing exclusion. Conversely, negative mood significantly increased following exclusion. No significant differences were found for either verbal WM performance (Digit Backwards) or visuospatial WM performance (Corsi Backwards).

Table 3: Descriptive Statistics and t-test

Measure	Pre-Test		Post-Test		*t*(169)	*p*	η^2
	M	*SD*	*M*	*SD*			
Positive mood	15.93	2.35	14.57	3.83	6.01***	< .001	0.46
Negative mood	5.43	2.00	6.22	2.99	-3.64***	< .001	-0.28
Corsi backwards subtest	15.75	4.82	15.68	4.79	0.19	.425	0.01
Digit backwards subtest	7.95	2.25	7.79	2.38	1.08	.142	0.08

Notes. * $p < .05$, ** $p < .01$, *** $p < .001$. η^2 (eta squared) indicates the proportion of variance in the dependent variable explained by the independent variable or effect. Values of approximately .01, .06, and .14 are typically interpreted as small, medium, and large effect sizes, respectively (Cohen, 1988).

H3: Gender Effects

To test the moderating role of gender, a 2 (Time: pre, post) × 2 (Gender: male, female) repeated measures ANOVA was conducted on mood and WM performance scores. Table 4 reports gender interaction effects, means and standard deviations. Full models and non-significant results are reported in Supplementary Material. For positive mood, a significant Time × Gender interaction and a main effect of Gender were found, $F(1, 168) = 4.42$, $p = .037$. Post hoc comparisons showed that both males and females experienced a significant decline in positive mood (*MDiff* = 1.37; *SE* = 0.22; $p <$ .001) and a significant increase in negative mood after the peer exclusion condition (*MDiff* = -0.80;

SE = 0.21; $p < .001$). However, females experienced a significantly greater decline in positive mood than males (*MDiff* = 1.47; *SE* = 0.58; $p = .012$). For negative mood, the Time × Gender interaction approached significance ($p = .053$), with females exhibiting stronger increases in negative mood than males (*MDdiff* = 1.21; *SE* = 0.31; $p < .001$). No Time × Gender interaction effects were found for WM performance tasks.

Table 4. Time × Gender Effects

Measure	*F*(1,168)	η^2	Males *M*±*SD*		Females *M*±*SD*	
			Pre	Post	Pre	Post
Positive Mood	6.49*	.037	16.09 (1.99)	15.29 (3.27)	15.76 (2.68)	13.82 (4.23)
Negative Mood	3.79	.022	5.45 (1.75)	5.83 (2.57)	5.41 (2.24)	6.63 (3.33)
Corsi Backward	1.83	.011	16.36 (5.13)	15.80 (4.90)	15.11 (4.40)	15.55 (4.69)
Digit Backward	2.35	.014	7.98 (2.34)	7.60 (2.36)	7.92 (2.17)	7.99 (2.40)

Notes. * $p < .05$, ** $p < .01$, *** $p < .001$. η^2 (eta squared) indicates the proportion of variance in the dependent variable explained by the independent variable or effect. Values of approximately .01, .06, and .14 are typically interpreted as small, medium, and large effect sizes, respectively (Cohen, 1988).

H4: Age Effects

A 2 (Time: pre, post) × 2 (Age: children, adolescents) repeated measures ANOVA was performed to examine the moderating role of age group on mood and WM performance scores. Table 5 reports main effects, means, and standard deviations for Age Groups. Full models and non-significant results are reported in Supplementary Material. For all dependent variables, a significant main effect of Age Group emerged. Post hoc analyses indicated that adolescents reported a larger reduction in positive mood (*MDiff* = - 1.77; *SE* = 0.41; $p < .001$) and a significant increase in negative mood (*MDiff* = 0.66; *SE* = 0.32; $p = .042$) following peer exclusion in comparison to children, who also showed a significant reduction in positive mood (*MDiff* = - 1.12; *SE* = 0.33; $p < .001$) but did no significant increase in negative mood (although there was an increase, this was not significant). For

Digit Backwards, post-hoc pairwise comparisons indicated that overall, adolescents performed better than children (*MDiff* = 1.82; *SE* = 0.29; $p < .001$). However, no significant interaction effects with age group were found for Digit Backwards. For Corsi Backwards, a main effect of Age Group and a significant Time × Age Group interaction were found, $F(1, 168) = 14.19$, $p < .001$. Children showed a significant decline in Corsi Backwards performance after peer exclusion (*MDiff* = - 1.51; *SE* = 0.52; $p = .005$), whereas adolescents demonstrated a significant improvement (*MDiff* = 1.21; *SE* = 0.49; $p = .016$).

Table 5. Age Group Effects

Measure	*F(1,168)*	η^2	Children *M±SD*		Adolescents *M±SD*	
			Pre	Post	Pre	Post
Positive Mood	18.44***	.099	16.75 (1.98)	15.63 (3.72)	15.20 (2.43)	13.63 (3.71)
Negative Mood	4.19*	.024	5.29 (1.70)	5.66 (2.74)	5.56 (2.23)	6.71 (3.12)
Corsi Backward	32.19***	.161	14.71 (3.80)	13.20 (4.11)	16.67 (5.43)	17.88 (4.27)
Digit Backward	38.46***	.186	7.04 (1.89)	6.77 (1.88)	8.76 (2.25)	8.69 (2.43)

Notes. * $p < .05$, ** $p < .01$, *** $p < .001$. η^2 (eta squared) indicates the proportion of variance in the dependent variable explained by the independent variable or effect. Values of approximately .01, .06, and .14 are typically interpreted as small, medium, and large effect sizes, respectively (Cohen, 1988).

H5: Mediation Analyses

To explore whether mood mediated the relationship between perceived peer exclusion and WM performance, we conducted two separate PROCESS mediation models using pre-post difference scores. In both models, peer exclusion (Manipulation Check) served as the independent variable; either positive or negative mood difference scores were tested as the mediator; and the WM performance difference scores (Digit Backwards and Corsi Backwards) were treated as outcomes. The indirect effects were not significant for either positive or negative mood in predicting changes in Digit Backwards or Corsi Backwards performance (*Positive Mood → Digit Backwards*: *B* = 0.014,

SE = 0.018, 95% *CI* [-0.022, 0.049], *p* = .448; *Negative Mood → Digit Backwards*: *B* = 0.000, *SE* = 0.014, 95% *CI* [-0.028, 0.028], *p* = .999; *Positive Mood → Corsi Backwards*: *B* = 0.021, *SE* = 0.018, 95% *CI* [-0.014, 0.057], *p* = .237; *Negative Mood → Corsi Backwards*: *B* = -0.018, *SE* = 0.015, 95% *CI* [-0.047, 0.011], *p* = .216). Given these null findings, we conducted exploratory follow-up mediation models to examine each of the eight mood items (good, happy, pleasant, friendly, bad, sad, unfriendly and angry) separately as mediators (See Supplementary Material). These analyses revealed two significant indirect effects: reductions in happiness mediated the effect of peer exclusion on decreased visuospatial WM performance (*B* = 0.024, *SE* = 0.012, 95% *CI* [0.000, 0.047], *p* = .043), whereas increases in anger mediated the effect of exclusion on increased visuospatial WM performance (*B* = -0.190, *SE* = 0.092, 95% *CI* [-0.371, -0.009], *p* = .040). No other mood items were significant mediators, and no significant mediation was observed for verbal WM (Digit Backwards) or for age-group differences.

H6: Moderating Role of Social Support and Previous Rejection Experiences

Table 6 reports a summary of all the continuous moderator variables' main effects and directions. Full models are reported in Supplementary Material.

Table 6. Summary of Moderators' Main Effects for Working Memory Performance

Effect	*F(1,168)*	*ηp²*	*B*	*SE*
Teacher Support → Digit Backward	8.03**	.046	-0.045	0.016
Teacher Support → Corsi Backward	8.42**	.048	-0.118	0.033
VR Features → Corsi Backward	5.02*	.029	-0.068	0.028
SES → Digit Backward	17.94***	.096	0.105	0.025
SES → Corsi Backward	13.96***	.077	0.222	0.059
Baseline WM → Digit Backward	755.32***	.818	0.692	0.062
Baseline WM → Corsi Backward	486.53***	.743	0.481	0.067
Problem Behaviours → Corsi Backward	14.40***	.079	-0.264	0.067

Note. η^2 (eta squared) indicates the proportion of variance in the dependent variable explained by the independent variable or effect. Values of approximately .01, .06, and .14 are typically interpreted as small, medium, and large effect sizes, respectively (Cohen, 1988). * $p < .05$, ** $p < .01$, *** $p < .001$

To investigate the impact of perceived social support and previous rejection experiences, a repeated measures ANOVA with Time (Pre vs. Post) as a within-subject factor was conducted on WM performance scores. Social Support scale and subscale scores (support provided by parents, by teachers, by classmates, and by close friends), as well as Previous Rejection Experiences scores, were added sequentially as covariates. Significant effects emerged only for social support provided by teachers. For both Digit and Corsi Backwards, a significant main effect of teachers' social support emerged, indicating that higher perceived teacher support was associated with lower WM performance. Parameter estimates confirmed that teachers' social support significantly and negatively predicted post-exclusion Digit Backwards and Corsi Backwards scores. A significant main effect of time was also found for Corsi Backwards, $F(1, 168) = 4.72$, $p = .031$, together with a significant Time × Teachers' Social Support interaction, $F(1, 168) = 5.15$, $p = .024$. No other significant effects emerged (see Supplementary Material).

H7: Moderating Role of VR Features

To investigate the impact of VR Features, a repeated measures ANOVA with Time (Pre vs. Post) as a within-subject factor was conducted on WM performance scores. The potential influence of VR experience features was examined by including the variable as a covariate. A significant main effect of VR features emerged. Parameter estimates showed that VR features significantly predicted post-exclusion Corsi Backwards, indicating that higher scores of perceived presence, realism and involvement were associated with lower visuospatial WM performance scores. No significant effects of Time, nor Time × VR Features interaction emerged (see Supplementary Material).

H8: Moderating Role of Socioeconomic Status (SES)

To explore the influence of socioeconomic status, a repeated measures ANOVA with Time (Pre vs. Post) as a within-subject factor was conducted on WM performance scores, including SES as a covariate. A significant main effect of SES emerged. Parameter estimates indicated that SES significantly moderated WM performance across both time points: students with higher SES consistently showed better performance on both the Digit Backwards and Corsi Backwards tasks, at pre-test and post-test alike. No significant effects of Time, nor Time × SES interactions emerged (see Supplementary Material).

H9: Moderating Role of Baseline WM Performance

To control for baseline WM performance, WM performance baseline scores were entered as covariates in a repeated measures ANOVA with Time (Pre vs. Post) as a within-subject factor on WM performance scores. For Digit Backward, all effects were significant. A main effect of baseline WM performance was accompanied by significant effects of time, $F(1, 168) = 20.20$, $p < .001$) and the Time × Baseline WM interaction, $F(1, 168) = 24.94$, $p < .001$). For Corsi Backward, results were comparable. A significant main effect of Baseline WM emerged, and was accompanied by significant effects of time, $F(1, 168) = 53.81$, $p < .001$, and a robust Time × Baseline WM interaction, $F(1, 168) = 59.86$, $p < .001$. Parameter estimates indicated that Baseline WM performance scores significantly predicted post-exclusion WM performance for both Digit Backwards and Corsi Backwards scores. Higher baseline WM performance scores corresponded with higher post-exclusion WM performance.

H10: Moderating Role of Problem Behaviours

To test the role of SDQ problem behaviours, a repeated measures ANOVA with Time (Pre vs. Post) as a within-subject factor was conducted on WM performance scores, including total Problem Behaviours as a covariate. A significant main effect of Problem Behaviours emerged. Parameter estimates indicated that Problem behaviour significantly predicted post-exclusion Corsi Backwards scores at both time points, with higher problem behaviour scores being associated with

lower Corsi Backwards scores. No significant effects of Time, nor Time × Problem Behaviours interaction emerged (see Supplementary Material).

Discussion

The present study investigated the immediate effects of peer exclusion on mood and WM performance using an immersive VR paradigm among students.

Effects on Mood and the Moderating Role of Age and Gender

We hypothesised that positive mood would decrease, and negative mood would increase after a peer exclusion situation, with females and adolescents being more affected than males and children by this negative impact. Consistent with our hypotheses and prior research (Abrams et al., 2011), students reported a significant decrease in positive mood and an increase in negative mood following the exclusion experience. This finding reinforces evidence that social exclusion leads to heightened distress and negative affect (Williams, 2001). A gender-based moderation effect also emerged for mood: females experienced a greater reduction in positive mood compared to males. This aligns with prior evidence indicating that girls generally report stronger emotional reactions to social exclusion and judge it as more unfair compared to boys (Horn, 2003). This gender difference may stem from the greater emphasis females as a group place on interpersonal relationships during development (Fuhrmann et al., 2019). Notably, age moderated this effect as well, with adolescents exhibiting a more pronounced decline in mood than children. This is congruent with developmental theories suggesting that adolescence represents a period of heightened sensitivity to peer relationships due to social and neurobiological changes (Larsen & Luna, 2018; Rubin et al., 2015). The increased salience of peer acceptance during adolescence likely exacerbated the emotional impact of peer exclusion.

Importantly, these age-related effects are consistent with our previous work comparing the Cyberball and 3D VR exclusion paradigms in a different sample of children and adolescents (De Luca et al., *in prep.*). In that study, adolescents also reported stronger emotional reactions to exclusion than children, confirming the developmental sensitivity of social exclusion experiences. The replication of these effects across different studies provides further support for the robustness of our findings and

enhances the construct validity of the immersive 3D VR paradigm as an ecologically valid tool for studying peer exclusion.

Effects on WM performance and Age-Related Differences

As highlighted in the introduction, proximal social contexts such as family, classroom, and peer groups play a critical role in shaping cognitive outcomes in children and adolescents, with adverse or exclusionary interactions shown to affect both socio-emotional adjustment and cognitive functioning negatively (Zarrella et al., 2018; Vandenbroucke et al., 2018b). Previous research has also shown that negative emotional or stressful contexts can impair WM performance. For example, studies demonstrated that negative affect reduced verbal and visuospatial WM capacity (Schoofs et al., 2008; Buelow et al., 2015). Based on this evidence, we hypothesised that WM performance scores would decrease after a peer exclusion situation, with females and adolescents being more affected than males and children by this negative impact. In contrast to the prevailing assumptions, the phenomenon of peer exclusion did not result in a uniform impairment of WM performance across the entire sample. However, a significant interaction effect with age was observed for visuospatial WM performance (Corsi Backwards). Specifically, children exhibited a decline in WM performance following exclusion, despite showing smaller effect sizes in mood changes compared to adolescents, while adolescents demonstrated a significant improvement. This intriguing pattern may reflect adolescents' more advanced emotional and cognitive regulation skills (Fuhrmann et al., 2019), allowing them to buffer the cognitive costs of exclusion, or potentially even experience arousal-based facilitation of performance. This interpretation is also in line with Cognitive Load Theory (Sweller, 1994), suggesting that under conditions of moderate arousal or pressure, well-developed learners (such as adolescents) may mobilise attentional and regulatory resources more efficiently, thereby improving task performance. Conversely, younger students may lack the regulatory capacity necessary to protect WM performance from the disruptive effects of exclusion-induced distress.

Furthermore, according to the findings of previous investigations grounded in the "fight-or-flight" response, the occurrence of intensive negative outcomes is associated with a heightened

probability of enhancement in cognitive performance quality (Spachtholz et al., 2014). Consequently, it can be hypothesised that adolescents, who experienced greater frustration following the exclusion experience, may implicitly store this negative frustration and utilise it to enhance their cognitive performance.

Nonetheless, the absence of a clear main effect of peer exclusion on WM stands in contrast with previous studies demonstrating peer-related influences (e.g., classroom-level peer WM) on WM performance in non-exclusion contexts (Finch et al., 2019). These discrepancies may suggest that different peer-related mechanisms—such as chronic peer context (e.g., long-term peer rejection, friendship quality, or peer status) versus acute social exclusion—engage distinct emotional and cognitive processes. For instance, chronic peer problems may be linked to enduring attentional biases, rumination, and resource depletion (McLaughlin et al., 2009). In contrast, acute peer exclusion may provoke immediate affective responses that can either hinder or, under certain conditions, temporarily enhance WM performance (Shields et al., 2016). This distinction between chronic and acute peer exclusion is supported by evidence showing that negative affect can both impair and, in some cases, facilitate WM performance depending on task demands and arousal level (Coles et al., 2019). Future studies should explicitly address whether and how chronic peer problems and acute exclusion experiences differentially affect children's and adolescents' WM.

Mediating Role of Mood

We hypothesised both positive and negative moods to mediate the causal relationship between perception of exclusion and WM performance. Although the main mediation analyses did not support a significant indirect effect of general mood (positive or negative) on WM performance, exploratory follow-up models revealed specific emotion-based mechanisms which work for both age groups. Notably, reductions in happiness mediated the negative effect of perceived exclusion on visuospatial WM performance, suggesting that students who felt less happy following exclusion also demonstrated greater cognitive decline. This finding aligns with studies linking positive emotions to enhanced EFs via increased dopaminergic activity and attentional flexibility (Yang et al., 2013). Conversely,

increases in anger were associated with improved WM performance, consistent with literature indicating that anger—unlike fear or sadness—can mobilize goal-directed effort and enhance cognitive task engagement (Harmon-Jones et al., 2013). This dual-pathway pattern suggests that emotional responses to exclusion are heterogeneous and may differentially influence cognitive performance depending on the nature of the emotion elicited.

Moderating Effects of Individual and Contextual Variables

It was hypothesised that social support provided by parents, teachers, classmates and friends would act as a mitigating factor against the adverse impact of peer exclusion. This was predicted to be observed in increasing WM performance scores. We also hypothesised that previous rejection experiences render students more sensitive to other forms of exclusion by increasing negative cognitive outcomes. Contrary to predictions, no significant impact of overall social support or previous rejection experiences reported by students was found. However, higher perceived social support from teachers was associated with poorer WM performance following exclusion. This counterintuitive finding may indicate that students who receive higher teacher support experienced a greater sense of destabilisation when excluded by their peers. This would then suggest that these students experienced a dissonance between their expectations of support and the reality of peer rejection (Arslan, 2018).

Building on this, as the effect of social support is based on attachment theory, it can be posited that the provision of support by teachers serves as a predictor of enhanced quality in peer relationships (Hamre & Pianta, 2001). It can be contended that students who perceive greater support from their teachers also exhibit a higher degree of social competence when engaging with their peers. Consequently, a breach of this expectation during a social situation has the potential to exacerbate the exclusion situation, and this amplifies the adverse cognitive outcome. In accordance with attachment theory, it was expected that parental support would also have had a significant moderating effect (i.e., similar to teacher support). However, in our study, parental support did not show a significant moderating effect, contrary to expectations. One potential explanation for this phenomenon may be

that, during the transition from childhood to adolescence, students rely increasingly on teachers as central emotional and instructional figures in the school context, even though peers remain the most important source of social validation (Roorda et al., 2011). This highlights the context-specificity of support effects: in classroom-based peer exclusion scenarios, the support of teachers—as proximal figures in that environment—carries greater weight than parental support, which may be less directly relevant in school-based peer interactions (Wentzel et al., 2017).

Previous literature suggested that lower quality relationships among teachers and students is linked to increased peer popularity during the transition from childhood to adolescence (Engels et al., 2016). Conversely, it is plausible to hypothesise that students with closer, conflict-free relationships with teachers may face heightened social exclusion and neglect, potentially amplifying their sensitivity to peer exclusion.

Beyond contextual factors, the specific features of the VR environment itself may also shape how students experience peer exclusion. We hypothesised that VR features would increase the ecological validity of the peer exclusion condition and, consequently, enhance the negative impact of peer exclusion on WM performance. In line with this hypothesis, VR features, such as spatial presence, involvement and realism, were found to have a detrimental effect on WM performance. As previous studies have highlighted the benefits of VR in terms of ecological validity (Parsons, 2015; Riva et al., 2004). The potential for highly immersive environments to elicit heightened emotional responses, potentially leading to impaired cognitive functioning in such demanding contexts, can be deduced. Specifically, the experience of peer exclusion as a more realistic scenario has the potential to reinforce the fundamental assumption of our research. This is because it demonstrates that genuine exclusionary experiences can adversely impact cognitive function (Prendergast & Schubert, 2020). We could then conclude that students who perceived the VR paradigm to be less realistic and less connected to real life may have experienced a reduced negative impact. Consequently, their cognitive functioning may not have been as significantly impaired.

In addition to contextual and VR-related factors, we also explored the moderating role of individual characteristics in shaping the impact of peer exclusion on WM performance. These analyses were aimed at identifying which personal resources or vulnerabilities might amplify or buffer the cognitive costs of exclusion. We hypothesised that low SES and baseline WM performance, along with higher problem behaviours reported, would be associated with a greater decline in WM performance after a peer exclusion situation (Hackman et al., 2010). First, regarding socioeconomic background, lower SES indeed was associated with reduced WM outcomes. Students from higher SES backgrounds exhibited superior WM performance both prior to and following the peer exclusion experience. This phenomenon may be attributable to enhanced access to cognitive enrichment and stress-buffering resources. This suggests that SES may moderate the effects of peer exclusion, with students from less advantaged backgrounds showing greater vulnerability to its negative cognitive impact.

Second, baseline WM performance was a strong predictor of post-exclusion WM performance outcomes. This underscores the role of individual cognitive capacity in buffering against situational stressors (Ouimet et al., 2009). In other words, students who entered the exclusion manipulation with stronger WM skills appeared more resilient to its disruptive effects.

Third, behavioural adjustment was also examined. The presence of problem behaviours has been shown to be a significant predictor of substandard WM performance following exclusion. This finding is consistent with the results of research that has linked behavioural difficulties to impaired EFs and vulnerability to stress (Donati et al., 2021). This outcome also aligns with the findings of previous research, which identified excluded and rejected students as being more likely to exhibit increasingly problematic behaviours and aggressive tendencies (Bukowski et al., 2018). Consequently, students exhibiting elevated levels of problem behaviours may also demonstrate heightened sensitivity to experiences of peer exclusion, resulting in a more pronounced cognitive impact.

Taken together, the present study offers important insights into the nuanced interplay between social context, emotional processes, and cognitive functioning in youth. While showing the cognitive toll of exclusion, our findings also illustrate that the emotional mechanisms underlying this effect are complex and multidimensional. Not all emotional reactions impair cognition; some may even facilitate it under specific conditions.

Theoretical and Practical Implications

From a theoretical perspective, this study reinforces the theoretical proposition that developmental outcomes, especially WM, are shaped not only by stable traits or distal environmental variables but also by immediate, affectively charged social contexts. As reflected in Bronfenbrenner's ecological systems theory (2005), our findings emphasise that proximal experiences—such as brief episodes of peer exclusion—can have acute effects on mood and cognition. Furthermore, the specific emotion elicited by exclusion (e.g., happiness vs. anger) appears to affect WM performance differently. This can be concluded from the fact that the peer exclusion experience first decreased feelings of happiness and increased feelings of anger; in turn, these changes had opposite effects on WM, with unhappiness predicting poorer performance and anger predicting enhanced performance. These findings align with dual-process models of emotion–cognition interaction (Pessoa, 2013) and highlight the necessity of parsing emotional responses rather than treating mood as a unitary construct (e.g., see Brosch et al., 2013). The study calls for future theoretical models to integrate emotion specificity into accounts of how social environments affect cognitive development.

A key methodological contribution of this research is the use of immersive 3D VR to simulate ecologically valid peer exclusion scenarios. Unlike traditional 2D paradigms such as Cyberball, VR increases realism, presence, and emotional engagement, which likely amplifies the psychological and cognitive effects of exclusion (Parsons, 2015; Prendergast & Schubert, 2020). Importantly, this methodological advance has already provided new insights. Our previous study showed that both the 2D Cyberball and the 3D VR paradigms successfully elicited decreases in positive mood, increases in negative mood, and threats to psychological needs. However, the VR paradigm was rated as more

realistic and immersive, particularly by adolescents (De Luca et al., *in prep.*). These findings indicate that VR is not only a valid tool for eliciting social exclusion-related emotional responses but also a developmentally sensitive paradigm capable of capturing nuanced age-related differences in reactions to social exclusion. This methodological advance opens new possibilities for studying emotional and cognitive responses to social stimuli in a controlled yet realistic setting. For example, the emerging 3D VR paradigm could assess how peer exclusion experiences in a school context influence other types of advanced EFs (like problem-solving or planning) or academic outcomes (such as test performance or academic success).

Additionally, the 3D VR paradigm provides a standardised manipulation of peer exclusion by ensuring that all participants are exposed to the same scripted exclusion scenario, with identical timing, avatar behaviour, and conversational flow. This guarantees comparability across participants while at the same time simulating a realistic, ecologically valid peer interaction context—something rarely achieved with traditional paradigms that lack verbal interaction or social presence. In this way, the paradigm offers a replicable methodology to operationalise, simulate, and measure peer exclusion experiences in a school-like setting. Given these benefits, VR is likely to be increasingly incorporated into developmental studies of complex social-emotional phenomena.

From an applied perspective, even brief episodes of social exclusion can have measurable impacts on students' emotional well-being and cognitive functioning. In educational settings, such experiences may undermine students' motivation, concentration, and capacity to engage effectively in classroom activities. Repeated exposure to peer exclusion can contribute to chronic stress responses, leading to difficulties in emotion regulation, attentional control, and working memory over time (Hawes et al., 2012; Riva & Eck, 2016). Importantly, the social nature of school environments means that exclusionary dynamics often go unnoticed by teachers and peers, despite their potential to shape academic trajectories and socioemotional development. Preventive approaches, such as promoting inclusive classroom climates, implementing socioemotional learning programs, and encouraging peer acceptance, can mitigate these risks and strengthen students' resilience to negative

social experiences (Jones et al., 2017; Oberle & Schonert-Reichl, 2017). These reflections highlight the importance of schools remaining attentive to peer exclusion and developing preventive strategies (Abrams & Killen, 2014).

Limitations and Future Directions

Despite its contributions, this study has several limitations that should be acknowledged. First, the sample consisted of students from a limited number of schools, and while diverse in some respects, it may not fully represent broader demographic or cultural variability. Replication with more heterogeneous and nationally representative samples is warranted to enhance generalisability.

Second, although the 3D VR paradigm enabled a controlled simulation of peer exclusion, it did not capture how experiences of peer exclusion naturally unfold and fluctuate within students' everyday school life, where peer dynamics can vary from one interaction or day to another. Incorporating ecological momentary assessment (EMA)—such as with daily diaries or mobile-based data collection—would allow researchers to record these real-world fluctuations in peer exclusion experiences and examine their short-term cognitive and emotional consequences across time and contexts (Silk et a., 2011).

Third, the study relied solely on self-reports for emotions and performance tasks for cognitive functioning, without including psychophysiological indicators such as heart rate variability, cortisol levels, or skin conductance. This is a limitation because we may be missing objective markers of stress, which could mean that our findings underestimate or overlook certain physiological reactions to peer exclusion. Nevertheless, as we only relied on self-report data for emotions, future research would benefit from incorporating neurophysiological measures (e.g., heart rate variability, cortisol) to more directly test whether these regulation processes are accompanied by biological changes, and to capture the biological stress responses triggered by peer exclusion more comprehensively (Gunnar & Quevedo, 2007).

Fifth, the study interpreted WM effects primarily through the lens of Baddeley's multicomponent model, which is widely supported in the literature (Baddeley, 2000). However,

alternative theoretical frameworks—such as Cowan's embedded-processes model—could offer additional insights, particularly in explaining attention-based variations in WM under social stress (Cowan, 2012). Future studies should consider cross-model comparisons to better elucidate the cognitive mechanisms involved.

Addressing these limitations in future research will not only enhance methodological rigour but also expand our understanding of how peer exclusion differentially affects emotional and cognitive development across age groups and individual profiles.

Conclusion

The present findings underscore the vulnerabilities of specific groups to the detrimental impact of peer exclusion on cognitive performance. While no overall cognitive decline was observed across the full sample, younger students exhibited a significant decrease in WM performance following peer exclusion. Furthermore, irrespective of age, students from lower SES backgrounds, those with lower baseline WM performance, and those exhibiting more internalising and externalising issues experienced increased cognitive impairments following peer exclusion. This study contributes to the extant literature on the academic challenges experienced by vulnerable students, emphasising their vulnerability to stressful social experiences such as peer exclusion. These findings suggest the necessity for educational institutions to establish inclusive environments that protect students from exclusionary dynamics, thereby ensuring the preservation of their cognitive resources and the promotion of academic success.

References

Abrams, D., & Killen, M. (2014). Social Exclusion of Children: Developmental Origins of Prejudice. *Journal of Social Issues*, *70*(1). https://doi.org/10.1111/josi.12043

Abrams, D., Weick, M., Thomas, D., Colbe, H., & Franklin, K. M. (2011). On-line ostracism affects children differently from adolescents and adults. *British Journal of Developmental Psychology*, *29*(1). https://doi.org/10.1348/026151010X494089

Achenbach, T. M. (1991). Child Behavior Checklist/4-18. *Journal of Abnormal Child Psychology*, *15*.

Arslan, G. (2018). Social Exclusion, Social Support and Psychological Wellbeing at School: A Study of Mediation and Moderation Effect. *Child Indicators Research*, *11*(3). https://doi.org/10.1007/s12187-017-9451-1

Asher, S. R., Hymel, S., & Renshaw, P. D. (1984). Loneliness in Children. *Child Development*, *55*(4), 1456–1464.

Baddeley, A. (2000). The episodic buffer: A new component of working memory? In *Trends in Cognitive Sciences* (Vol. 4, Issue 11). https://doi.org/10.1016/S1364-6613(00)01538-2

Berch, D. B., Krikorian, R., & Huha, E. M. (1998). The Corsi block-tapping task: Methodological and theoretical considerations. *Brain and Cognition*, *38*(3). https://doi.org/10.1006/brcg.1998.1039

Blanca, M. J., Alarcón, R., Arnau, J., Bono, R., & Bendayan, R. (2017). Non-normal data: Is ANOVA still a valid option? Psicothema, 29(4), 552–557.

Bolger, N., & Laurenceau, J. P. (2013). Intensive longitudinal methods: An introduction to diary and experience sampling research. Guilford press.

Bowlby, J. (1982). Attachment and loss: Attachment (Vol. 1). In *Attachment* (Vol. 1).

Bronfenbrenner, U. (2005). Making human beings human: Bioecological perspectives on human development. In *British Journal of Developmental Psychology* (Vol. 23, Issue 1).

Brosch, T., Scherer, K., Grandjean, D., & Sander, D. (2013). The impact of emotion on perception, attention, memory, and decision-making. Swiss medical weekly, 143(1920), w13786-w13786.

Buelow, M. T., Okdie, B. M., Brunell, A. B., & Trost, Z. (2015). Stuck in a moment and you cannot get out of it: The lingering effects of ostracism on cognition and satisfaction of basic needs. *Personality and Individual Differences*, *76*. https://doi.org/10.1016/j.paid.2014.11.051

Buhs, E. S., & Ladd, G. W. (2001). Peer rejection as an antecedent of young children's school adjustment: an examination of mediating processes. *Developmental Psychology*, *37*(4). https://doi.org/10.1037/0012-1649.37.4.550

Buhs, E. S., Ladd, G. W., & Herald, S. L. (2006). Peer exclusion and victimization: Processes that mediate the relation between peer group rejection and children's classroom engagement and achievement? In *Journal of Educational Psychology* (Vol. 98, Issue 1). https://doi.org/10.1037/0022-0663.98.1.1

Bukowski, W. M., Laursen, B., & Rubin, K. H. (2018). Peer Relations - Past, Present, and Promise. In *Handbook of peer interactions, relationships, and groups*.

Caemmerer, J. M., & Keith, T. Z. (2015). Longitudinal, reciprocal effects of social skills and achievement from kindergarten to eighth grade. *Journal of School Psychology*, *53*(4). https://doi.org/10.1016/j.jsp.2015.05.001

Campodifiori, E., Figura, E., Papini, M., & Ricci, R. (2010). *Istituto nazionale per la valutazione del sistema educativo di istruzione e di formazione Un indicatore di status socio-economico-culturale degli allievi della quinta primaria in Italia*.

Carretti, B., Borella, E., Cornoldi, C., & De Beni, R. (2009). Role of working memory in explaining the performance of individuals with specific reading comprehension difficulties: A meta-analysis. Learning and Individual Differences, 19(2), 246–251.

Cohen, J. (1988). Statistical power analysis for the behavioral sciences (2nd ed.). Lawrence Erlbaum Associates.

Cohen, S. (2004). Social relationships and health. In *American Psychologist* (Vol. 59, Issue 8). https://doi.org/10.1037/0003-066X.59.8.676

Coie, J. D., Dodge, K. A., & Coppotelli, H. (1982). Dimensions and types of social status: A cross-age perspective. *Developmental Psychology*, *18*(4). https://doi.org/10.1037//0012-1649.18.4.557

Coles, N. A., Larsen, J. T., & Lench, H. C. (2019). A meta-analysis of the facial feedback literature: Effects of facial feedback on emotional experience are small and variable. *Psychological bulletin*, 145(6), 610.

Cowan, N. (2012). An Embedded-Processes Model of Working Memory. In *Models of Working Memory*. https://doi.org/10.1017/cbo9781139174909.006

Crone, E. A., & Dahl, R. E. (2012). Understanding adolescence as a period of social-affective engagement and goal flexibility. *Nature Reviews Neuroscience*, *13*(9). https://doi.org/10.1038/nrn3313https://doi.org/10.2307/1421493

De Luca, G., Baeyens, D., Meixner, G., Khau, T., Benvenuti, M., & Mazzoni, E. (2026). Exploring social exclusion through immersive virtual reality: a qualitative comparison with the Cyberball paradigm in children and adolescents. *European Journal of Psychology of Education*, *41*(1), 20.

de Wilde, A., Koot, H. M., & van Lier, P. A. C. (2016). Developmental Links Between Children's Working Memory and their Social Relations with Teachers and Peers in the Early School Years. *Journal of Abnormal Child Psychology*, *44*(1). https://doi.org/10.1007/s10802-015-0053-4

Dimitrov, D. M., & Rumrill, P. D. (2003). Pretest–posttest designs and measurement of change. Work, 20(2), 159–165.

Dirk, J., & Schmiedek, F. (2016). Fluctuations in elementary school children's working memory performance in the school context. *Journal of Educational Psychology*, *108*(5). https://doi.org/10.1037/edu0000076

Donati, G., Meaburn, E., & Dumontheil, I. (2021). Internalising and externalising in early adolescence predict later executive function, not the other way around: a cross-lagged panel analysis. *Cognition and Emotion*, *35*(5). https://doi.org/10.1080/02699931.2021.1918644

Eisenberger, N. I., Lieberman, M. D., & Williams, K. D. (2003). Does rejection hurt? An fMRI study of social exclusion. *Science*, *302*(5643). https://doi.org/10.1126/science.1089134

Engels, M. C., Colpin, H., Van Leeuwen, K., Bijttebier, P., Van Den Noortgate, W., Claes, S., Goossens, L., & Verschueren, K. (2016). Behavioral Engagement, Peer Status, and Teacher–Student Relationships in Adolescence: A Longitudinal Study on Reciprocal Influences. *Journal of Youth and Adolescence*, *45*(6). https://doi.org/10.1007/s10964-016-0414-5

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods, 39*(2), 175–191. https://doi.org/10.3758/BF03193146

Finch, J. E., Garcia, E. B., Sulik, M. J., & Obradović, J. (2019). Peers Matter: Links Between Classmates' and Individual Students' Executive Functions in Elementary School. *AERA Open*, *5*(1). https://doi.org/10.1177/2332858419829438

Fredricks, J. A., Blumenfeld, P. C., & Paris, A. H. (2004). School engagement: Potential of the concept, state of the evidence. *Review of Educational Research*, 74(1), 59–109. https://doi.org/10.3102/00346543074001059

Friso-van den Bos, I., van der Ven, S. H. G., Kroesbergen, E. H., & van Luit, J. E. H. (2013). Working memory and mathematics in primary school children: A meta-analysis. *Educational Research Review*, 10, 29–44.

Fuhrmann, D., Casey, C. S., Speekenbrink, M., & Blakemore, S. J. (2019). Social exclusion affects working memory performance in young adolescent girls. *Developmental Cognitive Neuroscience*, *40*. https://doi.org/10.1016/j.dcn.2019.100718

Gini, G., Carli, G., & Pozzoli, T. (2009). Social support, peer victimisation, and somatic complaints: A mediational analysis. *Journal of Paediatrics and Child Health*, *45*(6). https://doi.org/10.1111/j.1440-1754.2009.01501.x

Gönül, B., Sahin-Acar, B., & Killen, M. (2023). Perceived contact with friends from lower socioeconomic status reduces exclusion based on social class. *Developmental Science*. https://doi.org/10.1111/desc.13440

Goodman. (1997). The Strengths and Difficulties Questionnaire_ A Research Note - Goodman - 1997 - Journal of Child Psychology and Psychiatry - Wiley Online Library. *J. Child Psychol. Psychiat*, *38*(5).

Gottlieb, G., & Lickliter, R. (2007). Probabilistic epigenesis. In *Developmental Science* (Vol. 10, Issue 1). https://doi.org/10.1111/j.1467-7687.2007.00556.x

Gunnar, M., & Quevedo, K. (2007). The neurobiology of stress and development. *Annual Review of Psychology*, *58*. https://doi.org/10.1146/annurev.psych.58.110405.085605

Hackman, D. A., Farah, M. J., & Meaney, M. J. (2010). Socioeconomic status and the brain: Mechanistic insights from human and animal research. In *Nature Reviews Neuroscience* (Vol. 11, Issue 9). https://doi.org/10.1038/nrn2897

Hamre, B. K., & Pianta, R. C. (2001). Early teacher-child relationships and the trajectory of children's school outcomes through eighth grade. *Child Development*, *72*(2). https://doi.org/10.1111/1467-8624.00301

Harmon-Jones, E., Harmon-Jones, C., & Price, T. F. (2013). What is approach motivation? *Emotion Review*, *5*(3). https://doi.org/10.1177/1754073913477509

Hawes, D. J., Zadro, L., Fink, E., Richardson, R., O'Moore, K., Griffiths, B., Dadds, M. R., & Williams, K. D. (2012). The effects of peer ostracism on children's cognitive processes. *European Journal of Developmental Psychology*, *9*(5). https://doi.org/10.1080/17405629.2011.638815

Hayes, A. F. (2019). The PROCESS macro for SPSS, SAS, and R. *Https://Processmacro.Org/Index.Html*.

Holmes, C. J., Kim-Spoon, J., & Deater-Deckard, K. (2016). Linking Executive Function and Peer Problems from Early Childhood Through Middle Adolescence. *Journal of Abnormal Child Psychology*, *44*(1). https://doi.org/10.1007/s10802-015-0044-5

Horn, S. S. (2003). Adolescents' Reasoning about Exclusion from Social Groups. In *Developmental Psychology* (Vol. 39, Issue 1). https://doi.org/10.1037/0012-1649.39.1.71

Hox, J., Moerbeek, M., & Van de Schoot, R. (2017). Multilevel analysis: Techniques and applications. Routledge.

Hu, L. T., & Bentler, P. M. (1999). Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Structural Equation Modeling*, *6*(1). https://doi.org/10.1080/10705519909540118

Iachini, T., Maffei, L., Masullo, M., Senese, V. P., Rapuano, M., Pascale, A., Sorrentino, F., & Ruggiero, G. (2019). The experience of virtual reality: are individual differences in mental imagery associated with sense of presence? *Cognitive Processing*, *20*(3). https://doi.org/10.1007/s10339-018-0897-y

Jakobsen, J. C., Gluud, C., Wetterslev, J., & Winkel, P. (2017). When and how should multiple imputation be used for handling missing data in randomised clinical trials - A practical guide with flowcharts. *BMC Medical Research Methodology*, *17*(1). https://doi.org/10.1186/s12874-017-0442-1

Jones, S., Brush, K., Bailey, R., Brion-Meisels, G., McIntyre, J., Kahn, J., ... & Stickle, L. (2017). Navigating SEL from the inside out. looking inside and across 25 leading SEL programs: a practical resource for schools and OST providers. Cambridge: Harvard Graduate School of Education.

Judd, N., Klingberg, T., & Sjöwall, D. (2021). Working memory capacity, variability, and response to intervention at age 6 and its association to inattention and mathematics age 9. *Cognitive Development*, *58*. https://doi.org/10.1016/j.cogdev.2021.101013

Knickenberg, M., Zurbriggen, C. L. A., & Schwab, S. (2022). Validation of the Student Version of the Perceptions of Inclusion Questionnaire in Primary and Secondary Education Settings. *SAGE Open*, *12*(1). https://doi.org/10.1177/21582440221079896

Ladd, G. W. (2005). Children's peer relations and social competence: A century of progress. Yale University Press.

Ladd, G. W., Herald-Brown, S. L., & Andrews, R. K. (2009). The Child Behavior Scale (CBS) Revisited: A Longitudinal Evaluation of CBS Subscales With Children, Preadolescents, and Adolescents. *Psychological Assessment*, *21*(3). https://doi.org/10.1037/a0016205

Ladd, G. W., Kochenderfer-Ladd, B., Ettekal, I., & Clifford, B. N. (2021). Manifestations of Solitude in Interpersonal Contexts and Negative Peer Experiences. In *The Handbook of Solitude* (pp. 117–132). Wiley. https://doi.org/10.1002/9781119576457.ch9

Larsen, B., & Luna, B. (2018). Adolescence as a neurobiological critical period for the development of higher-order cognition. In *Neuroscience and Biobehavioral Reviews* (Vol. 94). https://doi.org/10.1016/j.neubiorev.2018.09.005

Laursen, B., & Veenstra, R. (2021). Toward understanding the functions of peer influence: A summary and synthesis of recent empirical research. *Journal of Research on Adolescence*, 31(4), 889-907.

Lecce, S., Bianco, F., & Ronchi, L. (2020). Executive function in the school context: The role of peer relationships. *Infant and Child Development*, *29*(1). https://doi.org/10.1002/icd.2151

Lila, M., Van Aken, M., Musitu, G., & Buelga, S. (2020). Peer relations in adolescence. In *Handbook of Adolescent Development*. https://doi.org/10.4324/9780203969861-10

Long, E., Zucca, C., & Sweeting, H. (2021). School climate, peer relationships, and adolescent mental health: A social ecological perspective. Youth & society, 53(8), 1400-1415.

Luna, B., Marek, S., Larsen, B., Tervo-Clemmens, B., & Chahal, R. (2015). An Integrative Model of the Maturation of Cognitive Control. *Annual Review of Neuroscience*, *38*. https://doi.org/10.1146/annurev-neuro-071714-034054

Luna, B., Padmanabhan, A., & O'Hearn, K. (2010). What has fMRI told us about the Development of Cognitive Control through Adolescence? In *Brain and Cognition* (Vol. 72, Issue 1). https://doi.org/10.1016/j.bandc.2009.08.005

Lynch, K. M., Cabeen, R. P., Toga, A. W., et al. (2023). Spatiotemporal patterns of cortical microstructural maturation in children and adolescents with diffusion MRI. *Human Brain Mapping*, 45(1), e26528

Malecki, C. K., & Demaray, M. K. (2002). Measuring perceived social support: Development of the Child and Adolescent Social Support Scale (CASSS). *Psychology in the Schools*, *39*(1). https://doi.org/10.1002/pits.10004

Marcoen, A., Goossens, L., & Caes, P. (1987). Lonelines in pre-through late adolescence: Exploring the contributions of a multidimensional approach. *Journal of Youth and Adolescence*, *16*(6). https://doi.org/10.1007/BF02138821

McLaughlin, K. A., Hatzenbuehler, M. L., & Hilt, L. M. (2009). Emotion dysregulation as a mechanism linking peer victimization to internalizing symptoms in adolescents. *Journal of consulting and clinical psychology*, 77(5), 894.

Meta. (2020). Meta Quest 2 [VR headset]. Meta Platforms. https://www.meta.com/quest/

Meyer, M. L., & Lieberman, M. D. (2012). Social working memory: Neurocognitive networks and directions for future research. *Frontiers in Psychology*, 3, 571.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The Unity and Diversity of Executive Functions and Their Contributions to Complex "Frontal Lobe" Tasks: A Latent Variable Analysis. *Cognitive Psychology*, *41*(1). https://doi.org/10.1006/cogp.1999.0734

Mooney, K. E., Prady, S. L., Barker, M. M., Pickett, K. E., & Waterman, A. H. (2021). The association between socioeconomic disadvantage and children's working memory abilities: A systematic review and meta-analysis. In *PLoS ONE* (Vol. 16, Issue 12 December). https://doi.org/10.1371/journal.pone.0260788

Moore, G. F., Cox, R., Evans, R. E., Hallingberg, B., Hawkins, J., Littlecott, H. J., ... & Murphy, S. (2018). School, peer and family relationships and adolescent substance use, subjective wellbeing and mental health symptoms in Wales: A cross sectional study. Child indicators research, 11(6), 1951-1965.

Murty, V. P., Calabro, F. J., & Luna, B. (2016). The role of experience in adolescent cognitive development: Integration of executive, memory, and mesolimbic systems. Neuroscience & Biobehavioral Reviews, 70, 46–58. https://doi.org/10.1016/j.neubiorev.2016.07.034

Nezlek, J. B., Wesselmann, E. D., Wheeler, L., & Williams, K. D. (2015). Ostracism in Everyday Life: The Effects of Ostracism on Those Who Ostracize. *Journal of Social Psychology*, *155*(5). https://doi.org/10.1080/00224545.2015.1062351

Oaksford, M., Grainger, B., Morris, F., & Williams, J. M. G. (1996). Mood, reasoning, and central executive processes. *Journal of Experimental Psychology: Learning Memory and Cognition*, *22*(2). https://doi.org/10.1037/0278-7393.22.2.476

Oberer, N., Gashaj, V., & Roebers, C. M. (2018). Executive functions, visual-motor coordination, physical fitness and academic achievement: Longitudinal relations in typically developing children. *Human Movement Science*, *58*. https://doi.org/10.1016/j.humov.2018.01.003

Oberle, E., & Schonert-Reichl, K. A. (2017). Social and emotional learning: Recent research and practical strategies for promoting children's social and emotional competence in schools. In *Handbook of social behavior and skills in children* (pp. 175–197). Springer.

Ouimet, A. J., Gawronski, B., & Dozois, D. J. A. (2009). Cognitive vulnerability to anxiety: A review and an integrative model. In *Clinical Psychology Review* (Vol. 29, Issue 6). https://doi.org/10.1016/j.cpr.2009.05.004

Parsons, T. D. (2015). Virtual reality for enhanced ecological validity and experimental control in the clinical, affective and social neurosciences. *Frontiers in Human Neuroscience*, *9*(DEC). https://doi.org/10.3389/fnhum.2015.00660

Pessoa, L. (2013). The cognitive-emotional brain: From interactions to integration. In *The cognitive-emotional brain: From interactions to integration.*

Petkus, A., Reynolds, C. A., & Gatz, M. (2017). LONGITUDINAL ASSOCIATION OF ANXIETY AND COGNITIVE PERFORMANCE: GENETIC AND ENVIRONMENTAL INFLUENCES. *Innovation in Aging*, *1*(suppl_1). https://doi.org/10.1093/geroni/igx004.348

Popov, L. M., & Ilesanm, R. A. (2015). Parent-child relationship: Peculiarities and outcome. *Review of European Studies*, *7*(5). https://doi.org/10.5539/res.v7n5p253

Prendergast, C. N., & Schubert, T. (2020). Investigating Reflexive Responses to Explicit and Implicit Forms of Social Exclusion Using Immersive Virtual Environment Technology. *Frontiers in Psychology*, *11*. https://doi.org/10.3389/fpsyg.2020.575783

Prinstein, M. J., & Giletta, M. (2020). Future directions in peer relations research. Journal of Clinical Child & Adolescent Psychology, 49(4), 556-572.

Qualtrics. (2023). Qualtrics XM [Computer software]. Qualtrics. https://www.qualtrics.com

Regenbrecht, H., & Schubert, T. (2002). Real and illusory interactions enhance presence in virtual environments. In *Presence: Teleoperators and Virtual Environments* (Vol. 11, Issue 4). https://doi.org/10.1162/105474602760204318

Riggs, N. R., Jahromi, L. B., Razza, R. P., Dillworth-Bart, J. E., & Mueller, U. (2006). Executive function and the promotion of social-emotional competence. *Journal of Applied Developmental Psychology*, 27(4), 300–309.

Riva, G., Mantovani, F., & Gaggioli, A. (2004). Presence and rehabilitation: Toward second-generation virtual reality applications in neuropsychology. In *Journal of NeuroEngineering and Rehabilitation* (Vol. 1). https://doi.org/10.1186/1743-0003-1-9

Riva, P., & Eck, J. (2016). Social exclusion: Psychological approaches to understanding and reducing its impact. In *Social Exclusion: Psychological Approaches to Understanding and Reducing Its Impact*. https://doi.org/10.1007/978-3-319-33033-4

Roorda, D. L., Koomen, H. M. Y., Spilt, J. L., & Oort, F. J. (2011). The influence of affective teacher-student relationships on students' school engagement and achievement: A meta-analytic approach. *Review of Educational Research*, *81*(4). https://doi.org/10.3102/0034654311421793

Rubin, K. H., Bukowski, W. M., & Bowker, J. C. (2015). Children in Peer Groups. In *Handbook of Child Psychology and Developmental Science*. https://doi.org/10.1002/9781118963418.childpsy405

Rytioja, M., Lappalainen, K., & Savolainen, H. (2019). Behavioural and emotional strengths of sociometrically popular, rejected, controversial, neglected, and average children. *European Journal of Special Needs Education*, *34*(5). https://doi.org/10.1080/08856257.2018.1560607

Sankalaite, S., Huizinga, M., Dewandeleer, J., Xu, C., de Vries, N., Hens, E., & Baeyens, D. (2021). Strengthening Executive Function and Self-Regulation Through Teacher-Student Interaction in Preschool and Primary School Children: A Systematic Review. In *Frontiers in Psychology* (Vol. 12). https://doi.org/10.3389/fpsyg.2021.718262

Satterthwaite, T. D., Shinohara, R. T., Wolf, D. H., Hopson, R. D., Elliott, M. A., Vandekar, S. N., Ruparel, K., Calkins, M. E., Roalf, D. R., Gennatas, E. D., Jackson, C., Erus, G., Prabhakaran, K., Davatzikos, C., Detre, J. A., Hakonarson, H., Gur, R. C., & Gur, R. E. (2014). Impact of puberty on the evolution of cerebral perfusion during adolescence. *Proceedings of the National Academy of Sciences of the United States of America*, *111*(23). https://doi.org/10.1073/pnas.1400178111

Schmider, E., Ziegler, M., Danay, E., Beyer, L., & Bühner, M. (2010). Is it really robust? Reinvestigating the robustness of ANOVA against violations of the normal distribution assumption. *Methodology*, 6(4), 147–151

Schmidt, A., Dirk, J., & Schmiedek, F. (2019). The importance of peer relatedness at school for affective well-being in children: Between- and within-person associations. *Social Development*, *28*(4). https://doi.org/10.1111/sode.12379

Schoofs, D., Preuß, D., & Wolf, O. T. (2008). Psychosocial stress induces working memory impairments in an n-back paradigm. Psychoneuroendocrinology, 33(5), 643-653.

Sebastian, C., Viding, E., Williams, K. D., & Blakemore, S. J. (2010). Social brain development and the affective consequences of ostracism in adolescence. In *Brain and Cognition* (Vol. 72, Issue 1). https://doi.org/10.1016/j.bandc.2009.06.008

Secker, J., Hacking, S., Kent, L., Shenton, J., & Spandler, H. (2009). Development of a measure of social inclusion for arts and mental health project participants. *Journal of Mental Health*, *18*(1). https://doi.org/10.1080/09638230701677803

Seltman, H. J. (2018). Experimental design and analysis. Carnegie Mellon University.

Shackman, A. J., Sarinopoulos, I., Maxwell, J. S., Pizzagalli, D. A., Lavric, A., & Davidson, R. J. (2006). Anxiety selectively disrupts visuospatial working memory. In *Emotion* (Vol. 6, Issue 1). https://doi.org/10.1037/1528-3542.6.1.40

Shields, G. S., Sazma, M. A., & Yonelinas, A. P. (2016). The effects of acute stress on core executive functions: A meta-analysis and comparison with cortisol. Neuroscience & Biobehavioral Reviews, 68, 651-668.

Silk, J. S., Forbes, E. E., Whalen, D. J., Jakubcak, J. L., Thompson, W. K., Ryan, N. D., Axelson, D. A., Birmaher, B., & Dahl, R. E. (2011). Daily emotional dynamics in depressed youth: A cell phone ecological momentary assessment study. *Journal of Experimental Child Psychology*, *110*(2). https://doi.org/10.1016/j.jecp.2010.10.007

Skårbrevik, K. J. (2005). The quality of special education for students with special needs in ordinary classes. *European Journal of Special Needs Education*, *20*(4). https://doi.org/10.1080/08856250500268601

Söderqvist, S., & Nutley, S. B. (2015). Working memory training is associated with long term attainments in math and reading. *Frontiers in Psychology*, *6*(NOV). https://doi.org/10.3389/fpsyg.2015.01711

Spachtholz, P., Kuhbandner, C., & Pekrun, R. (2014). Negative affect improves the quality of memories: Trading capacity for precision in sensory and working memory. *Journal of Experimental Psychology: General*, *143*(4). https://doi.org/10.1037/xge0000012

Stoet, G. (2017). PsyToolkit: A novel web-based method for running online questionnaires and reaction-time experiments. *Teaching of Psychology*, 44(1), 24–31. https://doi.org/10.1177/0098628316677643

Sweller, J. (1994). Cognitive load theory, learning difficulty, and instructional design. *Learning and Instruction*, *4*(4). https://doi.org/10.1016/0959-4752(94)90003-5

Sweller, J., van Merriënboer, J. J. G., & Paas, F. (2019). Cognitive Architecture and Instructional Design: 20 Years Later. In *Educational Psychology Review* (Vol. 31, Issue 2). https://doi.org/10.1007/s10648-019-09465-5

Tamnes, C. K., Walhovd, K. B., Grydeland, H., Holland, D., Østby, Y., Dale, A. M., & Fjell, A. M. (2013). Longitudinal working memory development is related to structural maturation of frontal and parietal cortices. *Journal of cognitive neuroscience*, *25*(10), 1611-1623.

Taylor, A. K. (2013). Digit Span. In *Encyclopedia of Human Memory: [3 volumes]* (Vols. 1–3). https://doi.org/10.1201/9781003309604-8

Telzer, E. H., Fuligni, A. J., Lieberman, M. D., Miernicki, M. E., & Galván, A. (2013). The quality of adolescents peer relationships modulates neural sensitivity to risk taking. *Social Cognitive and Affective Neuroscience*, *10*(3). https://doi.org/10.1093/scan/nsu064

Tervo-Clemmens, B., Calabro, F. J., Parr, A. C., Fedor, J., Foran, W., & Luna, B. (2023). A canonical trajectory of executive function maturation from adolescence to adulthood. *Nature Communications*, *14*(1). https://doi.org/10.1038/s41467-023-42540-8

Timeo, S., Riva, P., & Paladino, M. P. (2020). Being liked or not being liked: A study on social-media exclusion in a preadolescent population. *Journal of Adolescence*, *80*. https://doi.org/10.1016/j.adolescence.2020.02.010

Tobia, V., & Marzocchi, G. M. (2018). The Strengths and Difficulties Questionnaire-Parents for Italian School-Aged Children: Psychometric Properties and Norms. *Child Psychiatry and Human Development*, *49*(1). https://doi.org/10.1007/s10578-017-0723-2

Tobia, V., Riva, P., & Caprin, C. (2017). Who Are the Children Most Vulnerable to Social Exclusion? The Moderating Role of Self-Esteem, Popularity, and Nonverbal Intelligence on Cognitive Performance Following Social Exclusion. *Journal of Abnormal Child Psychology*, *45*(4). https://doi.org/10.1007/s10802-016-0191-3

Valcan, D. S., Davis, H., & Pino-Pasternak, D. (2018). Parental Behaviours Predicting Early Childhood Executive Functions: a Meta-Analysis. *Educational Psychology Review*, *30*(3). https://doi.org/10.1007/s10648-017-9411-9

Vandenbroucke, L., Spilt, J. L., Verschueren, K., & Baeyens, D. (2018a). The effects of peer rejection, parent and teacher support on working memory performance: An experimental approach in middle childhood. *Learning and Individual Differences*, *67*. https://doi.org/10.1016/j.lindif.2018.06.007

Vandenbroucke, L., Spilt, J., Verschueren, K., Piccinin, C., & Baeyens, D. (2018b). The classroom as a developmental context for cognitive development: A meta-analysis on the importance of teacher–student interactions for children's executive functions. *Review of Educational Research*, *88*(1). https://doi.org/10.3102/0034654317743200

Vandenbroucke, L., Verschueren, K., & Baeyens, D. (2017). The development of executive functioning across the transition to first grade and its predictive value for academic achievement. *Learning and Instruction*, *49*.

Vygotsky, L. S., Cole, M., John-Steiner, V., Scribner, S., Souberman, E., & Wertsch, J. V. (1979). L. S. Vygotsky: Mind in Society. The Development of Higher Psychological Processes. *The American Journal of Psychology*, 92(1).

Warrington, M., & Younger, M. (2011). "Life is a tightrope": Reflections on peer group inclusion and exclusion amongst adolescent girls and boys. *Gender and Education*, *23*(2). https://doi.org/10.1080/09540251003674121

Welsh, J. A., Nix, R. L., Blair, C., Bierman, K. L., & Nelson, K. E. (2010). The Development of Cognitive Skills and Gains in Academic School Readiness for Children From Low-Income Families. *Journal of Educational Psychology*, *102*(1). https://doi.org/10.1037/a0016738

Wentzel, K. R., Muenks, K., McNeish, D., & Russell, S. (2017). Peer and teacher supports in relation to motivation and effort: A multi-level study. *Contemporary Educational Psychology*, 49, 32-45.

Weyns, T., Colpin, H., De Laet, S., Engels, M., & Verschueren, K. (2018). Teacher Support, Peer Acceptance, and Engagement in the Classroom: A Three-Wave Longitudinal Study in Late Childhood. *Journal of Youth and Adolescence*, *47*(6). https://doi.org/10.1007/s10964-017-0774-5

Will, G. J., van Lier, P. A. C., Crone, E. A., & Güroğlu, B. (2016). Chronic Childhood Peer Rejection is Associated with Heightened Neural Responses to Social Exclusion During Adolescence. *Journal of Abnormal Child Psychology*, *44*(1). https://doi.org/10.1007/s10802-015-9983-0

Williams, K. D. (2001). *Ostracism: the power of silence. (Emotions and social behavior)*. Guilford.

Williams, K. D. (2009). Chapter 6 Ostracism. A Temporal Need-Threat Model. In *Advances in Experimental Social Psychology* (Vol. 41). https://doi.org/10.1016/S0065-2601(08)00406-1

Williams, K. D., Cheung, C. K. T., & Choi, W. (2000). Cyberostracism: Effects of being ignored over the internet. *Journal of Personality and Social Psychology*, *79*(5). https://doi.org/10.1037/0022-3514.79.5.748

Xu, C., Huizinga, M., Tekelia Ekubagewargies, D., Soetaert, J., Van Den Noortgate, W., & Baeyens, D. (2024). The relation between teacher–student interaction and executive function performance in children: A cross-cultural meta-analysis. *Educational Psychologist*, *59*(3). https://doi.org/10.1080/00461520.2024.2315527

Yang, H., Yang, S., & Isen, A. M. (2013). Positive affect improves working memory: Implications for controlled cognitive processing. *Cognition and Emotion*, *27*(3). https://doi.org/10.1080/02699931.2012.713325

Zarrella, I., Lonigro, A., Perrella, R., Caviglia, G., & Laghi, F. (2018). Social behaviour, socio-cognitive skills and attachment style in school-aged children: what is the relation with academic outcomes? *Early Child Development and Care*, *188*(10). https://doi.org/10.1080/03004430.2016.1266486

Zelazo, P. D., & Carlson, S. M. (2012). Hot and Cool Executive Function in Childhood and Adolescence: Development and Plasticity. *Child Development Perspectives*, *6*(4). https://doi.org/10.1111/j.1750-8606.2012.00246.x

Supplementary Material

Full Models for Gender as a Moderator of the Effects of Peer Exclusion

Positive Mood

A significant Time × Gender interaction emerged, $F(1, 168) = 6.49$, $p = .012$, partial $\eta p^2 = .037$. Females (*Mpre* = 15.76, *SD* = 2.68 → *Mpost* = 13.82, *SD* = 4.23) showed a greater decrease in positive mood than males (*Mpre* = 16.09, *SD* = 1.99 → *Mpost* = 15.29, *SD* = 3.27). Post-hoc pairwise comparisons confirmed that this difference was significant, *MDiff* = –1.47, $p = .012$. The main effect of Time was significant, $F(1, 168) = 37.95$, $p < .001$, partial $\eta p^2 = .184$, showing that positive mood decreased overall from pre- to post-exclusion. The main effect of Gender was also significant, $F(1, 168) = 4.42$, $p = .037$. Post-hoc pairwise comparisons showed that females reported an overall lower positive mood compared to males, *MDiff* = -0.90, $p = .037$.

Negative Mood

The Time × Gender interaction approached significance, $F(1, 168) = 3.79$, $p = .053$, partial $\eta p^2 = .022$, suggesting a trend for differential changes in negative mood between males and females. Post-hoc comparisons indicated that both genders reported higher negative mood after exclusion, but the increase was slightly greater among females (*Mpre* = 5.41, *SD* = 2.24 → *Mpost* = 6.63, *SD* = 3.33) than among males (*Mpre* = 5.45, *SD* = 1.75 → *Mpost* = 5.83, *SD* = 2.57; *Mdiff* = 1.21; $p < .001$). The main effect of Time was significant, $F(1, 168) = 13.77$, $p < .001$, partial $\eta p^2 = .076$, indicating an overall increase in negative mood from pre- to post-exclusion. The main effect of Gender was non-significant, $F(1, 168) = 1.38$, $p = .24$.

Digit Backwards

Neither the Time, $F(1, 168) = 1.08$, $p = .29$, partial $\eta p^2 = .006$, Gender effect, $F(1, 168) = 0.26$, $p = .61$, partial $\eta p^2 = .002$, nor the Time × Gender interaction, $F(1, 168) = 2.35$, $p = .12$, partial $\eta p^2 = .014$, was significant.

Corsi Backwards

No significant effects were found for Time, $F(1, 168) = 0.25$, $p = .86$, partial $\eta p^2 = .000$, or for Gender, $F(1, 168) = 1.34$, $p = .26$, partial $\eta p^2 = .008$, either for the Time × Gender interaction, $F(1, 168) = 1.83$, $p = .18$, partial $\eta p^2 = .011$. Males and females performed comparably across both sessions.

Full Models for Age Group as a Moderator of the Effects of Peer Exclusion

Positive Mood

The main effect of Age Group, $F(1, 168) = 18.44$, $p < .001$, partial $\eta p^2 = .099$, was significant. Adolescents showed a greater decrease in positive mood from pre- to post-exclusion ($M = 15.20 \rightarrow 13.63$) than children ($M = 16.75 \rightarrow 15.63$). Post-hoc tests revealed that this difference was significant, indicating that adolescents started and ended with lower positive mood, and their reduction across time was larger than that of children, $MDiff = -1.77$, $p < .001$. The main effect of Time, $F(1, 168) = 35.24$, $p < .001$, partial $\eta p^2 = .173$, was significant, indicating an overall decrease in positive mood from pre- to post-exclusion. A significant Time × Age Group interaction was not found, $F(1, 168) = 0.95$, $p = .033$, partial $\eta p^2 = .006$.

Negative Mood

The Time × Age Group interaction trended toward significance, $F(1, 168) = 3.27$, $p = .072$, partial $\eta p^2 = .019$, with adolescents showing a greater increase in negative mood than children, $MDiff = 1.05$, $p = .022$. The main effects of Time, $F(1, 168) = 12.58$, $p < .001$, partial $\eta p^2 = .070$, was significant, indicating an overall increase in negative mood from pre- to post-exclusion. A main effect of Age Group, $F(1, 168) = 4.19$, $p = .021$, partial $\eta p^2 = .042$, was also significant. Post-hoc comparisons indicated that adolescents reported higher negative mood overall than children, $MDiff = 0.66$, $p = .042$.

Digit Backwards

Neither Time, $F(1, 168) = 1.23$, $p = .27$, partial $\eta p^2 = .007$, nor the Time × Age Group interaction, $F(1, 168) = 0.44$, $p = .51$, partial $\eta p^2 = .003$, reached significance. A significant main effect of Age Group emerged, $F(1, 168) = 38.46$, $p < .001$, partial $\eta p^2 = .186$. Post-hoc pairwise comparisons indicated that overall, adolescents performed better than children, *MDiff* = 1.82, $p < .001$.

Corsi Backwards

A significant Time × Age Group interaction emerged, $F(1, 168) = 14.19$, $p < .001$, partial $\eta p^2 = .078$. Post-hoc comparisons revealed that adolescents' performance increased slightly, *MDiff* = 1.21, $p = .016$, whereas children's scores decreased, M*Diff* = -1.51, $p = .005$. The main effect of Age Group was significant, $F(1, 168) = 32.19$, $p < .001$, partial $\eta p^2 = .161$, with adolescents outperforming children, *MDiff* = 3.32, $p < .001$. The Time effect was non-significant, $F(1, 168) = 0.17$, $p = .68$, partial $\eta p^2 = .001$.

Exploratory Mediation Analyses by Individual Mood States

To further probe the potential role of mood in mediating the effect of exclusion on WM, eight additional PROCESS models were tested using individual mood items (good, bad, friendly, unfriendly, happy, pleasant, sad, and angry) as mediators. Results revealed two significant indirect effects. Specifically, the decrease in "happy" mood significantly mediated the effect of perceived exclusion on visuospatial WM performance (Corsi Backwards) by showing a significant indirect mediation ($B = 0.024$, $SE = 0.012$, 95% *C.I.*[0.000, 0.047], $p = .043$), such that higher perceived exclusion was associated with a greater reduction in happiness ($B = 0.073$, $SE = 0.019$, 95% *C.I.*[0.035, 0.111], $p < .001$), which in turn predicted poorer post-exclusion WM performance ($B = 1.055$, $SE = 0.513$, 95% *C.I.*[0.050, 2.060], $p = .040$). Conversely, the increase in "angry" mood also served as a significant mediator on visuospatial WM performance (Corsi Backwards) by showing a

significant indirect mediation (B = -0.190, SE = 0.092, 95% $C.I.$[-0.371, -0.009], p = .040) but in the opposite direction: higher perceived exclusion predicted greater increases in anger (B = -0.173, SE = 0.017, 95% $C.I.$[-0.207, -0.139], p < .001), which were associated with improved post-exclusion WM performance (B = 1.096, SE = 0.552, 95% $C.I.$[0.074, 2.118], p = .036). By adding age groups (children vs. adolescents) as a between-subject variable, no differences in the aforementioned mediation paths were found among the two age groups. No significant effects were found for the other moods, and no significant mediation was found for any mood item on Digit Backwards scores.

Full Models for Moderation Analyses

Teachers' Social Support

For Digit Backward, the main effect of teachers' social support was significant, F(1, 168) = 8.03, p = .005, partial ηp^2 = .046, while the main effect of time, F(1, 168) = 0.19, p = .66, and the Time × Teachers' Social Support interaction, F(1, 168) = 0.48, p = .49, were not. Parameter estimates indicated a consistent negative relation both before (B = –0.035, p = .021) and after (B = –0.045, p = .006) exclusion, suggesting that higher perceived teacher support was linked to slightly lower verbal working-memory performance across sessions.

For Corsi Backwards, a significant main effect of teachers' social support emerged, F(1, 168) = 8.42, p = .004, partial ηp^2 = .048, indicating that higher perceived teacher support was associated with lower working-memory performance. A significant main effect of time was also found, F(1, 168) = 4.72, p = .031, partial ηp^2 = .027, together with a significant Time × Teachers' Social Support interaction, F(1, 168) = 5.15, p = .024, partial ηp^2 = .030. Parameter estimates showed that the negative effect of teacher support was not significant at pre-test (B = –0.043, p = .194) but became significant at post-test (B = –0.118, p < .001), suggesting that students who perceived lower teacher support displayed better post-exclusion spatial working-memory performance.

VR Features

For Digit Backward, no significant effects were found: Time, $F(1, 166) = 0.36$, $p = .55$; VR Features, $F(1, 166) = 0.93$, $p = .34$; Time × VR Features, $F(1, 166) = 0.68$, $p = .41$.

For Corsi Backward, a significant main effect of VR Features was found, $F(1, 166) = 5.02$, $p = .026$, partial $\eta p^2 = .029$, whereas the main effect of time, $F(1, 166) = 0.70$, $p = .40$, and the Time × VR Features interaction, $F(1, 166) = 0.76$, $p = .39$, were not significant. Parameter estimates indicated that VR features were not significantly related to Corsi scores at pre-test ($B = –0.042$, $p = .144$) but showed a small negative relation at post-test ($B = –0.068$, $p = .018$), suggesting that higher subjective VR Features might have been linked to slightly lower spatial WM performance after exclusion.

Socioeconomic Status (SES)

For Digit Backwards, SES showed a strong main effect, $F(1, 168) = 17.94$, $p < .001$, partial $\eta p^2 = .096$, indicating that higher SES predicted better verbal working-memory performance. Neither the main effect of time, $F(1, 168) = 0.22$, $p = .64$, nor the Time × SES interaction, $F(1, 168) = 0.42$, $p = .52$, was significant. Parameter estimates revealed stable positive coefficients at pre-test ($B = 0.121$, $p < .001$) and post-test ($B = 0.105$, $p < .001$), suggesting that SES influenced overall WM ability.

For Corsi Backward, a significant main effect of SES was observed, $F(1, 168) = 13.96$, $p < .001$, partial $\eta p^2 = .077$, showing that participants from higher-SES backgrounds achieved better spatial working-memory scores. Neither the main effect of time, $F(1, 168) = 0.56$, $p = .46$, nor the Time × SES interaction, $F(1, 168) = 0.52$, $p = .47$, reached significance. Parameter estimates confirmed a robust positive association at both pre-test ($B = 0.175$, $p = .006$) and post-test ($B = 0.222$, $p < .001$).

Baseline Working Memory Performance

For Digit Backwards, all effects were significant. A strong main effect of baseline Digit ability ($F(1, 168) = 755.32$, $p < .001$, partial $\eta p^2 = .818$), accompanied by significant effects of time ($F(1, 168) = 20.20$, $p < .001$, partial $\eta p^2 = .107$) and the Time × Baseline WM interaction ($F(1, 168) = 24.94$, $p < .001$, partial $\eta p^2 = .129$). The post-test coefficient confirmed a strong predictive effect ($B = 0.692$, $p < .001$). These results indicate that baseline WM was the most powerful determinant of post-exclusion WM outcomes.

For Corsi Backwards, results were comparable. The main effect of Baseline WM performance was very strong, $F(1, 168) = 486.53$, $p < .001$, partial $\eta p^2 = .743$, and was accompanied by significant effects of time, $F(1, 168) = 53.81$, $p < .001$, partial $\eta p^2 = .243$, and a robust Time × Baseline WM interaction, $F(1, 168) = 59.86$, $p < .001$, partial $\eta p^2 = .263$. Parameter estimates confirmed that baseline ability predicted post-test performance ($B = 0.481$, $p < .001$), indicating that those with higher initial WM levels maintained stronger performance after exclusion.

Problem Behaviours

For Digit Backward, the main effect of Problem Behaviours scores approached significance, $F(1, 168) = 3.44$, $p = .065$, partial $\eta p^2 = .020$, whereas neither the main effect of time, $F(1, 168) = 0.09$, $p = .77$, nor the interaction, $F(1, 168) = 0.26$, $p = .61$, reached significance.

For Corsi Backward, a significant main effect of problem behaviours was found, $F(1, 168) = 14.40$, $p < .001$, partial $\eta p^2 = .079$, showing that higher Problem Behaviours scores were associated with poorer spatial WM. Neither the main effect of time, $F(1, 168) = 1.36$, $p = .25$, nor the Time × Problem Behaviours interaction, $F(1, 168) = 1.50$, $p = .22$, was significant. Parameter estimates confirmed this consistent negative relationship at both pre-test ($B = –0.177$, $p = .011$) and post-test ($B = –0.264$, $p < .001$).

CHAPTER 6

How Peers Shape the Mind: Affective and Cognitive Consequences of Daily Relatedness in Children's School Lives

Giuseppe De Luca[1,2], Andrea Irmer[3,4], Florian Schmiedek[3,4,5], Friederike Blume[3,4]

[1] Department of Psychology "Renzo Canestrari", Alma Mater Studiorum – University of Bologna, Bologna, Italy

[2]Parenting and Special Education Research Unit, KU Leuven, Leuven, Belgium

[3] DIPF | Leibniz Institute for Research and Information in Education, Frankfurt am Main, Germany

[4] IDeA Center for Research on Individual Development and Adaptive Education of Children at Risk, Frankfurt am Main, Germany

5 Goethe-University Frankfurt am Main, Germany.

CHAPTER 6

Abstract

Peer relationships are central to children's emotional and cognitive development, yet prior research has primarily examined stable differences between children, leaving it unclear how daily fluctuations in peer relatedness relate to core cognitive processes. To address this gap, this study investigated how peer relatedness satisfaction and frustration were associated with children's working memory updating performance (WMUP) and perceived academic success at both the between-person level (average differences between children) and the within-person level (day-to-day fluctuations within children). It further examined potential mediating roles of positive and negative affect.

Data from two intensive longitudinal studies collecting data across 20 consecutive school days at the end of primary school (Grade 4, $N = 90$) and at the beginning of secondary school (Grade 5, $N = 108$) were analysed.

Multilevel Bayesian modelling revealed that, at the between- and within-person level, peer relatedness satisfaction was associated with higher perceived academic success in Grades 4 and 5. Furthermore, at both levels, higher peer relatedness frustration was associated with lower WMUP in Grade 4, but not in Grade 5. Positive affect partially mediated links between relatedness and academic success in specific cases, whereas negative affect co-occurred WMUP but did not mediate either academic success or cognitive performance.

The study showed that positive peer experiences, both in general and at the daily level, are linked to higher perceived academic success across school levels, whereas negative peer experiences are associated with lower cognitive performance particularly in primary school. Possible explanations for these differential findings across grades are discussed.

Keywords

Peer relatedness; Working memory updating; Academic success; Affect; Within-person variability; Multilevel modelling.

CHAPTER 6

Working memory is a fundamental cognitive function that enables the temporary storage and manipulation of information necessary for complex learning and problem solving and is therefore central to children's functioning in school contexts. Working memory updating is a core function of working memory that refers to the ability of constant monitoring and rapid addition, manipulation, or deletion of working memory contents (Ecker et al., 2010; Miyake & Friedman, 2012). Working memory updating has been found to be particularly relevant for students' academic functioning, especially in classroom settings that require sustained attention, goal-directed updating, and the integration of ongoing instructional input (Gathercole et al., 2004; Peng et al., 2018)

Peer relatedness is a particularly relevant domain in this regard, as the quality of children's daily social experiences has been shown to be linked with both emotional adjustment and learning processes in school (Wentzel et al., 2016). Because peer-related experiences vary from day to day, the school environment provides a critical context for examining variability in working memory updating (Nezlek et al., 2015; Schmidt et al., 2020). The vast majority of research examining social processes and cognitive functioning has focused on stable, trait-like differences between individuals, that is, on the between-person (BP) level (Hamaker et al., 2005; Molenaar, 2004). However, accumulating evidence indicates that both social interactions and cognitive functioning fluctuate dynamically across time and contexts within individuals, that is, on the within-person (WP) level (Dirk & Schmiedek, 2016; Fleeson, 2001). To better understand BP and WP differences and variations in working memory updating performance (WMUP), we focus on peer relatedness within the school setting. Importantly, affective experiences may serve as a key mechanism through which peer relatedness is linked to cognitive and academic outcomes, making it necessary to consider them alongside WMUP and perceived academic success (Pekrun, 2024; Moran, 2016). Nevertheless, much of the existing research has focused primarily on BP variation, with associations typically interpreted at the level of stable interindividual differences, and less attention has been paid to how these

associations may unfold at the WP level when examined with methods that explicitly separate these sources of variance (Curran & Bauer, 2011; Hamaker et al., 2005). More specifically, emerging evidence suggests that social relationships, especially peer relationships, significantly lead to BP differences in cognitive functioning (e.g., Holmes et al., 2016; Lecce et al., 2020; Suor et al., 2017). However, research on how peer relatedness and WMUP are associated at the daily level remains limited. Nevertheless, understanding how daily peer relatedness contributes to daily manifestations and fluctuations in WMUP over time is crucial for gaining a more nuanced perspective on the role of social contexts in cognitive development. This methodological distinction provides a critical foundation for the level-specific perspective adopted in the present study.

Psychological and cognitive phenomena can therefore be analysed at two distinct levels, the BP level, which captures relatively stable interindividual differences, and the WP level, which captures intraindividual variability across time and situations (Curran & Bauer, 2010). Considering the WP level is methodologically essential, as associations observed at the BP level can differ in strength or even direction from those at the WP level (Braver et al., 2014; Molenaar & Campbell, 2009). Differentiating between BP and WP levels is especially critical in developmental contexts, where learning, motivation, and emotional regulation evolve nonlinearly and vary across individuals (Fleeson, 2001). According to ergodic theory, the generalisation from one of these levels to the other is only valid under strict conditions—namely, homogeneity (i.e., the psychological processes of all individuals follow the same statistical model) and stationarity (i.e., the processes remain constant over time), both of which are rarely met in developmental research (Hamaker et al., 2005; Molenaar, 2004). As such, BP and WP distinctions are particularly necessary when processes are expected to vary dynamically within children across time and context, such as in classroom learning or peer relationships (Curran & Bauer, 2011). Without distinguishing between these levels of analysis, conclusions drawn from group averages may misrepresent individual experiences (Molenaar & Campbell,

2009). Intensive longitudinal methods (e.g., daily diary, ecological momentary assessment; Bolger & Laurenceau, 2013; Shiffman et al., 2008) provide repeated measurements over short intervals (e.g., day-to-day, moment-to-moment), thereby enabling to the examination of WP differences in real life contexts (Bolger & Laurenceau, 2013). Such approaches contribute to a more nuanced understanding of how day-to-day experiences are associated with cognitive functioning.

The specific effects of peer relatedness on WMUP and perceived academic success in children's daily school experiences remain underexplored. The lack of WP evidence prevents us from understanding how fluctuations in peer relatedness are linked to momentary changes in cognitive and academic functioning. Furthermore, without such evidence, we cannot capture how these processes unfold dynamically during key developmental periods, such as the transition from primary to secondary school. To address this gap, the present study aimed to clarify how the quality of both average and daily peer relationships contributes to children's cognitive and academic functioning by investigating the BP and WP level associations of peer relatedness satisfaction and frustration with WMUP and perceived academic success, and to investigate the potential mediating role of positive and negative affect. To this end, the present investigation analysed data from two ambulatory assessment studies with 9 to 11-year-olds, covering the transition from primary to secondary school.

Working Memory

Working memory is a cognitive system, limited in time and capacity, that enables individuals to retain and manipulate information (Baddeley, 2012). Working memory updating represents a complex, dynamic process that bridges maintenance and manipulation processes within working memory. It involves continuously monitoring incoming information, discarding no longer relevant content, and updating the stored information by applying operations to the existing content (Hitch & Baddeley, 1976), for example, applying arithmetic operations in numerical tasks.

Working memory updating has consistently been linked to students' academic success. At the BP level, several studies have shown that children with higher average working memory updating tend to demonstrate better academic outcomes. For example, in cross-sectional works, Lechuga and colleagues (2016) found that BP differences in working memory updating were associated with students' overall academic attainment, while Linares and Pelegrina (2023) showed that better working memory updating was associated with improved performance in reading comprehension and mathematical reasoning. Moreover, longitudinal and cross-sectional studies have shown higher working memory updating to be positively associated with performance in key academic domains, including mathematics, reading, and writing (Lee & Bull, 2015; St Clair-Thompson & Gathercole, 2006). Meta-analyses and longitudinal work have further confirmed that working memory updating consistently predicts school achievement (Linares & Pelegrina, 2023; Peng et al., 2018).

At the WP level, more recent work has demonstrated meaningful fluctuations in working memory updating across days and contexts. For example, Dirk and Schmiedek (2016) showed substantial day-to-day variability in children's WMUP across, providing clear evidence that working memory updating is not a fixed capacity but a dynamically varying cognitive process. Further work has linked these fluctuations to daily indicators of learning-related engagement and motivation, such as momentary task interest, perceived competence, and school-related affect (e.g., Brose et al., 2012; Schmidt et al., 2020). These findings suggest that children's momentary cognitive performance is closely intertwined with their affective and motivational states. Collectively, these studies underscore that working memory updating is not merely a stable trait (i.e., the average level of working memory updating across people), but also a state, reflecting real-time contextual and internal influences (see also Könen et al., 2015).

Working Memory Performance in Contexts

Children's cognitive development unfolds within everyday contexts in which they repeatedly engage in learning-related activities and social interactions, most prominently the

school context (Bronfenbrenner, 2005). In this sense, the development of stable individual differences in WMUP can be understood as emerging from children's repeated engagement with cognitively demanding situations in their daily environments, such as classroom instructions and peer interactions (Li et al., 2018; Vogel & Awh, 2008). Rather than reflecting a fixed capacity alone, WMUP is therefore shaped by situational demands and experiences encountered in daily life. Such moment-to-moment dynamics of WMUP in daily life are not merely noise, but reflect systematic variation (Troller-Renfree et al., 2020). However, despite this evidence for meaningful short-term variability, relatively little research has examined how specific everyday contexts, such as children's school experiences, shape fluctuations in WMUP at the daily level. Therefore, it is crucial to investigate how WMUP functions in everyday situations.

Peer Relatedness

Peer relationships are among the most powerful socialisation agents during childhood and adolescence, shaping students' development (e.g., Rubin et al., 2015; Wentzel et al., 2004). According to the basic psychological needs' theory (Ryan & Deci, 2000), the need for relatedness represents one of three fundamental psychological needs that are essential for optimal development and well-being. Within this framework, satisfaction of the need for relatedness is reflected in experiences of acceptance, inclusion, and companionship among classmates, which foster emotional security, intrinsic motivation, and engagement in learning contexts (Baumeister & Leary, 1995; Wentzel, 2017). In contrast, frustration of the need for relatedness involves experiences of rejection, exclusion, or social marginalisation (Bartholomew et al., 2011; Schmidt et al., 2020). Peer relatedness frustration, manifested as peer rejection and exclusion, has been linked to internal distress, including feelings of unhappiness and anger (Schmidt et al., 2020). As a result, rejected children and adolescents are more likely to experience exacerbated symptoms of internalising problems, such as anxiety, social withdrawal, loneliness, solitude, and depression (Platt et al., 2013; Rudolph, 2008). Taken

together, relatedness satisfaction and frustration represent key mechanisms through which peer relationships support or undermine children's socioemotional development.

At the BP level, children with higher peer relatedness satisfaction at school have been found to display more positive emotions and prosocial behaviour in comparison to those who experience higher peer relatedness frustration at school (Rytioja et al., 2019). This pattern is robust across multiple samples and methods (Wentzel et al., 2016; Rubin et al., 2015). Meta-analytic and longitudinal work further supported these links, indicating that more positive peer experiences are linked to better socioemotional adjustment and social competence over time (Giletta et al., 2021; Newcomb et al., 1993; Parker & Asher, 1987).

At the WP level, fluctuations in peer relatedness have been found to be meaningfully associated with students' affect, cognition, and academic self-perception in the short-term. On days when students feel more accepted by their peers than usual, they report higher positive affect and lower negative affect (Schmidt et al., 2019; Schmidt et al., 2020). Daily diary and ambulatory assessment studies showed that day-to-day increases in perceived peer relatedness were followed by higher same-day positive affect and greater academic engagement and perceived competence (van der Kaap-Deeder et al., 2017). Day-level analyses thus indicate that momentary increases in relatedness satisfaction are accompanied by immediate improvements in mood and learning-related engagement, highlighting the state-like nature of peer relatedness experiences in daily school life.

Conversely, for peer relatedness frustration at the BP level, large longitudinal and meta-analytic studies found that children who are chronically rejected, victimised, or who perceive persistent social exclusion show elevated levels of depressive and anxious symptoms, greater social withdrawal, and worse overall emotional adjustment (Giletta et al., 2021; McDougall & Vaillancourt, 2015; Platt et al., 2013). Peer relatedness frustration has also been found to be associated with academic outcomes. At the BP level, students who felt persistently disconnected from their peer group tended to show lower academic achievement, disengagement from

learning, and reduced classroom participation (Caemmerer & Keith, 2015; Wentzel & Asher, 1995). These effects are thought to reflect emotional distress and diminished school belonging, which can undermine academic motivation and focus (Maynard et al., 2016).

At the WP level, intensive longitudinal studies demonstrated that days with higher perceived peer relatedness frustration are associated with same-day increases in negative affect and reductions in perceived belonging and concentration (e.g., Herres et al., 2016; Nezlek et al., 2015; Schmidt et al., 2020). Momentary experiences of peer relatedness frustration can lead to immediate negative emotional reactions, even among generally well-connected children (Nezlek et al., 2015). Converging evidence from daily diary studies showed that momentary peer relatedness frustration was immediately followed by negative emotional reactions and cognitive disruption (e.g., poorer concentration, increased worry), which could transiently undermine classroom functioning and task focus (Giletta et al., 2021).

However, some research suggests that peer-related adversity may, under specific conditions, be linked to increased academic engagement or success (Chen et al., 1995; Ladd et al., 1997; Yang et al., 2018). This seemingly paradoxical association is often interpreted as a compensatory mechanism: children who experience peer relatedness frustration may turn toward academic pursuits as an alternative domain for self-worth and validation (Leary et al., 1995). For example, socially withdrawn children who were academically oriented have been found to perform well in school, possibly due to fewer social distractions and greater focus on learning (Chen et al., 1995). Similarly, children facing peer relatedness frustration may develop greater independence and persistence in schoolwork as a coping strategy (Ladd et al., 1997; Yang et al., 2018). While such findings challenge the assumption that peer relatedness frustration uniformly undermines academic functioning, they represent exceptions rather than the norm and should not overshadow the broader literature showing predominantly negative academic effects of peer relatedness frustration.

Beyond its motivational significance, peer relatedness may also play a role in cognitive functioning. From a self-determination perspective, experiencing social inclusion and acceptance can reduce concerns about social threat or rejection, thereby freeing cognitive resources that would otherwise be allocated to social vigilance (Ryan & Deci, 2017). In turn, these freed resources could be redirected toward cognitively demanding tasks, such as executive functioning. This reasoning suggests that peer relatedness satisfaction may indirectly support cognitive performance by fostering a psychologically safe social environment.

Overall, this body of evidence highlights peer relatedness as a dynamically fluctuating experience that varies from day to day and exerts immediate effects on children's emotional well-being, motivation, and learning-related functioning. Although evidence suggests peer interactions may influence attention, motivation, and stress regulation (Wentzel & Caldwell, 1997; Parker & Asher, 1987), only limited empirical work has explored peer-related effects on working memory dynamics specifically (cf., Vandenbroucke et al., 2018).

Peer Relatedness and Working Memory

At the BP level, existing longitudinal evidence suggests that children's peer relationships are systematically linked to their working memory performance over time, such that higher peer relatedness satisfaction was positively associated with working memory performance, while peer-relatedness frustration was negatively associated with working memory performance (de Wilde et al., 2016; Holmes et al., 2016; Lecce et al., 2020). For example, de Wilde and colleagues (2016) found that children with closer relationships to peers showed stronger improvement of working memory performance across time. Holmes and colleagues (2016) similarly observed that early negative peer relationships—characterised by peer rejection and victimisation— predicted later lower working memory performance, and Lecce and colleagues (2020) linked supportive peer contexts to improved working memory performance over the school year. While these studies provide important insights into the BP-level associations between peer relationships and children's working memory, they relied on

third-party reports of students' popularity, using peer nominations or teacher ratings (e.g., Coie et al., 1982; Asher & Dodge, 1986). Such information, however, do not adequately capture children's subjective feelings of inclusion or exclusion, which are particularly relevant because children's own perceptions are more proximally linked to their emotional responses, motivational states, and cognitive engagement than externally assigned social status (Zegers et al., 2006). Consequently, these studies may not provide an accurate reflection of the children's own perceptions.

The WP level has not been considered when examining the impact of peer relatedness on children's WMUP. This is a notable omission, given evidence that both peer experiences and cognitive functioning vary meaningfully from day to day (Nezlek et al., 2015; Schmidt et al., 2020). From a theoretical perspective, daily experiences of acceptance or exclusion may influence WMUP by altering attentional focus, emotional arousal, and the allocation of cognitive resources, such that WMUP may be temporarily enhanced on days of higher relatedness satisfaction and disrupted on days of heightened relatedness frustration (Ellis & Ashbrook, 1988; Neubauer et al., 2019). Investigating these associations at the WP level is therefore crucial for understanding when and why a child's WMUP deviates from their typical level. As a consequence, there remains a critical need to investigate how daily experiences of peer relatedness satisfaction and frustration dynamically influence WMUP and perceived academic success. A WP approach that models daily variation in peer experiences and WMUP is needed to address this gap.

When embedded in research designs that allow for stronger causal inference (e.g., intensive longitudinal or experimental approaches), a WP perspective is essential for identifying how everyday social contexts are linked to momentary cognitive performance states and for informing interventions aimed at optimising daily learning conditions (Bolger & Laurenceau, 2013; Hamaker et al., 2005). Moreover, WP analyses allow for the examination of dynamic coupling between peer relatedness and WMUP within individuals, capturing whether

fluctuations in peer experiences are systematically associated with changes in WMUP that remain invisible at the trait level (Curran & Bauer, 2011; Neubauer et al., 2019).

To date, research examining associations between peer relatedness and working memory has focused almost exclusively on BP level differences. Only few studies have sought to examine these associations, with even fewer research focusing on WMUP. Moreover, as these studies focused almost exclusively on BP differences, they lack the temporal resolution needed to capture how daily fluctuations in peer experiences are linked to cognitive processes. In other words, while they tell us which children generally perform better in working memory tasks, they do not reveal when or why a specific child might perform better or worse on a given day.

Peer Relatedness and Affect

Affect—defined as the experience of positive and negative emotional states such as joy, enthusiasm, sadness, or anger (Russell, 2003)—is closely linked to children's experiences of peer relatedness (Watson & Tellegen, 1985). Peer relatedness has consistently been linked to children's day-to-day emotional experiences, both at the trait and state levels (Herres et al., 2016; Nezlek et al., 2015; Schmidt et al., 2019; 2020; van der Kaap-Deeder et al., 2017).

At the BP level, empirical evidence indicated that peer relatedness satisfaction was positively associated with positive affect (Ladd et al., 2021; King, 2015; Wentzel et al., 2016). More specifically, children who generally experienced higher peer relatedness satisfaction reported greater levels of positive affect, including more frequent feelings of joy, enthusiasm, and contentment during the school day (King, 2015; Wentzel, 2017). They were found to feel more joyful, relaxed, and enthusiastic during the school day, likely because consistent experiences of peer acceptance foster emotional security and social belonging (King, 2015). These positive emotional experiences are thought to arise because stable experiences of peer relatedness satisfaction foster emotional security and a sense of belonging, which in turn support motivation and engagement in academic activities (Ryan & Deci, 2017; Wentzel, 2017). In contrast, peer relatedness frustration has been consistently associated with elevated negative

affect (Emery et al., 2015; Ladd et al., 2021; Rubin et al., 2015). At the BP level, children who typically experienced more peer relatedness frustration showed higher rates of sadness, anger, social withdrawal, and internalising symptoms over time (Ladd et al., 2021; Rubin et al., 2015). In the long term, peer relatedness frustration was associated with a greater prevalence of negative affect, including anxious moods and depressive symptoms (Emery et al., 2015).

Comparable findings have been found at the WP level: fluctuations in peer relatedness satisfaction and frustration have been found to be linked to children's affective states. Initial research showed that on days when students felt more satisfied in their peer relatedness than usual, they tended to report higher levels of positive affect and overall well-being (Schmidt et al., 2020; Lehman & Repetti, 2007). Additionally, peer relatedness frustration was found to predict negative affect. For example, Schmidt and colleagues (2020) found that children reported feeling sadder and more afraid, unhappy, and miserable on days when they felt more excluded by peers than usual. These findings indicate that peer relatedness frustration, even when temporary or subtle, can elicit powerful affective reactions and disrupt children's affective balance in real time. Examining peer relatedness and affect at the WP level thus provides insight into the short-term processes through which social experiences shape children's emotional momentary experiences.

Importantly, prior research indicated that peer relatedness satisfaction and frustration are differentially associated with distinct affective systems. Relatedness satisfaction tends to enhance positive affect by fulfilling the fundamental need for social connection and belonging (Deci & Ryan, 2000; Sheldon et al., 1996), whereas relatedness frustration primarily predicts negative affect, reflecting feelings of exclusion, loneliness, and threat to belonging (Bartholomew et al., 2011; Chen et al., 2015). This distinction suggests that positive and negative affect may operate as separate mediational pathways: satisfaction enhances adaptive emotional states that facilitate cognitive and academic functioning, while frustration evokes maladaptive affective responses that may impair them.

The Mediating Role of Affect

Positive affect has also been consistently associated with beneficial academic outcomes, including greater engagement, persistence, and achievement (King, 2015; Pekrun & Linnenbrink-Garcia, 2012). Extensive research within the control-value theory of achievement emotions demonstrates that positive academic emotions such as enjoyment and enthusiasm are positively linked to motivation, engagement, and achievement across childhood and adolescence (Frenzel et al., 2018; Goetz et al., 2012; Pekrun, 2024). At the WP level, momentary increases in positive affect during learning activities have been shown to predict same-day increases in academic engagement, effort, and perceived competence (Frenzel et al., 2009; Goetz et al., 2013). Consistent with this perspective, positive affect has been identified as a key mechanism linking supportive social contexts to academic success and cognitive functioning, including executive processes such as WMUP (Brose et al., 2012; Neubauer et al., 2019; Pekrun, 2024). Together, these findings suggest that children who consistently experience satisfying peer relations may develop more positive affective dispositions, which in turn foster motivation and promote academic success.

At the WP level, emerging evidence has also begun to clarify how affective states are linked to momentary cognitive performance, particularly executive functioning. Chronic negative emotional states, such as stress or social rejection, have been found to deplete cognitive resources and hinder executive functioning (Ladd et al., 2021; Moran, 2016). From a theoretical perspective, heightened negative affect is assumed to consume attentional resources and increase cognitive load, thereby impairing WMUP and flexible cognitive control, whereas positive affect may broaden attentional scope and support efficient information processing (Eysenck et al., 2007; Fredrickson, 2001). From an empirical perspective, Neubauer and colleagues (2019) demonstrated that momentary fluctuations in affect predicted concurrent variability in WMUP among children. Similar WP coupling between affect and cognitive performance has been observed in daily-life studies, showing that children perform worse on

cognitively demanding tasks on days characterised by higher negative affect and stress (Brose et al., 2012). These results support the view that affective states influence how effectively children process, update, and manage cognitive information in real time. Moreover, day-to-day variations in supportive peer exchanges have been associated with concomitant increases in momentary well-being and school-related motivation. For example, Wang and Eccles (2012) found that adolescents' daily experiences of peer support predicted higher school engagement via school belonging on the same day. Comparable findings from intensive longitudinal research indicate that daily positive affect serves as a proximal predictor of both academic engagement and perceived academic success, suggesting that affective states may act as a short-term mechanism translating social experiences into learning-related outcomes (Goetz et al., 2013). These findings indicate that affective states may explain why children feel and perform better academically on days when they experience higher peer relatedness satisfaction

Taken together, prior evidence supports the idea that affect mediates the relationship between peer relatedness and both cognitive and academic functioning. Specifically, peer relatedness satisfaction may enhance positive affect, which in turn supports children's perceived academic success and cognitive performance, whereas peer relatedness frustration may elicit negative affect that undermines these outcomes. Affect plays a crucial role in shaping learning and cognitive processes. It is not only an important outcome of peer relatedness but may also serve as a key mechanism linking peer relatedness with cognitive and academic functioning.

The Present Study

Peer relatedness is central to children's academic and cognitive functioning as well as their affective well-being. However, the momentary interplay among these factors has remained largely unexplored. The present study addressed this gap by examining how daily peer relatedness satisfaction and frustration are associated with WMUP and perceived academic success. Additionally, the present study explored the role of positive and negative affect as potential mediators of these associations. Both BP and WP level effects were examined, with

the BP level capturing stable interindividual differences and the WP level reflecting day-to-day intraindividual variability, modelled using intensive longitudinal data collected across approximately 20 consecutive school days. The transition period was chosen because it involves substantial changes in peer networks, classroom structure, and learning demands, making it a developmentally sensitive context in which peer-related dynamics and their cognitive and academic consequences may shift (Lorijn et al., 2024).

The dataset used in the present study has been analysed in previous publications. Prior analyses revealed that daily fluctuations in peer relatedness satisfaction and frustration were consistently linked to children's affective well-being (Schmidt et al., 2020, 2021). Specifically, at the BP level, children who generally experienced greater peer relatedness satisfaction also reported higher average positive affect, while those experiencing higher average relatedness frustration showed higher average negative affect. At the WP level, days with higher peer relatedness satisfaction were days with increased positive affect, whereas days with higher peer relatedness frustration were days with increased negative affect. Furthermore, previous analyses on these data indicated that, at the BP level, primary school students with higher average WMUP reported higher perceived academic success at the daily level (Blume et al., 2022). This association was not evident among secondary school students, and WMUP and perceived academic success were unrelated at the WP level in both samples. The following new hypotheses were tested in the present study:

At the WP level, fluctuations in peer relatedness satisfaction were expected to be positively associated with fluctuations in WMUP (H1a) and perceived academic success (H3a), whereas fluctuations in peer relatedness frustration were expected to be negatively associated with fluctuations in WMUP (H2a) and perceived academic success (H4a).

At the BP level, average peer relatedness satisfaction was expected to be positively associated with average WMUP (H1b) and perceived academic success (H3b), whereas average

peer relatedness frustration was expected to be negatively associated with average WMUP (H2b) and perceived academic success (H4b).

At the WP level, the associations between peer relatedness satisfaction and WMUP (H5a) and perceived academic success (H6a) were expected to be mediated by positive affect. The associations between peer relatedness frustration and WMUP (H5b) and perceived academic success (H6b) were expected to be mediated by negative affect.

At the BP level, the associations between peer relatedness satisfaction and WMUP (H5c) and perceived academic success (H6c) were expected to be mediated by positive affect, whereas the associations between peer relatedness frustration and WMUP (H5d) and perceived academic success (H6d) were expected to be mediated by negative affect.

Methods

Participants

Data were drawn from the SASCHA (Social and Academic School Transition Challenges) project, which comprised two ambulatory assessment studies collecting data on children's daily academic and social experiences across the transition from primary to secondary school (DFG Grant no. SCHM 2411/9-1). Study 1 included 90 fourth-grade students (41 boys; aged 9–11 years; 75.6% indicated German as mother tongue) from two German primary schools in the federal state of Hesse, where primary education typically ends after Grade 4. Study 2 included 108 fifth-grade students (48 boys; aged 9–11 years; 83.3% indicated German as mother tongue) from an academic track secondary school in the same state. Four students participated in both studies. Accordingly, Study 1 was conducted at the end of the final year of primary school (Grade 4, immediately before the summer holidays), and Study 2 in the beginning of the first year of secondary school (Grade 5, immediately after the summer holidays).

Recruitment was carried out by contacting schools directly, delivering presentations to school personnel and parents, and obtaining informed parental consent. Prior to the start of the

data collection, the research team provided classroom-based training sessions, giving standardised instructions and demonstrations on how to use the study smartphones. During the assessment period, children completed daily surveys on the smartphones. Parents who completed the baseline questionnaire received a €10 voucher. Children were compensated with up to €40 in vouchers based on compliance (€25 base participation fee and up to €15 in performance-based bonuses). To maintain motivation during the assessment phase, a gamified reinforcement system was implemented. No participants dropped out during the assessment period.

Procedure

Over approximately 28 consecutive days, including weekends, children completed four daily assessments using smartphones provided by the research team. The present investigation focused exclusively on school days, resulting in a total of 20 consecutive school days per participant. The assessments took place in the morning (before school), during school, in the afternoon (after school), and in the evening (before bedtime). WMUP was assessed twice per day, in the morning and in the afternoon. Affective states were assessed at all four daily measurement occasions. Peer relatedness satisfaction and frustration, as well as perceived academic success, were assessed once per day in the evening assessment only. The present investigation analysed data from the afternoon and evening sessions only. Children received reminders to complete self-report questionnaires and WMU tasks on schedule. Each session lasted approximately 5-15 minutes. Assessments were administered via a smartphone app developed for ambulatory assessment studies at the DIPF | Leibniz Institute for Research and Information in Education (Frankfurt/Main). Data were securely transmitted to a central server daily. The study was approved by the ethics committee of the German Psychological Society (DGPs; protocol number FS 092013). The hypotheses and analyses were preregistered in November 2024 in the Open Science Framework (OSF; https://osf.io/twyse/?view_only=375bdac4e7af46b59704b92825b14788). The preregistration

specified the central research question concerning associations between peer relatedness (satisfaction and frustration), affect (positive and negative), WMUP, and perceived academic success, as well as the use of intensive longitudinal data and multilevel modeling to distinguish BP and WP processes. In particular, hypotheses concerning mediation (H5 and H6) were preregistered at a conceptual level, stating that positive and negative affect would mediate the associations between daily peer relatedness and daily WMUP and perceived academic success. In the present work, these preregistered hypotheses were refined and operationalised more explicitly by differentiating satisfaction and frustration components of peer relatedness, by estimating separate mediation models for positive and negative affect, and by testing effects separately at the BP and WP levels and across the two studies. These refinements were theoretically motivated, align with contemporary recommendations for multilevel mediation in intensive longitudinal designs, and served to increase conceptual clarity and interpretability rather than to introduce post hoc hypotheses. All analyses reported as follows are consistent with the preregistered analytic framework, and no unreported deviations from the preregistered plan were made. Where the analytical implementation exceeded the level of specificity provided in the preregistration, this reflected principled elaboration rather than substantive changes to the originally preregistered hypotheses.

Measures

Peer Relatedness Satisfaction and Frustration

Each evening, children reported on their perceived peer relatedness satisfaction and frustration at school using eight items adapted from Schmidt and colleagues (2019). Four items assessed relatedness satisfaction (e.g., “Today, I got along well with the kids in my class”), and four items assessed relatedness frustration (e.g., “Today, someone in my class excluded me”). Responses were provided on a 5-point Likert scale (1 = not at all, 5 = very much). Daily values referred to the child’s reports at each evening assessment, while average scores were calculated as the mean of all available daily values across the four-week study period (cf. Schmidt et al.,

2020). Multilevel confirmatory factor analysis (MLCFA; see Schmidt et al., 2020) on the same data used in the present study confirmed a two-factor structure with adequate factor loadings (Schmidt et al., 2020). The results further indicated that a two-factor model fitted the data better than a one-factor model (Schmidt et al., 2020). At the BP level, Schmidt and colleagues (2020) did not identify significant associations between peer relatedness satisfaction and frustration, neither in Study 1 nor in Study 2 of the present investigation. On the WP level, peer relatedness satisfaction and frustration were positively correlated only in Study 1 (Schmidt et al., 2020). As for the reliability, McDonald's Omega was calculated (Geldhof et al., 2014). Scales showed acceptable reliability both in Study 1 and Study 2 (see Schmidt et al., 2020).

Working Memory Updating

WMUP was assessed in the afternoon using a numerical updating and a spatial updating task.

Numerical WMU Task: In the numerical WMU task (cf. Dirk & Schmiedek, 2016), children completed two load conditions: one with lower memory demands (Load 3) and one with higher demands (Load 4), each consisting of four trials. At the start of each trial, three (Load 3) or four (Load 4) single-digit numbers (ranging from 0 to 9) were displayed horizontally at the top of the smartphone screen for 3,000 ms. Each number field was paired with a small object (e.g., a candy), and participants were instructed to imagine a bag containing the same quantity of those objects. Following a 250 ms inter-stimulus interval (ISI), participants performed a series of mental arithmetic subtraction or addition operations. The number of operations varied, ranging from 3 to 20 updates, depending on the load condition that simulated adding or removing objects from the bag. Each trial contained Load + 1 updating operations — that is, 4 updating operations in the Load 3 condition and 5 updating operations in the Load 4 condition — and across a given trial each field was updated at least once (in the higher-load condition one field was updated twice). These operations were cued by presenting a plus or minus sign followed by a number,1 or 2, in one of the number fields for 1,500 ms. The design

ensured that every field was updated at least once. All results remained positive and ≤ 9. At the end of each trial, children had up to 20,000 ms to enter the updated quantities into the respective fields.

Spatial WMU Task: The spatial WMU task (cf. Dirk & Schmiedek, 2016) involved remembering and updating the locations of colourful cartoon characters (items) in a 4 × 4 grid. Similar to the numerical task, children completed four trials in two load conditions: Load 2 (tracking two items) and Load 3 (tracking three items). During the encoding phase, the relevant items were shown at different 4 × 4 grid locations for 3,000 ms. Then, updating cues appeared sequentially in the center of the screen for 1,500 ms each, separated ISIs of 250 ms each. The number of updating cues per trial equalled the number of updates (i.e., three updating cues in the Load 2 condition and four updating cues in the Load 3 condition). Each cue consisted of a coloured arrow matching one of the items, along with the item's image, indicating the direction (horizontal, vertical, or diagonal) in which that item should be mentally moved. No item was updated consecutively, and start and end positions always differed. Following the updates, children were prompted to retrieve the final positions of the items by tapping on the grid, with a maximum response time of 20,000 ms per trial. For each assessment, up to 20 responses were recorded (8 for Load 2, 12 for Load 3). As with the numerical task, responses were coded as 1 (correct) or 0 (incorrect), and an accuracy score for spatial WMU was computed.

Only sessions in which children responded to at least one trial in each condition were included. Accuracy scores were averaged across load levels for each task, and a WMU composite score was computed by averaging the two task scores. MLCFAs supported the factorial validity of the WMU measurement model, indicating that task-specific indicators loaded on a common latent WMU factor at both the BP and WP levels, while allowing for task-specific residual variance, and indicated adequate factor loadings (see Blume et al., 2022; Dirk & Schmiedek, 2016; Galeano-Keiner et al., 2022). Reliability was acceptable at the BP level in both studies, comparably low at the WP level for Study 1, and acceptable for Study 2 of the

present investigation (see Blume et al., 2022; Dirk & Schmiedek, 2016; Galeano-Keiner et al., 2022).

Affect

Children's affect was assessed using seven items adapted from the Child Affect Measure (Leonhardt et al., 2016) which is based on the Positive and Negative Affect Schedule (PANAS; Watson et al., 1988) but adapted for use with elementary school children. Three items measured positive affect (PA; e.g., "Right now, I feel good"), and four measured negative affect (NA; e.g., "Right now, I feel miserable"). Items were rated on a 5-point Likert scale (0 = strongly disagree, 5 = strongly agree). Daily values referred to the child's reports at each afternoon assessment, while average scores were calculated as the mean of all available afternoon daily values across the four-week study period (cf. Schmidt et al., 2020). In previous studies, MLCFAs supported a two-factor structure distinguishing PA and NA at both the WP and BP levels, with items loading substantially on their respective latent factors and minimal cross-loadings (see Leonhardt et al., 2016). This factorial structure indicates that PA and NA represent related but distinct affective dimensions that can be meaningfully examined at both levels of analysis. This factor structure implied the existence of systematic common variance, thereby justifying the computation of scale means across the items. Internal consistency on the BP and WP levels was acceptable across all assessments (see Schmidt et al., 2020).

Perceived Academic Success

Children completed three items assessing perceived academic success at school (e.g., "Today I solved a difficult task in class"). Responses were rated on a 5-point Likert scale (0 = strongly disagree, 5 = strongly agree). Daily values referred to the child's reports at each evening assessment, while average scores were calculated as the mean of all available daily values across the four-week study period (cf. Blume et al. 2022). An MLCFA confirmed significant factor loadings of the three items on one factor for both studies (see Neubauer et al., 2019). Reliability was adequate for both Study 1 and Study 2 (see Neubauer et al., 2019).

Statistical Analyses

The study employed an ambulatory assessment design. The data had a nested data structure, with repeated daily assessments (Level 1) nested within children (Level 2). Observed data were decomposed into BP and WP components. Variables assessed at the daily level were centred on person means, thereby reflecting daily deviations from the individual mean. Individual mean scores were grand-mean centred, thereby reflecting deviations from the sample means. The effects of time-varying predictors are therefore estimates of pure WP effects, and the effects of time-invariant predictors are estimates of pure BP effects (Wang & Maxwell, 2015). Identical instruments, procedures, and models were applied across Study 1 and Study 2. All models described below were run separately for both studies. All analyses were conducted in M*plus* 8.11 (Muthén & Muthén L., 2023) using Bayesian multilevel modelling. Default noninformative priors were used for all parameters. Estimation was based on 3,000 Markov Chain Monte Carlo (MCMC) iterations (50% burn-in, thinning factor = 50) with two parallel chains. Convergence was assessed via potential scale reduction (PSR < 1.05) and visual inspection of trace and autocorrelation plots. Statistical significance was determined based on whether the 95% Bayesian credible interval (CI) included zero. In addition to CIs, Bayesian *p*-values (i.e., the posterior probability that the parameter differs from zero; $p < .05$ is considered significant) are reported in tables and figures for transparency and comparability with previous research conventions. These *p*-values should be interpreted descriptively rather than as strict thresholds for significance.

Direct Effects Models

To test hypotheses H1 to H4, multilevel models were fitted with daily and average peer relatedness satisfaction and peer relatedness frustration as the independent variables, and WMUP and perceived academic success as dependent variables in separate models. This approach allowed examination of the combined effects of peer relatedness satisfaction and frustration on the dependent variables. In total, two models were estimated per study, one for

WMUP and one for perceived academic success as the dependent variables, resulting in four models across Study 1 and Study 2. The formal model description included child j's WMUP and perceived academic success on day d, where RELSAT = peer relatedness satisfaction, RELFRU = peer relatedness frustration, j = child, d = day, and the subscript ". ." denotes the grand mean.

Hypotheses H1-H4 were tested with the following multilevel model:

Level 1:

$$WM/AS_{dj} = \beta_{oj} + \beta_{1j}\left(RELSAT_{dj} - RELSAT_{.j}\right) + \beta_{2j}\left(RELFRU_{dj} - RELFRU_{.j}\right) + \varepsilon_{dj}$$

Level 2:

$$\beta_{oj} = \gamma_{00} + \gamma_{01}\left(RELSAT_{.j} - RELSAT_{..}\right) + \gamma_{02}\left(RELFRU_{.j} - RELFRU_{..}\right) + u_{0j}$$

$$\beta_{1j} = \gamma_{10} + u_{1j}$$

$$\beta_{2j} = \gamma_{20} + u_{2j}$$

With WM_{dj} being the WMUP of child j on day d, $RELSAT_{dj}$/$RELFRU_{dj}$ the peer relatedness satisfaction/frustration of child j on day d, $RELSAT_{.j}$/$RELFRU_{.j}$ the average peer relatedness satisfaction/frustration of child j across all assessments, and the subscript ". ." the grand mean of peer relatedness satisfaction/frustration. β_{oj} is a child-specific intercept, for which individual differences are explained by a linear combination of a mean intercept γ_{00} (fixed effect) and effects of the individual deviation of relatedness satisfaction and relatedness frustration from the grand mean (γ_{01} and γ_{02}) and a residual term u_{0j} (random effect). β_{1j} is the child-specific coefficient for the effect of within-child fluctuations in relatedness satisfaction, for which individual differences are distributed around a mean γ_{01} (fixed effect) with individual deviations u_{1j} (random effect).β_{2j} is the child-specific coefficient for the effect of within-child fluctuations in relatedness frustration, for which individual differences are distributed around a mean γ_{02} (fixed effect) with individual deviations u_{2j} (random effect).

CHAPTER 6

Mediation Models

To test H5 and H6, two-level mediation models were estimated. These models simultaneously captured BP and WP associations, and accounted for individual variability in peer relatedness, affect, WMUP, and perceived academic success, and the strength of associations between constructs (Preacher et al., 2010). The independent variables were peer relatedness satisfaction and frustration, the mediators were positive and negative affect, and the dependent variables were WMUP and perceived academic success. Accordingly, four distinct models were tested per study: (1) peer relatedness satisfaction → positive affect → WMUP , (2) peer relatedness frustration → negative affect → WMUP, (3) peer relatedness satisfaction → positive affect → perceived academic success, and (4) peer relatedness frustration → negative affect → perceived academic success. Figures 1 and 2 illustrate these mediation models graphically.

Figure 4

Peer Relatedness Satisfaction → Positive Affect→ WMUP/ Perceived Academic Success

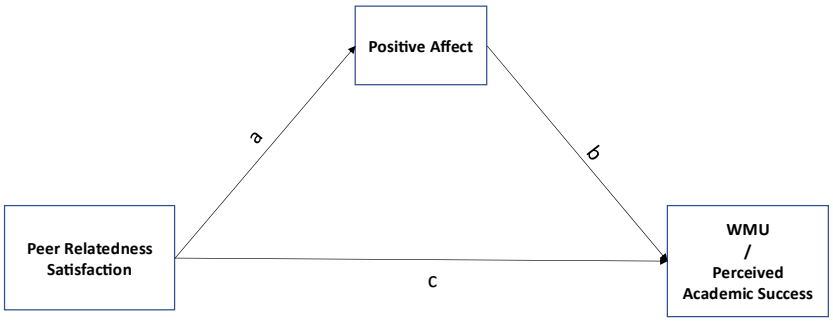
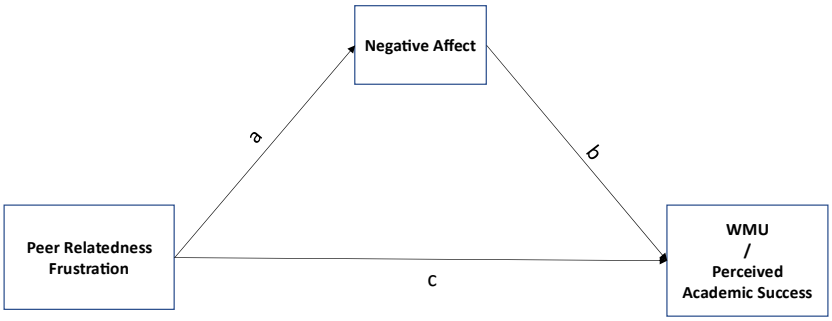


Figure 2

Peer Relatedness Frustration → Negative Affect→ WMUP/ Perceived Academic Success



Each model included both WP and BP paths and random slopes for all WP effects. We ran each of these four mediation models separately for Study 1 and Study 2 (eight mediation models in total). This approach allowed us to evaluate both direct effects of peer relatedness satisfaction or frustration on WMUP and perceived academic outcomes, and indirect effects mediated by positive and negative affect. Random slopes were estimated for all WP effects. The multilevel mediation model included: (1) a-paths representing the effect of peer relatedness satisfaction on positive affect and the effect of peer relatedness frustration on negative affect, (2) b-paths for the effect of positive and negative affect on WMUP and perceived academic success, and (3) c-paths for the direct effect of peer relatedness satisfaction and frustration on WMUP and perceived academic success. Indirect effects at the WP level were calculated as aw*bw + cov(aw, bw), where aw represents the WP effect of peer relatedness satisfaction or frustration on positive or negative affect, and bw represents the WP effect of positive or negative affect on WMUP or perceived academic success. This method of calculating indirect effects

follows the approach used in multilevel modelling frameworks for mediation analyses (Preacher et al., 2010). Total effects were the sum of the direct and indirect effects. At the BP level, indirect effects were calculated as ab*bb, with ab as the BP effect of peer relatedness satisfaction or frustration on positive or negative affect, and bb as the BP effect of positive or negative affect on WMUP and perceived academic success. The total effect was the sum of the direct and indirect effects. Effect sizes are reported as standardised regression coefficients (β) at both the BP (average) and WP (daily) levels; following Irmer and Schmiedek (2023), we present β with 95% credible intervals to indicate the proportion of variance explained at each level. As a heuristic for interpreting standardised coefficients, we loosely follow conventional benchmarks (β ≈ .10 small, ≈ .30 medium, ≈ .50 large), but we emphasise contextual interpretation via the 95% credible intervals rather than strict cut-offs. For all models, posterior predictive *p*-values (PPP) near .50 were considered indicative of adequate fit. No data exclusions were applied at the participant level. Missing item responses were handled using full Bayesian estimation with latent variables to preserve uncertainty and improve inference robustness.

Results

Descriptive statistics, intraclass correlations (ICCs), and observed ranges for each study variable are reported in Table 1. Across both studies, children reported higher levels of peer relatedness satisfaction and comparatively lower levels of peer relatedness frustration. Positive affect was generally high, whereas negative affect was low. Perceived academic success showed moderately high average ratings. Decomposing the variance using ICCs showed substantial WP variability, in peer relatedness, affect, WMUP, and perceived academic success.

Table 1

Descriptive Statistics, Intraclass Correlations, and Ranges for Study Variables in Study 1 and Study 2

Variable	Study	*M*	*SD*	ICC	Range
Relatedness Frustration	1	2.07	1.39	.43	1–5
	2	2.09	1.37	.43	1–5
Relatedness Satisfaction	1	3.84	1.29	.41	1–5
	2	3.96	1.16	.45	1–5
Positive Affect	1	3.91	1.29	.44	1–5
	2	3.85	1.23	.36	1–5
Negative Affect	1	1.85	1.26	.36	1–5
	2	2.00	1.28	.37	1–5
WMUP	1	0.61	0.34	.49	0–1
	2	0.81	0.28	.53	0–1
Perceived Academic Success	1	3.86	1.34	.47	1–5
	2	3.95	1.18	.40	1–5

Note. M = Mean, SD = Standard Deviation, ICC = Intraclass Correlation Coefficient. WMUP = Working Memory Updating Performance

Table 2 presents the intercorrelations of the study variables of interest for both Study 1 and Study 2. At the BP level, peer relatedness satisfaction was positively associated with positive affect and perceived academic success in Study 1. Additionally, peer relatedness satisfaction was negatively associated with peer relatedness frustration. Peer relatedness frustration was positively correlated with negative affect and negatively with positive affect and WMUP. In Study 2, peer relatedness satisfaction was positively associated with perceived academic success and WMUP. Additionally, WMUP was positively associated with positive affect. Moreover, perceived academic success was positively related to positive affect. Overall, the pattern of positive and negative associations, as well as the numerical values, were quite similar across Studies 1 and 2, with the differences in significance largely driven by statistical cutoffs rather than substantial variation in effect sizes.

At the WP level, peer relatedness satisfaction was positively associated with positive affect and perceived academic success in Study 1. Peer relatedness frustration was positively associated with negative affect and negatively with positive affect. Positive affect was negatively correlated with negative affect. In Study 2, WMUP was positively linked to positive affect and peer relatedness satisfaction.

Table 2

Between-person and within-person correlations among study variables for Study 1andStudy 2

	1	2	3	4	5	6
1. Peer relatedness satisfaction	—	-.32/-.34	**.28**/.31	-.06/-.05	.07/**.08**	**.22**/.24
2. Peer relatedness frustration	**-.45**/-.47	—	**-.05**/-.06	**.34**/.36	-.04/-.03	-.07/-.05
3. Positive affect	**.56**/.59	**-.08**/-.07	—	**-.09**/-.10	.05/**.07**	.18/.20
4. Negative affect	-.05/-.04	**.51**/.54	-.09/-.10	—	-.03/-.02	-.06/-.05
5. WMUP	.07/**.08**	-.**04**/-.03	.12/**.14**	-.03/-.02	—	.09/.10
6. Perceived academic success	**.48**/**.50**	-.07/-.05	.42/**.45**	-.06/-.05	.09/.10	—

Note. Values below the diagonal represent between-person (BP) correlations, values above the diagonal represent within-person (WP) correlations. Study 1 and Study 2 values are presented as Study 1 / Study 2. WMUP = working memory updating performance. $p < .05$ are highlighted in bold.

CHAPTER 6

Direct Effects Models: Peer Relatedness Effects on WMUP

Table 3 summarises the multilevel model testing hypotheses H1a, H1b, H2a, and H2b. At the BP level, results for the effects of peer relatedness satisfaction on WMUP showed that peer relatedness satisfaction was not significantly associated with WMUP in Study 1. This indicates that children who, on average, reported higher peer relatedness satisfaction did not reliably show higher WMUP. In contrast, higher average peer relatedness frustration was significantly negatively associated with WMUP, indicating that children who generally reported higher peer relatedness frustration across the study period showed lower WMUP. At the WP level, peer relatedness satisfaction was not significantly related to daily WMUP, reflecting that on days when children reported more peer relatedness satisfaction than usual, they did not show higher WMUP. In contrast, daily peer relatedness frustration was significantly negatively linked to WMUP, suggesting that on days when children reported more peer relatedness frustration than usual, they showed lower WMUP. The BP model accounted for 13.8% of the variance, while the WP model accounted for 20.5% of the day-to-day variance in WMUP.

For Study 2, at the BP level, neither peer relatedness satisfaction nor peer relatedness frustration were significantly associated with WMUP, showing that children who, on average, reported higher or lower levels of peer relatedness satisfaction or frustration did not differ significantly in WMUP. At the WP level, neither daily peer relatedness satisfaction nor peer relatedness frustration were significantly associated with daily WMUP. The findings thus indicate neither feeling socially included and connected nor feeling excluded and rejected by classmates was linked to WMUP daily. The BP model explained 6.4% of the variance, while the WP model accounted for 17.9% of the variance in WMUP.

Table 3

Multilevel model results for the associations between peer relatedness satisfaction and frustration with WMUP (Study 1/ Study 2).

	Null Model			Full Model		
	Est.	95% CI		*Est.*	95% CI	
		LL	*UL*		*LL*	*UL*
WMUP (BP)	0.893 / 0.040	—	—	0.755 / 0.037	—	—
WMUP (WP)	1.785 / 0.079	—	—	1.419 / 0.050	—	—
Peer relatedness satisfaction (BP)	—	—	—	0.147 / 0.024	–0.102 / –0.228	0.379 / 0.289
Peer relatedness satisfaction (WP)	—	—	—	0.017 / –0.005	–0.060 / –0.073	0.086 / 0.062
Peer relatedness frustration (BP)	—	—	—	**–0.312 /** –0.209	–0.529 / –0.460	–0.052 / 0.060
Peer relatedness frustration (WP)	—	—	—	**–0.081 /** –0.042	–0.155 / –0.105	–0.003 / 0.020
R^2 (within)		-			0.205 / 0.179	
R^2 (between)		-			0.138 / 0.064	

Note. Standardized coefficients are reported. Unstandardized estimates are available in the Supplementary Materials. WMUP = working memory updating performance. BP = between-person; WP = within-person. $p < .05$ are highlighted in bold. R^2 = proportion of BP/WP variance in WMUP explained by the predictors.

.

CHAPTER 6

Direct Effects Models: Peer Relatedness Effects on Perceived Academic Success

Table 4 presents the multilevel models testing hypotheses H3a, H3b, H4a, and H4b. At the BP level, peer relatedness satisfaction was positively associated with perceived academic success in Study 1. That is, children who, on average, reported higher peer relatedness satisfaction also perceived themselves as more academically successful. In contrast, peer relatedness frustration was not significantly associated with perceived academic success, showing that children who generally experienced higher frustration of their need for relatedness did not perceive themselves as less academically successful. At the WP level, peer relatedness satisfaction was positively associated with perceived daily academic success. That is, on days when children felt that their need for relatedness was more satisfied by their peers than usual, they also perceived themselves as more academically successful. The model explained 79.4% of the BP variance and 34.6% of the WP variance in daily perceived academic success.

Results for Study 2 showed that, at the BP level, both peer relatedness satisfaction and peer relatedness frustration were significantly positively associated with perceived academic success. The findings thus indicate that children who experienced higher average peer relatedness satisfaction or frustration reported greater perceived academic success. At the WP level, daily peer relatedness satisfaction was significantly positively associated with daily perceived academic success. Thus, children perceived themselves as more academically successful on days when their peer relatedness satisfaction was higher than usual. Daily peer relatedness frustration was not significantly linked with daily perceived academic success. The model explained 64.7% of the BP variance and 30.2% of the WP variance in daily perceived academic success.

Table 4

Multilevel model results for the associations between peer relatedness satisfaction and frustration with perceived academic success (Study 1/ Study 2).

	Null Model			Full Model		
	Est.	95% CI		*Est.*	95% CI	
		LL	*UL*		*LL*	*UL*
Perceived academic success (BP)	0.338 / 0.438	—	—	—	—	—
Perceived academic success (WP)	0.638 / 0.693	—	—	—	—	—
Peer relatedness satisfaction (BP)	—	—	—	**0.888** / **0.774**	0.796 / 0.661	0.942 / 0.860
Peer relatedness satisfaction (WP)	—	—	—	**0.453** / **0.428**	0.384 / 0.372	0.511 / 0.477
Peer relatedness frustration (BP)	—	—	—	0.030 / **0.195**	–0.112 / 0.042	0.171 / 0.344
Peer relatedness frustration (WP)	—	—	—	0.042 / 0.011	–0.017 / –0.042	0.099 / 0.062
R^2 (within)		-			0.346 / 0.302	
R^2 (between)		-			0.794 / 0.647	

Note. Standardized coefficients are reported. Unstandardized estimates are available in the Supplementary Materials. WMUP = working memory updating performance. BP = between-person; WP = within-person. $p < .05$ are highlighted in bold. R^2 = proportion of BP/WP variance in WMUP explained by the predictors.

CHAPTER 6

Mediation Effects of Affect in the Association Between Peer Relatedness and WMUP

Positive Affect as a Mediator

Table 5 presents the results of the multilevel mediation model aimed to test whether positive affect mediated the association between peer relatedness satisfaction and WMUP (H5a, H5c).

Table 5

Results of multilevel mediation analyses testing positive affect as a mediator of the association between peer relatedness satisfaction and WMUP

Effect	Path a	Path b	Direct Effect	Total Effect	Indirect Effect
Between-person					
Peer satisfaction → WMUP (Study 1)	**0.865 [0.773, 0.922]**	−0.291 [−0.810, 0.223]	**0.519 [0.000, 1.040]**	**0.076 [0.011, 0.145]**	−0.070 [−0.204, 0.054]
Peer satisfaction → WMUP (Study 2)	**0.801 [0.698, 0.873]**	−0.028 [−0.418, 0.373]	0.183 [−0.207, 0.570]	0.031 [−0.010, 0.072]	−0.004 [−0.063, 0.056]
Within-person					
Peer satisfaction → WMUP (Study 1)	**0.270 [0.203, 0.335]**	0.044 [−0.030, 0.119]	0.009 [−0.071, 0.089]	0.015 [−0.008, 0.038]	**0.012 [0.000, 0.027]**
Peer satisfaction → WMUP (Study 2)	**0.267 [0.208, 0.325]**	−0.002 [−0.062, 0.062]	0.006 [−0.068, 0.081]	0.004 [−0.024, 0.031]	0.002 [−0.008, 0.013]

Note. Table shows standardized parameter estimates (β) and their 95% credible intervals in brackets. Effects whose 95% credible interval does not include zero are highlighted in bold. Path a represents the association between peer relatedness satisfaction and positive affect; path b represents the association between positive affect and working memory updating performance (WMUP). Direct effects represent the association between peer relatedness satisfaction and WMUP controlling for positive affect.

At the BP level, the results showed a significant association between average peer relatedness satisfaction over the study period with positive affect in Study 1. That is, children who generally experienced higher peer relatedness satisfaction also reported more positive affect. However, average positive affect over the study period was not significantly linked to WMUP. Therefore, the indirect effect was not significant, indicating that children who generally reported higher peer relatedness satisfaction also reported higher positive affect, but this did not account for differences in their WMUP. Notably, the direct effect from average peer satisfaction to average WMUP was significant, as was the total effect. The findings thus reflect that children with higher overall peer relatedness satisfaction also showed higher WMUP, although this effect was not accounted for by higher positive affect. At the WP level, daily peer relatedness satisfaction was positively associated with positive affect. That is, on days children reported higher peer relatedness satisfaction than usual, they also reported higher positive affect. However, daily positive affect was not significantly linked to WMUP on the same day. Although children reported higher positive affect on days when they experienced higher peer relatedness satisfaction than usual, these fluctuations in affect were not related to higher WMUP. The indirect effect via positive affect was not statistically significant. Likewise, the direct association between peer relatedness satisfaction and WMUP, as well as the total effect, was non-significant. Thus, the results did not support either a direct or an indirect within-day link between daily peer relatedness satisfaction and daily WMUP in Study 1.

In Study 2, at the BP level, children with higher overall peer relatedness satisfaction again reported higher positive affect; however, positive affect was not associated with WMUP. The indirect effect was not significant, nor were the direct or total effects. Thus, although children with generally higher peer relatedness satisfaction experienced higher positive affect across the study, these average differences in affect were not related to WMUP. At the WP level, children reported higher positive affect on days with higher than average peer relatedness satisfaction, but positive affect was not associated with daily WMUP, and the indirect effect

was non-significant. No significant direct or total effects emerged. This pattern suggests that, similar to Study 1, children experienced higher positive affect on days with higher peer relatedness satisfaction, yet these day-to-day affective variations were not linked to their WMUP.

Negative Affect as a Mediator

Table 5 shows the results of the multilevel mediation model testing whether negative affect mediated the association between peer relatedness frustration and WMUP (H5b, H5d).

Table 6

Results of multilevel mediation analyses testing negative affect as a mediator of the association between peer relatedness frustration and WMUP

Effect	Path a	Path b	Direct Effect	Total Effect	Indirect Effect
Between-person					
Peer frustration → WMUP (Study 1)	**0.829 [0.719, 0.902]**	−0.166 [−0.588, 0.302]	−0.146 [−0.595, 0.274]	**−0.075 [−0.133, −0.019]**	−0.035 [−0.133, 0.066]
Peer frustration → WMUP (Study 2)	**0.914 [0.853, 0.953]**	−0.240 [−0.908, 0.422]	−0.118 [−0.765, 0.553]	**−0.053 [−0.087, −0.020]**	−0.034 [−0.138, 0.063]
Within-person					
Peer frustration → WMUP (Study 1)	**0.213 [0.143, 0.282]**	**−0.121 [−0.203, −0.034]**	−0.042 [−0.125, 0.040]	−0.020 [−0.044, 0.005]	−0.009 [−0.022, 0.004]
Peer frustration → WMUP (Study 2)	**0.264 [0.209, 0.319]**	**−0.067 [−0.134, −0.004]**	−0.048 [−0.115, 0.021]	**−0.017 [−0.036, −0.002]**	−0.005 [−0.016, 0.006]

Note. Table shows standardized parameter estimates (β) and their 95% credible intervals in brackets. Effects whose 95% credible interval does not include zero are highlighted in bold. Path a represents the association between peer relatedness frustration and negative affect; path b represents the association between negative affect and working memory updating performance (WMUP). Direct effects represent the association between peer relatedness frustration and WMUP controlling for negative affect.

In Study 1, at the BP level, average peer relatedness frustration over the study period was positively linked to negative affect. That is, children who generally reported higher peer relatedness frustration also reported higher average negative affect. However, negative affect was not associated with WMUP, and the indirect and direct effects were not significant. The total effect was significant. At the WP level, daily peer relatedness frustration was significantly associated with daily negative affect, indicating that children reported higher negative affect on days when they experienced greater peer relatedness frustration than usual. Daily negative affect was, in turn, significantly linked to lower WMUP on the same day. Nevertheless, the direct and the indirect effects between daily peer relatedness frustration and daily WMUP were not statistically significant. The total effect was not significant either.

In Study 2, at the BP level, average peer relatedness frustration was positively associated with negative affect. That is, children who experienced higher average peer relatedness frustration over the study period also reported greater negative affect. Average negative affect was not significantly related to WMUP. Consequently, the indirect and direct effects were not statistically significant, but the total effect was significant. At the WP level, daily peer relatedness frustration was significantly positively linked to daily negative affect, indicating that children reported higher negative affect on days when they experienced higher peer relatedness frustration. Daily negative affect was significantly negatively associated with WMUP, such that WMUP tended to be lower on days with more negative affect. The indirect and direct effects were not significant, but the total effect was significant.

Mediation Effects of Affect in the Association Between Peer Relatedness and Perceived Academic Success

Positive Affect as a Mediator

Table 7 shows the results of the multilevel mediation model testing whether positive affect mediated the association between peer relatedness satisfaction and perceived academic success (H6a, H6c).

Table 7

Results of multilevel mediation analyses testing positive affect as a mediator of the association between peer relatedness satisfaction and perceived academic success

Effect	Path a	Path b	Direct Effect	Total Effect	Indirect Effect
Between-person					
Peer satisfaction → perceived academic success (Study 1)	**0.868 [0.778, 0.925]**	0.109 [−0.183, 0.403]	**0.788 [0.484, 1.056]**	**0.999 [0.853, 1.146]**	0.105 [−0.181, 0.404]
Peer satisfaction → perceived academic success (Study 2)	**0.802 [0.698, 0.871]**	**0.527 [0.321, 0.725]**	**0.394 [0.185, 0.591]**	**0.789 [0.659, 0.923]**	**0.406 [0.238, 0.600]**
Within-person					
Peer satisfaction → perceived academic success (Study 1)	**0.270 [0.203, 0.335]**	**0.182 [0.116, 0.246]**	**0.418 [0.347, 0.484]**	**0.489 [0.384, 0.598]**	**0.049 [0.013, 0.090]**
Peer satisfaction → perceived academic success (Study 2)	**0.263 [0.201, 0.320]**	**0.111 [0.059, 0.165]**	**0.436 [0.381, 0.487]**	**0.505 [0.412, 0.592]**	0.028 [−0.012, 0.070]

Note. Table shows standardized parameter estimates (β) and their 95% credible intervals in brackets. Effects whose 95% credible interval does not include zero are highlighted in bold. Path a represents the association between peer relatedness satisfaction and positive affect; path b represents the association between positive affect and perceived academic success. Direct effects represent the association between peer relatedness satisfaction and perceived academic success controlling for positive affect.

In Study 1, at the BP level, children who on average reported higher peer relatedness satisfaction also reported higher positive affect, but positive affect was not significantly associated with perceived academic success. Consequently, the indirect effect was not significant. The direct effect from average peer satisfaction to perceived academic success was significant, and the total effect was also significant. At the WP level, children reported higher positive affect on days when they felt higher peer relatedness satisfaction than usual. Peer relatedness satisfaction was significantly associated with positive affect, and positive affect, in turn, was significantly positively linked to perceived academic success. The indirect effect was significant, indicating that positive affect partially explained the day-to-day association between peer relatedness satisfaction and perceived academic success. The direct effect from daily peer relatedness satisfaction to academic success remained significant, as did the total effect, suggesting that peer relatedness satisfaction is associated with perceived academic success both directly and indirectly through positive affect.

In Study 2, at the BP level, children who on average experienced higher peer relatedness satisfaction also reported higher positive affect, which was significantly related to greater perceived academic success. The indirect, direct and total effects were significant, indicating that positive affect partially mediated the association between peer relatedness satisfaction and perceived academic success. At the WP level, children reported higher positive affect on days with greater peer relatedness satisfaction, and positive affect was significantly positively associated with perceived academic success. The indirect effect was not significant, suggesting that day-to-day variation in positive affect did not significantly mediate the association between peer relatedness satisfaction and perceived academic success. However, the direct and total effects were significant.

Negative Affect as a Mediator

Table 8 reports the results of the multilevel mediation model aimed to test whether negative affect mediated the association between peer relatedness frustration and perceived academic success (H6b, H6d).

Table 8

Results of multilevel mediation analyses testing negative affect as a mediator of the association between peer relatedness frustration and perceived academic success

Effect	Path a	Path b	Direct Effect	Total Effect	Indirect Effect
Between-person					
Peer frustration → Academic success (Study 1)	**0.827 [0.711, 0.900]**	−0.118 [−0.533, 0.330]	0.144 [−0.336, 0.622]	0.045 [−0.186, 0.287]	−0.102 [−0.502, 0.303]
Peer frustration → Academic success (Study 2)	**0.914 [0.854, 0.954]**	−0.194 [−0.867, 0.453]	0.263 [−0.378, 0.926]	0.080 [−0.117, 0.280]	−0.159 [−0.734, 0.358]
Within-person					
Peer frustration → Academic success (Study 1)	**0.216 [0.144, 0.286]**	−0.005 [−0.084, 0.070]	**0.139 [0.069, 0.209]**	**0.155 [0.063, 0.244]**	0.014 [−0.026, 0.054]
Peer frustration → Academic success (Study 2)	**0.275 [0.215, 0.326]**	**−0.109 [−0.169, −0.050]**	0.023 [−0.040, 0.086]	0.005 [−0.088, 0.092]	−0.018 [−0.056, 0.021]

Note. Table shows standardized parameter estimates (β) and their 95% credible intervals in brackets. Effects whose 95% credible interval does not include zero are highlighted in bold. Path a represents the association between peer frustration and negative affect; path b represents the association between negative affect and academic success. Direct effects represent the association between peer frustration and academic success controlling for negative affect.

In Study 1, at the BP level, children who reported higher peer relatedness frustration also showed higher negative affect. That is, children who on average experienced more peer relatedness frustration also reported higher negative affect. Negative affect was not significantly related to perceived academic success, and the indirect, direct, and total effects were not significant. These results do not provide support for negative affect to mediate the association between peer relatedness frustration and perceived academic success. At the WP level, daily peer relatedness frustration was positively associated with daily negative affect, indicating that children reported more negative affect on days when they experienced more peer relatedness frustration than usual. Negative affect was not significantly associated with daily perceived academic success. The indirect, direct, and total effects were all non-significant.

In Study 2, at the BP level, average peer relatedness frustration was positively associated with negative affect, indicating that children who reported higher average peer relatedness frustration also reported higher negative affect. Negative affect was not significantly associated with perceived academic success. The indirect, direct, and total effects were all non-significant, suggesting that BP differences in peer relatedness frustration did not explain perceived academic success. At the WP level, daily peer relatedness frustration was significantly positively associated with negative affect, indicating that children reported higher negative affect on days with higher peer relatedness frustration. Daily negative affect was significantly negatively associated with perceived academic success. However, the indirect, direct, and total effects were not significant.

Discussion

The present study aimed to examine how peer relatedness, both satisfaction and frustration, is associated with students' daily cognitive functioning and perceived academic success. Additionally, it examined whether these effects were accounted for by affective experiences. To this end, data from two intensive longitudinal studies were analysed, one conducted at the end of primary school (i.e., Study 1) and the other at the beginning of secondary school (i.e., Study 2).

Peer Relatedness and Cognitive Functioning

Peer Relatedness Satisfaction

At the BP level, peer relatedness satisfaction was not associated with WMUP in either Study 1 or Study 2. This pattern indicates that children and adolescents who, on average, experienced higher peer relatedness satisfaction across the assessment period did not show better overall WMUP compared to their peers. This finding contrasts with theoretical expectations and prior work suggesting that feeling socially included and accepted may be linked to enhanced cognitive functioning during development (e.g., Ryan & Deci, 2017). From a BP perspective, these results suggest that stable interindividual differences in perceived peer relatedness satisfaction may not translate into corresponding differences in executive functioning performance, at least as captured by daily WMUP tasks. Importantly, this lack of association was consistent across the transition from primary to secondary school, indicating that the developmental context did not moderate BP-level relations between peer relatedness satisfaction and WMUP.

Complementing the BP results, WP analyses likewise showed that daily fluctuations in peer relatedness satisfaction were unrelated to same-day WMUP in both Study 1 and Study 2. Thus, on days when students felt more satisfied with their peer relationships than usual, they did not perform better on WMUP tasks than on days characterised by lower-than-usual peer relatedness satisfaction. These WP-level null findings extend prior research by demonstrating that not only stable differences between individuals, but also short-term intraindividual changes in peer relatedness satisfaction, may be largely decoupled from momentary cognitive performance. This adds a novel dynamic perspective, suggesting that increases in daily social satisfaction do not necessarily confer immediate cognitive benefits in demanding executive function tasks.

Taken together, the BP- and WP-level findings indicate that the association between peer relatedness satisfaction and WMUP may not be robust across levels of analysis or developmental stages. One possible explanation is that peer relatedness satisfaction may not elicit sufficient physiological arousal or cognitive alertness to optimize performance on demanding executive tasks.

Classic state regulation theories posit that cognitive performance follows an inverted U-shaped function of arousal, such that both under- and over-arousal impair performance (Yerkes & Dodson, 1908). Similarly, early attentional models suggest that low arousal states may reduce the allocation of attentional resources required for complex cognitive operations (Easterbrook, 1959; Kahneman, 1973). From this perspective, experiences of social satisfaction may reflect a relatively low-arousal, emotionally safe state that does not mobilize the level of cognitive activation needed to enhance WMUP.

An additional, more methodological explanation should also be considered, particularly at the WP level. Daily WM tasks are known to show relatively low WP reliability, which may limit their sensitivity to detect associations with fluctuating predictors (Dirk & Schmiedek, 2016). Thus, the absence of WP-level effects may partly reflect measurement constraints rather than the absence of true dynamic relations between peer relatedness satisfaction and executive functioning (Cranford et al., 2006).

Peer Relatedness Frustration

At the BP level, the findings from Study 1 indicated that children who, on average, experienced higher levels of peer relatedness frustration also showed lower overall WMUP. This pattern is consistent with theoretical expectations and prior evidence suggesting that chronically frustrating peer environments are linked to poorer cognitive functioning (e.g., Lecce et al., 2020). From a resource-based perspective, repeatedly experiencing peer-related frustration may place sustained demands on self-regulatory and executive resources, resulting in lower trait-like levels of cognitive performance (Baumeister et al., 2002). In contrast, this BP association was not observed in Study 2, suggesting that the longer-term linkage between peer relatedness frustration and cognitive functioning may weaken following the transition to secondary school, potentially due to changes in peer contexts, coping strategies, or increasing cognitive autonomy.

At the WP level, Study 1 further demonstrated that elevated daily levels of peer relatedness frustration were associated with concomitant reductions in WMUP, indicating a contemporaneous

coupling between fluctuations in peer experiences and momentary cognitive functioning. This finding extends BP-level evidence by showing that peer-related frustration is not only associated with lower overall cognitive performance but also predicts short-term decrements in WMUP within individuals. Such experiences may elicit immediate processes such as heightened threat vigilance, affective arousal, ruminative thoughts, and attempts to down-regulate negative feelings, which have been shown to draw on the same limited executive resources required for WMUP, including attention allocation, interference control, and updating processes (Eysenck et al., 2007; Joormann & Gotlib, 2008). Because these regulatory demands compete for limited cognitive resources, experiences of peer relatedness frustration are likely to coincide with transient reductions in WMUP. Notably, this WP-level association did not replicate in Study 2, suggesting that momentary cognitive costs of peer-related frustration may be particularly pronounced at the end of primary school, when executive functions are still developing and peer exclusion may be experienced as especially salient and disruptive.

Contrary to expectations and findings from Study 1, results from Study 2 did not show significant associations between peer relatedness frustration and WMUP at either the WP or BP level, although the direction of the numerical estimates was negative. This contrast is particularly noteworthy given that children in Study 2 were only some weeks older than children in Study 1 but had just transitioned to secondary school. This divergence may thus reflect contextual differences between the two cohorts. Study 1 was conducted at the end of primary school, and peer groups can be assumed to be stable and long-standing. During this time, children have typically developed strong affiliative bonds with classmates, and experiences of exclusion may represent as a particularly salient threat to social belonging (Rubin et al., 2015; Eccles, 1999). In contrast, Study 2 was conducted at the beginning of secondary school, when peer groups were newly forming and affiliative bonds were not yet well established. During this transitional period, students encounter a less personalised school environment and must adjust to new academic and social expectations. From the perspective of stage-environment fit theory (Schweder & Raufelder, 2024), these conditions may temporarily reduce the

salience of peer dynamics, as peer interactions are not yet central to students' sense of belonging. Thus, early secondary school may constitute a period in which peer dynamics are less salient than in late primary school. During the transition, students encounter a new and less personalised school environment and are still adjusting to novel academic and social expectations. Consequently, experiences of peer relatedness frustration may have been perceived as less personally meaningful, coinciding with a weaker association between peer relatedness frustration and WMUP.

Peer Relatedness and Perceived Academic Success

Peer Relatedness Satisfaction

At the BP level, findings from both Study 1 and Study 2 supported the assumption that students who, on average, experienced higher levels of peer relatedness satisfaction also reported higher perceived academic success. These results align with prior research suggesting that positive peer relatedness experiences are linked to students' self-perceptions of academic competence (Furrer & Skinner, 2003; Raufelder & Kulakow; 2021; Wentzel, 1998). The consistency of this association across both studies indicates that feeling liked and connected to classmates is robustly related to students' perceived academic success both before and after the transition to secondary school. This is consistent with theories of social development, proposing that peers become increasingly important for children's self-views as they grow older (Brown & Larson, 2009; Laursen & Veenstra, 2021; Ragelienė, 2016; Veenstra & Laninga-Wijnen, 2022; Yu et al., 2023).

At the WP level, both Study 1 and Study 2 further showed that day-to-day increases in peer relatedness satisfaction were associated with higher perceived academic success within individuals. This finding extends BP-level evidence by demonstrating that fluctuations in peer experiences are meaningfully linked to momentary changes in students' academic self-perceptions. Rather than reflecting a developmental intensification of effects across school levels, the similarity of WP-level associations before and after the transition may point to age-related differences in the processes linking peer relatedness and perceived academic success. Specifically, in primary school, peer acceptance may be associated with perceived academic success through emotional security and

teacher-supported belonging, whereas in early secondary school, it may relate more strongly to validation and feedback within newly forming peer groups.

Peer Relatedness Frustration

At the BP level, peer relatedness frustration was unrelated to perceived academic success in Study 1. This null association at the end of primary school may indicate that, at this developmental stage, children's perceived academic success are less strongly shaped by negative peer experiences and more closely tied to feedback from teachers, parents, and formal achievement indicators (Eccles & Wigfield, 2002; Harter, 2015). In primary school, academic success is often evaluated within a more structured and supportive instructional context, in which teachers play a central role in scaffolding students' competence beliefs. As a result, experiences of peer-related frustration may be less likely to generalise into stable academic self-evaluations, even when they occur repeatedly (Nurmi, 2004; Wigfield et al., 2006). Moreover, peer conflicts or frustrations in late primary school may still be perceived as situational and transient, limiting their impact on broader perceived academic success.

Contrasting expectations, peer relatedness frustration and perceived academic success were positively associated in Study 2. One possible explanation is that during this transition to secondary school, peer relations are newly forming, and students may interpret different levels of peer relatedness—whether more satisfied or more frustrated—as indicators of their standing in the academic context. In competitive, academically selective environments, students may focus more strongly on academic achievement and use it as a central point of reference for self-evaluation (Marsh & Hau, 2003; Seaton et al., 2009). Consequently, self-concept may become increasingly tied to academic performance rather than social belonging. High-achieving students might therefore perceive themselves as competent and successful even when peer relatedness satisfaction is lower or frustration higher. Such a pattern would be compatible with the idea that social costs can accompany academic excellence—for instance, when strong academic performance reduces peer popularity or evokes competitiveness within the class (Chen et al., 2009; Rudolph et al., 2007). This interpretation

also aligns with comparative perspectives such as the Big-Fish–Little-Pond effect (Marsh & Parker, 1984; Marsh et al., 2008), which posits that students evaluate their academic competence relative to their class. In high-performing environments, students who perceive themselves as doing well academically may maintain positive self-appraisals even when their sense of peer relatedness is less positive, suggesting that academic self-concept may function as a compensatory resource when social belonging is uncertain.

Contrary to expectations, findings from both Study 1 and Study 2 indicated that peer-relatedness frustration was not associated with perceived academic success at the WP level. This pattern suggests that day-to-day fluctuations in negative peer experiences may not be sufficiently salient or enduring to translate into immediate changes in students' academic self-evaluations (Marsh & Craven, 2006; Bong & Skaalvik, 2003). Perceived academic success likely reflects a more stable, cumulative appraisal of one's competence that integrates longer-term feedback and achievement experiences, rather than momentary social setbacks. Accordingly, while peer-related frustration may exert immediate effects on affective states or cognitive functioning, its influence on academic self-perceptions may unfold more slowly and require sustained exposure (Eccles & Roeser, 2011; Goetz et al., 2012). In addition, students may engage in short-term regulatory or compensatory processes—such as reaffirming academic strengths or attributing peer difficulties to external causes—that buffer their academic self-views against transient negative social experiences (Skinner & Zimmer-Gembeck, 2007; Yeager & Dweck, 2012). Thus, the absence of WP-level associations may reflect the relative stability and resilience of perceived academic success in the face of everyday peer-related stressors.

The Mediating Role of Affect

Peer Relatedness Satisfaction & Working Memory Updating Performance

Contrary to expectations and previous BP level evidence (Isen, 2008; Rowe et al., 2007), affect played only a limited role in linking peer relatedness satisfaction to WMUP. Although peer relatedness satisfaction was positively associated with positive affect at the BP level in both studies, positive affect was unrelated to WMUP. This pattern suggests that stable individual differences in affective

experience, while closely tied to social satisfaction, may not translate into differences in domain-general executive control processes such as WMUP (Diamond, 2013; Miyake & Friedman, 2012). Rather, affective dispositions may be more strongly linked to motivational or well-being outcomes than to performance in neutral cognitive updating tasks. Consistent with control-value theory (Pekrun, 2024), emotions are most likely to influence learning and performance when they are directly tied to task value and perceived control—conditions that may not have been strongly activated in the present WMUP task.

At the WP level, in Study 1, daily peer relatedness satisfaction predicted higher positive affect, yet daily positive affect was not significantly associated with WMUP; in Study 2, similar patterns emerged, with day-to-day increases in peer satisfaction linked to higher positive affect but not to WMUP. This suggests that fluctuations in daily affect may not be strong enough to influence executive functioning, or that children can maintain WMUP performance despite transient affective changes, consistent with evidence that working memory performance shows relative stability across moderate affective fluctuations (Schmeichel et al., 2008).

Peer Relatedness Frustration & Working Memory Updating Performance

At the BP level, according to expectations, in both Study 1 and Study 2, average peer relatedness frustration was linked to higher average negative affect (see Schmidt et al., 2020), but negative affect was not linked to average WMUP. However, as we found average peer relatedness frustration to be linked to lower WMUP, this suggests that chronic peer difficulties may undermine cognitive functioning through other pathways, such as physiological stress or reduced opportunities for engagement, rather than self-reported affect alone (Hostinar et al., 2018). Consistent with the allostatic load framework (McEwen & Morrison, 2013), persistent social stress can produce repeated activation of the HPA axis and sympathetic nervous system, leading over time to cumulative wear and tear on neural circuits supporting executive functions, including the prefrontal cortex. Such chronic activation may dysregulate stress hormone release, impair synaptic plasticity, and reduce neural efficiency in networks critical for WM and attentional control, even when children do not

consciously report heightened negative affect (Lupien et al., 2009; Peper & Dahl, 2013). This pattern aligns with evidence that early and sustained social stress can affect cognitive outcomes via neurobiological mechanisms rather than through immediate subjective experience of affect.

At the WP level, in accordance with expectations, in Study 1 higher daily peer relatedness frustration was linked to higher negative affect (see Schmidt et al., 2020), which in turn was associated with poorer daily WMUP. This supports the idea that negative affect can interfere with WMUP by consuming attentional resources (Schmeichel, 2007; Shields et al., 2016). Negative affect typically narrows cognitive focus and triggers self-referential or ruminative processing (Gotlib & Joormann, 2010), thereby reducing WM capacity (Pe & al., 2013). In Study 2, however, this mediation effect was not significant, possibly reflecting reduced salience of peer relatedness frustration directly after school transition. The developmental shift observed here echoes research suggesting that early adolescence marks a recalibration of social threat sensitivity (Crone & Dahl, 2012), potentially weakening short-term links between social distress and cognitive control immediately after transition.

Peer Relatedness Satisfaction & Perceived Academic Success

We expected that both positive and negative affect would mediate the relationship between peer relatedness and perceived academic success. The results of the mediation analyses provided partial support for this expectation, with evidence for positive affect as a mediator emerging in some cases, while negative affect played no mediating role.

At the BP level in both Study 1 and Study 2, in line with expectations (e.g., Wentzel et al., 2016), children who on average reported higher peer relatedness satisfaction also reported higher positive affect (see Schmidt et al., 2020). However, only in Study 2 positive affect was significantly linked to higher average perceived academic success, yielding a significant indirect effect. This indicates that, at the BP level in early secondary school, children who generally experienced higher peer relatedness satisfaction also tended to report higher positive affect, which in turn was associated with higher overall perceived academic success (van der Kaap-Deeder et al., 2017). This

developmental change might reflect an increasing integration of social and academic self-concepts during early adolescence, as peer relationships become a key source of feedback about one's competence and self-worth (Wentzel et al., 2016; Meeus et al., 2010).

At the WP level, in line with expectations (e.g., van der Kaap-Deeder et al., 2017), peer relatedness satisfaction was consistently associated with higher positive affect in both Study 1 and Study 2 (see Schmidt et al., 2020). In Study 1, positive affect in turn was associated with higher same-day perceived academic success, resulting in a significant indirect effect. This indicates that daily co-variation in positive affect partly accounted for the association between peer relatedness satisfaction and perceived academic success. In Study 2, both constituent paths, from peer relatedness satisfaction to positive affect and from positive affect to perceived success, were significant, but the overall indirect effect was not, suggesting that the day-to-day co-variation was less consistent, or that statistical power was insufficient for the indirect effect to reach significance (MacKinnon et al., 2004). This pattern aligns with prior evidence that positive peer experiences are linked to immediate improvements in mood and engagement, which may coincide with stronger perceptions of competence, although such patterns are not always robust. The link between daily positive affect and perceived competence also resonates with the broaden-and-build theory (Fredrickson, 2001), according to which positive affect broadens cognitive and behavioural repertoires, promoting self-efficacy and mastery appraisals (Caprara et al., 2008). Taken together, these findings suggest that positive affect is a consistent mediator of the link between peer relatedness satisfaction and perceived academic success, even though positive affect played this role only in specific contexts. In late primary school, daily positive affect partly explained why children felt more successful on days with higher peer relatedness satisfaction, while in early secondary school average positive affect accounted for stable differences between children who generally felt more or less satisfied in their need for relatedness.

Peer Relatedness Frustration & Perceived Academic Success

In line with expectations at the BP level in both studies, average peer relatedness frustration was associated with higher average negative affect, but average negative affect was not associated with average perceived academic success. Thus, while children with greater chronic experiences of relatedness frustration reported generally higher negative affect, this affective profile did not translate into differences in how successful they perceived themselves academically. This suggests that the cumulative impact of peer relatedness frustration may shape well-being but does not necessarily undermine children's perceived academic success through affect alone (Ladd et al., 2021; Rubin et al., 2015).

In line with expectations at the WP level, peer relatedness frustration was reliably associated with higher negative affect in both studies. Yet, negative affect only showed a significant association with perceived academic success in Study 2, where higher daily negative affect was linked to lower same-day academic self-perceptions. Nevertheless, the indirect effect was not statistically significant in either study, indicating that although relatedness frustration increases negative affect, these mood fluctuations did not reliably explain children's day-to-day perception of academic success. This suggests that while chronic peer difficulties shape affective well-being, these cumulative mood experiences do not directly undermine children's perceived academic success. Consistent with theoretical accounts of chronic stress and its more distal impact on motivation and self-concept (Dweck, 2017; Ladd et al., 2021), repeated experiences of peer-related frustration may influence longer-term motivational beliefs or learned helplessness patterns, which could in turn affect academic outcomes over extended periods rather than day-to-day self-perceptions. Therefore, negative affect did not significantly mediate associations between peer relatedness frustration and perceived academic success at either level. Overall, these mediation analyses highlight that while peer relatedness strongly shapes children's affect, affect is only one mechanism through which these experiences may translate into perceived academic success, pointing to the importance of considering additional pathways such as motivation, self-efficacy, or social comparison processes (Leary et al.,

1995; Yang et al., 2018). Overall, these mediation patterns illustrate that affect operates as a partial and context-dependent mechanism linking social experiences to self-evaluative outcomes. Beyond mood, motivational constructs such as perceived competence, intrinsic value, and belonging regulation (Elliot et al., 2019; Furrer & Skinner, 2003) may better capture how peer experiences shape academic self-perceptions over time.

Theoretical and Practical Implications

The present findings have several theoretical implications. Specifically, peer relatedness frustration was associated with lower WMUP, whereas peer relatedness satisfaction was more strongly related to perceived academic success. Separately, we observed developmental differences across grades: the negative association between peer relatedness frustration and WMUP was pronounced in Grade 4 but not significant in Grade 5. Conversely, the positive association between peer relatedness satisfaction and perceived academic success was present in both grades, indicating that satisfaction consistently supports academic self-evaluations. This differential pattern is consistent with dual-pathway models of social experience and motivation (Skinner & Pitzer, 2012), which propose that social-emotional experiences can influence outcomes via two distinct routes: the absence of negative experiences helps preserve cognitive resources, while the presence of positive experiences promotes motivation and self-evaluative processes. In the present context, peer frustration may deplete cognitive resources needed for WMUP, whereas peer satisfaction enhances academic self-perceptions by supporting motivational and affective engagement. By examining both BP and WP levels, the present investigation extends multilevel perspectives on socio-emotional influences on cognitive processes (Reyes et al., 2012). Specifically, BP-level findings highlight that children with generally higher peer satisfaction or frustration differ in stable affective and cognitive profiles, reflecting cumulative developmental experiences. WP-level findings demonstrate that day-to-day fluctuations in peer experiences and affect can transiently influence cognitive performance and perceived academic success. This underscores that social-emotional processes operate both as stable traits and as dynamic states, emphasising the importance of integrating longitudinal and intensive

repeated-measures designs to capture these mechanisms in future research. The present results align with interdisciplinary models of learning as inherently social and emotionally embedded (Immordino-Yang & Damasio, 2007). This implies that cognitive and academic outcomes cannot be fully understood without considering the social-affective context, and future research should investigate how neural, affective, and social processes jointly shape learning and academic self-concept across developmental transitions.

Beyond these specific theoretical contributions, the present findings highlight that social relationships in the classroom serve as regulatory contexts associated with children's cognitive capacity and thus their engagement in learning (Pianta et al., 2012). In developmental neuroscience, peer connectedness has been linked to variation in activation of brain regions involved in cognitive control and reward processing (e.g., Crone & Dahl, 2012), indicating that relatedness experiences may be associated with adjustments in cognitive effort and motivational salience in everyday school life.

The present findings have implications for classroom practice at both BP and WP levels. Teachers could benefit from addressing both chronic and daily variations in peer experiences. First, the stronger associations of peer relatedness frustration with WMUP suggest that reducing experiences of peer relatedness frustration may be particularly important for sustaining students' cognitive functioning. At the BP level, classroom-based social–emotional learning programmes that are aimed to enhance empathy, perspective-taking, and prosocial behaviour have been associated with improvements in both peer relationships and academic functioning (Durlak et al., 2011; Oberle et al., 2011). At the WP level, teachers could support this by fostering inclusive classroom environments that proactively identify and address subtle forms of exclusion, such as being ignored or overlooked, that have been found to be associated with cognitive engagement (Juvonen et al., 2000). Experiences of social exclusion or perceived isolation have been linked to vigilance and self-monitoring processes that can tax cognitive resources (Baumeister et al., 2002), underscoring the value of structured cooperative learning activities that promote belonging and shared goals (Johnson & Johnson, 2009).

Second, we found that peer relatedness satisfaction was significantly associated with perceived academic success, indicating that children who felt more satisfied with their peer relationships also perceived themselves as more academically successful. Teachers may therefore benefit from fostering peer encouragement and recognition systems that value not only achievement but also collaboration, effort, and mutual support. Regarding peer encouragement, our findings suggest that fostering peer relatedness satisfaction can enhance perceived academic success. Mastery goal orientations focus on individual learning and competence acquisition rather than performance relative to others (Ames, 1992); therefore, promoting an environment where children aim to understand and improve, rather than outperform peers, aligns with the positive effects of peer relatedness satisfaction on academic self-evaluations.

Finally, educators should recognise peer effects may vary across educational transitions rather than strictly by developmental age. During the transition to secondary school, students may initially focus more on academic adaptation than peer integration, with peer dynamics gaining importance as social networks stabilise. The results suggest that interventions should aim to stabilize peer networks and foster supportive peer interactions early after transitions, rather than delaying. Faster social integration may help children experience higher peer satisfaction, which, in turn, enhances perceived academic success and positive affect, supporting both immediate and cumulative developmental outcomes. In practical terms, programs that combine academic scaffolding with peer mentorship or cooperative goal setting may support students' engagement and confidence during transition (Hamm et al., 2011).

Finally, the mediation findings highlight that positive affect partly explains the link between peer satisfaction and perceived academic success, particularly at the WP level in Grade 4 and at the BP level in Grade 5. This underscores that fostering emotionally supportive peer environments not only improves mood but also strengthens motivation and self-efficacy, suggesting that interventions should simultaneously target social and emotional processes to maximize academic benefits (Elliot et al., 2011; Furrer & Skinner, 2003).

CHAPTER 6

Limitations and Future Directions

While the present investigation offers novel insights into links between peer relatedness, affect, and children's cognitive and academic functioning, several limitations should be acknowledged. First, the observational nature of the design limited the ability to draw causal inferences. Future research could address this limitation by employing intensive longitudinal or short-term intervention designs that are practically feasible, such as daily or weekly within-person manipulations of social experiences that naturally occur in school settings (e.g., structured group activities, cooperative learning tasks), rather than purely experimental paradigms that may be unrealistic in everyday classrooms. For instance, short-term interventions embedded within the school curriculum could vary peer interaction quality or opportunities for inclusion across days or weeks, thereby examining directional associations between social experiences, affect, and cognitive performance in ecologically valid ways (Nezlek, 2012; Mehl & Wrzus, 2021).

Second, although ambulatory assessments offer greater ecological validity than laboratory-based assessments or surveys, the associative patterns between WMUP and other variables should be interpreted with caution given the limited WP reliability of the WMUP task. Additionally, it is important to distinguish between children's remembered versus momentary experiences of self and affect (Barrett, 2006), as our measures rely on evening reports reflecting the day as a whole rather than moment-to-moment cognitive states. Therefore, our interpretations concern associative patterns between WMUP and other variables, not direct task performance effects. Future research should therefore aim to replicate and validate these findings using alternative tasks or longer task series to improve measurement precision.

Third, perceived academic success reflects students' self-appraisals but does not reflect other important academic constructs such as objective achievement or teacher evaluations. While multi-informant assessments at the WP level are challenging, is it possible to include report card grades at the BP level. Future studies could therefore complement self-report perceived academic success with these objective academic indicators to strengthen BP inferences.

Fourth, our sample in Study 2 included only children attending Gymnasium, the academic track of the German school system. As such, the generalisability of the findings to students in intermediate or lower tracks remains unclear. Peer dynamics and academic self-perceptions may differ substantially across these settings. Future research should therefore replicate the study in other school tracks and compare patterns across educational contexts to examine whether the observed associations generalise.

Fifth, relatedness measures were assessed in the evening, although they referred to school-time experiences. Although this timing may have helped children reflect on their full school day and integrate multiple experiences, it also introduces the possibility of retrospective distortion. Furthermore, affect measures were collected in the afternoon and may not precisely capture moment-to-moment fluctuations linked to specific school experiences. Future research could combine in-school momentary assessments of affect and relatedness experiences with evening summaries to enhance temporal precision, reduce reconstruction bias, and disentangle actual momentary experiences from remembered or generalised impressions of the day (Lehman & Repetti, 2007; Feldman Barrett, 2012).

Finally, future research could integrate physiological indicators such as cortisol or heart rate variability to more objectively capture stress-related mechanisms underlying the associations between peer relatedness, affect, and cognitive or academic functioning, thereby complementing subjective reports and addressing limitations of retrospective and aggregated measures.

Conclusion

This study contributes to research on associations between peer experiences and children's functioning in school by distinguishing WP from BP effects. Peer relatedness frustration was consistently associated with lower WMUP, whereas satisfaction was linked to higher perceived academic success. Affect played only a limited mediating role, suggesting that social connections are related to cognition and self-perceptions through multiple pathways. The findings also differed between the end of primary and the beginning of secondary school, indicating that peer dynamics

may be sensitive to educational transitions. Overall, the study highlights the relevance of examining both situational fluctuations and stable differences in peer experiences, and it points to the potential value of fostering positive peer relations as children navigate school transitions.

References

Ames, C. (1992). Classrooms: Goals, structures, and student motivation. Journal of Educational Psychology, 84(3), 261–271.

Asher, S. R., & Dodge, K. A. (1986). Identifying children who are rejected by their peers. *Developmental Psychology, 22*(4), 444–449. https://doi.org/10.1037/0012-1649.22.4.444

Baddeley, A. (2012). Working Memory, Thought, and Action. In *Working Memory, Thought, and Action*. https://doi.org/10.1093/acprof:oso/9780198528012.001.0001

Barrett, L. F. (2006). Are emotions natural kinds?. *Perspectives on psychological science*, *1*(1), 28-58.

Bartholomew, K. J., Ntoumanis, N., Ryan, R. M., Bosch, J. A., & Thøgersen-Ntoumani, C. (2011). Self-determination theory and diminished functioning: The role of interpersonal control and psychological need thwarting. *Personality and Social Psychology Bulletin*, 37(11), 1459–1473. https://doi.org/10.1177/0146167211413125

Baumeister, R. F., & Leary, M. R. (1995). The need to belong: Desire for interpersonal attachments as a fundamental human motivation. *Psychological Bulletin, 117*(3), 497–529.

Baumeister, R. F., Twenge, J. M., & Nuss, C. K. (2002). Effects of social exclusion on cognitive processes: Anticipated aloneness reduces intelligent thought. *Journal of Personality and Social Psychology*, *83*(4). https://doi.org/10.1037/0022-3514.83.4.817

Blume, F., Irmer, A., Dirk, J., & Schmiedek, F. (2022). Day-to-day variation in students' academic success: The role of self-regulation, working memory, and achievement goals. *Developmental Science*, *25*(6). https://doi.org/10.1111/desc.13301

Bolger, N., & Laurenceau, J.-P. (2013). Intensive longitudinal methods: An introduction to diary and experience-sampling research. Guilford Press.

Bong, M., & Skaalvik, E. M. (2003). Academic self-concept and self-efficacy: How different are they really?. *Educational psychology review*, *15*(1), 1-40.

Braver, T. S., Krug, M. K., Chiew, K. S., et al. (2014). Mechanisms of motivation–cognition interaction: Challenges and opportunities. Cognitive, Affective, & Behavioral Neuroscience, 14(2), 443–472.

Bronfenbrenner, U. (2005). Making human beings human: Bioecological perspectives on human development. In *British Journal of Developmental Psychology* (Vol. 23, Issue 1).

Brose, A., Schmiedek, F., Lövdén, M., & Lindenberger, U. (2012). Daily variability in working memory is coupled with negative affect: The role of attention and motivation. *Emotion, 12*(3), 605–617. https://doi.org/10.1037/a0024436

Brown, B. B., & Larson, J. (2009). Peer Relationships in Adolescence. In *Handbook of Adolescent Psychology*. https://doi.org/10.1002/9780470479193.adlpsy002004

Caemmerer, J. M., & Keith, T. Z. (2015). Longitudinal, reciprocal effects of social skills and achievement from kindergarten to eighth grade. *Journal of School Psychology*, *53*(4). https://doi.org/10.1016/j.jsp.2015.05.001

Caprara, G. V., Di Giunta, L., Eisenberg, N., Gerbino, M., Pastorelli, C., & Tramontano, C. (2008). Assessing regulatory emotional self-efficacy in three countries. Psychological Assessment, 20(3), 227–237. https://doi.org/10.1037/1040-3590.20.3.227

Chen, B., Vansteenkiste, M., Beyers, W., Boone, L., Deci, E. L., Van der Kaap-Deeder, J., Duriez, B., Lens, W., Matos, L., Mouratidis, A., Ryan, R. M., Sheldon, K. M., Soenens, B., Van Petegem, S., & Verstuyf, J. (2015). Basic psychological need satisfaction, need frustration, and need strength across four cultures. Motivation and Emotion, 39(2), 216–236. https://doi.org/10.1007/s11031-014-9450-1

Chen, X., Rubin, K. H., & li, B. (1995). Social and school adjustment of shy and aggressive children in China. *Development and Psychopathology*, *7*(2). https://doi.org/10.1017/S0954579400006544

Chen, X., Wang, L., & Wang, Z. (2009). Shyness-sensitivity and social, school, and psychological adjustment in rural migrant and urban children in China. Child development, 80(5), 1499-1513.

Coie, J. D., Dodge, K. A., & Coppotelli, H. (1982). Dimensions and types of social status: A cross-age perspective. *Developmental Psychology, 18*(4), 557–570. https://doi.org/10.1037/0012-1649.18.4.557

Cranford, J. A., Shrout, P. E., Iida, M., Rafaeli, E., Yip, T., & Bolger, N. (2006). A procedure for evaluating sensitivity to within-person change: Can mood measures in diary studies detect change reliably?. *Personality and Social Psychology Bulletin*, *32*(7), 917-929.

Crone, E. A., & Dahl, R. E. (2012). Understanding adolescence as a period of social–affective engagement and goal flexibility. Nature Reviews Neuroscience, 13(9), 636–650

Curran, P. J., & Bauer, D. J. (2011). The disaggregation of within-person and between-person effects in longitudinal models of change. *Annual Review of Psychology*, *62*. https://doi.org/10.1146/annurev.psych.093008.100356

Deci, E. L., & Ryan, R. M. (2000). The “what” and “why” of goal pursuits: Human needs and the self-determination of behavior. Psychological Inquiry, 11(4), 227–268. https://doi.org/10.1207/S15327965PLI1104_01

de Wilde, A., Koot, H. M., & van Lier, P. A. C. (2016). Developmental Links Between Children’s Working Memory and their Social Relations with Teachers and Peers in the Early School Years. *Journal of Abnormal Child Psychology*, *44*(1). https://doi.org/10.1007/s10802-015-0053-4

Diamond, A. (2013). Executive functions. Annual Review of Psychology, 64, 135–168.

Dirk, J., & Schmiedek, F. (2016). Fluctuations in elementary school children’s working memory performance in the school context. *Journal of Educational Psychology*, *108*(5). https://doi.org/10.1037/edu0000076

Durlak, J. A., Weissberg, R. P., Dymnicki, A. B., Taylor, R. D., & Schellinger, K. B. (2011). The impact of enhancing students’ social and emotional learning: A meta-analysis of school-based universal interventions. Child Development, 82(1), 405–432.

Dweck, C. S. (2017). Mindset: The new psychology of success (Updated ed.). Ballantine.

Easterbrook, J. A. (1959). The effect of emotion on cue utilization and the organization of behavior. *Psychological Review, 66*(3), 183–201. https://doi.org/10.1037/h0047707Eccles, J. S. (2009). Who am I and what am I going to do with my life? *Educational Psychologist, 44*(2), 78–89.

Eccles, J. S., & Wigfield, A. (2002). Motivational beliefs, values, and goals. *Annual Review of Psychology, 53*, 109–132.

Eccles, J. S., & Roeser, R. W. (2011). Schools as developmental contexts during adolescence. Journal of Research on Adolescence, 21(1), 225–241.

Eccles, J. S. (1999). The development of children ages 6 to 14. In *Future of Children* (Vol. 9, Issue 2). https://doi.org/10.2307/1602703

Ecker, U. K. H., Lewandowsky, S., Oberauer, K., & Chee, A. E. H. (2010). The Components of Working Memory Updating: An Experimental Decomposition and Individual Differences. *Journal of Experimental Psychology: Learning Memory and Cognition*, *36*(1). https://doi.org/10.1037/a0017891

Elliot, A. J., Murayama, K., & Pekrun, R. (2011). A 3× 2 achievement goal model. *Journal of educational psychology*, *103*(3), 632.

Ellis, H. C., & Ashbrook, P. W. (1988). Resource allocation model of the effects of depressed mood states on memory. In K. Fiedler & J. Forgas (Eds.*), Affect, cognition, and social behavior* (pp. 25–43). Göttingen: Hogrefe.

Emery, A. A., Toste, J. R., & Heath, N. L. (2015). The balance of intrinsic need satisfaction across contexts as a predictor of depressive symptoms in children and adolescents. *Motivation and Emotion*, 39(6), 753–765

Eysenck, M. W., Derakshan, N., Santos, R., & Calvo, M. G. (2007). Anxiety and cognitive performance: Attentional control theory. *Emotion, 7*(2), 336–353.

Feldman Barrett, L. (2012). Emotions are real. Emotion, 12(3), 413–429. https://doi.org/10.1037/a0027555

Fleeson, W. (2001). Toward a structure- and process-integrated view of personality: Traits as density distributions of states. *Journal of Personality and Social Psychology*, *80*(6). https://doi.org/10.1037/0022-3514.80.6.1011

Fredrickson, B. L. (2001). The role of positive emotions in positive psychology: The broaden-and-build theory of positive emotions. American Psychologist, 56(3), 218–226.

Frenzel, A. C., Becker-Kurz, B., Pekrun, R., Goetz, T., & Lüdtke, O. (2018). Emotion transmission in the classroom revisited: A reciprocal effects model of teacher and student enjoyment. *Journal of Educational Psychology, 110*(5), 628–639. https://doi.org/10.1037/edu0000228

Frenzel, A. C., Goetz, T., Stephens, E. J., & Jacob, B. (2009). Antecedents and effects of teachers' emotional experiences: An integrative perspective and empirical test. In P. A. Schutz & M. Zembylas (Eds.), *Advances in teacher emotion research: The impact on teachers' lives* (pp. 129–151). Springer. https://doi.org/10.1007/978-1-4419-0564-2_7

Furrer, C., & Skinner, E. (2003). Sense of relatedness as a factor in children's academic engagement and performance. Journal of Educational Psychology, 95(1), 148–162.

Galeano-Keiner, E. M., Neubauer, A. B., Irmer, A., & Schmiedek, F. (2022). Daily fluctuations in children's working memory accuracy and precision: Variability at multiple time scales and links to daily sleep behavior and fluid intelligence. *Cognitive Development*, *64*. https://doi.org/10.1016/j.cogdev.2022.101260

Gathercole, S. E., Pickering, S. J., Knight, C., & Stegmann, Z. (2004). Working memory skills and educational attainment: Evidence from national curriculum assessments. *Applied Cognitive Psychology, 18*(1), 1–16. https://doi.org/10.1002/acp.934

Geldhof, G. J., Preacher, K. J., & Zyphur, M. J. (2014). Reliability estimation in a multilevel confirmatory factor analysis framework. Psychological Methods, 19(1). https://doi.org/10.1037/a0032138

Giletta, M., Choukas-Bradley, S., Maes, M., Linthicum, K. P., Card, N. A., & Prinstein, M. J. (2021). A meta-analysis of longitudinal peer influence effects in childhood and adolescence. Psychological bulletin, 147(7), 719.

Goetz, T., Nett, U. E., Martiny, S. E., Hall, N. C., Pekrun, R., Dettmers, S., & Trautwein, U. (2012). Students' emotions during homework: Structures, self-concept antecedents, and achievement outcomes. *Learning and Individual Differences*, *22*(2), 225-234.

Goetz, T., Bieg, M., Lüdtke, O., Pekrun, R., & Hall, N. C. (2013). Do girls really experience more anxiety in mathematics?. *Psychological science*, *24*(10), 2079-2087.

Gotlib, I. H., & Joormann, J. (2010). Cognition and depression: Current status and future directions. Annual Review of Clinical Psychology, 6, 285–312

Hamaker, E. L., Dolan, C. V., & Molenaar, P. C. M. (2005). Statistical modelling of the individual. Psychological Methods, 10(2), 201–219.

Hamm, J. V., Farmer, T. W., Dadisman, K., Gravelle, M., & Murray, A. R. (2011). Teachers' attunement to students' peer group affiliations as a source of improved student experiences of the school social–affective context following the middle school transition. Journal of Applied Developmental Psychology, 32(5), 267–277. https://doi.org/10.1016/j.appdev.2010.06.003

Harter, S. (2015). *The construction of the self: Developmental and sociocultural foundations*. Guilford Publications.

Herres, J., Ewing, E. S. K., & Kobak, R. (2016). Emotional Reactivity to Negative Adult and Peer Events and the Maintenance of Adolescent Depressive Symptoms: a Daily Diary Design. *Journal of Abnormal Child Psychology*, *44*(3). https://doi.org/10.1007/s10802-015-0043-6

Hitch, G. J., & Baddeley, A. D. (1976). Verbal reasoning and working memory. The Quarterly Journal of Experimental Psychology, 28(4), 603-621.

Holmes, C. J., Kim-Spoon, J., & Deater-Deckard, K. (2016). Linking Executive Function and Peer Problems from Early Childhood Through Middle Adolescence. *Journal of Abnormal Child Psychology*, *44*(1). https://doi.org/10.1007/s10802-015-0044-5

Hostinar, C. E., Stellern, S. A., Schaefer, C., Carlson, S. M., & Gunnar, M. R. (2012). Associations between early life adversity and executive function in children adopted internationally from orphanages. Proceedings of the National Academy of Sciences, 109(supplement_2), 17208-17212.

Immordino-Yang, M. H., & Damasio, A. (2007). We feel, therefore we learn: The relevance of affective and social neuroscience to education. Mind, Brain, and Education, 1(1), 3–10.

Irmer, A., & Schmiedek, F. (2023). Associations between youth's daily social media use and well-being are mediated by upward comparisons. *Communications Psychology*, *1*(1), 12.

Isen, A. M. (2008). Some ways in which positive affect influences decision making and problem solving. In M. Lewis, J. M. Haviland-Jones, & L. F. Barrett (Eds.), Handbook of emotions (3rd ed., pp. 548–573). The Guilford Press.

Johnson, D. W., & Johnson, R. T. (2009). An educational psychology success story: Social interdependence theory and cooperative learning. Educational Researcher, 38(5), 365–379.

Joormann, J., & Gotlib, I. H. (2008). Updating the contents of working memory in depression: Interference from irrelevant negative material. *Journal of Abnormal Psychology, 117*(1), 182–192. https://doi.org/10.1037/0021-843X.117.1.182

Juvonen, J., Nishina, A., & Graham, S. (2000). Peer harassment, psychological adjustment, and school functioning in early adolescence. *Journal of Educational Psychology, 92*(2), 349–359. https://doi.org/10.1037/0022-0663.92.2.349

Kahneman, D. (1973). *Attention and effort*. Prentice Hall.

King, R. B. (2015). Sense of relatedness boosts engagement, achievement, and well-being: A latent growth model study. *Contemporary Educational Psychology*, *42*. https://doi.org/10.1016/j.cedpsych.2015.04.002

Könen, T., Dirk, J., Leonhardt, A., & Schmiedek, F. (2016). The interplay between sleep behavior and affect in elementary school children's daily life. Journal of Experimental Child Psychology, 150. https://doi.org/10.1016/j.jecp.2016.04.003

Ladd, G. W., Kochenderfer, B. J., & Coleman, C. C. (1997). Classroom Peer Acceptance, Friendship, and Victimization: Distinct Relational Systems That Contribute Uniquely to Children's School Adjustment? *Child Development*, *68*(6). https://doi.org/10.1111/j.1467-8624.1997.tb01993.x

Ladd, G. W., Kochenderfer-Ladd, B., Ettekal, I., & Clifford, B. N. (2021). Manifestations of Solitude in Interpersonal Contexts and Negative Peer Experiences. In *The Handbook of Solitude* (pp. 117–132). Wiley. https://doi.org/10.1002/9781119576457.ch9

Laursen, B., & Veenstra, R. (2021). Toward understanding the functions of peer influence: A summary and synthesis of recent empirical research. Journal of Research on Adolescence, 31(4), 889-907.

Leary, M. R., Tambor, E. S., Terdal, S. K., & Downs, D. L. (1995). Self-Esteem as an Interpersonal Monitor: The Sociometer Hypothesis. *Journal of Personality and Social Psychology*, *68*(3). https://doi.org/10.1037/0022-3514.68.3.518

Lecce, S., Bianco, F., & Ronchi, L. (2020). Executive function in the school context: The role of peer relationships. *Infant and Child Development*, *29*(1). https://doi.org/10.1002/icd.2151

Lechuga, M. T., Pelegrina, S., Pelaez, J. L., Martin-Puga, M. E., & Justicia, M. J. (2016). Working memory updating as a predictor of academic attainment. *Educational Psychology*, *36*(4). https://doi.org/10.1080/01443410.2014.950193

Lee, K., & Bull, R. (2015). Developmental changes in working memory, updating, and math achievement. *Journal of Educational Psychology*, *108*(6). https://doi.org/10.1037/edu0000090

Lehman, B. J., & Repetti, R. L. (2007). Bad days don't end when the school bell rings: The lingering effects of negative school events on children's mood, self-esteem, and perceptions of parent-child interaction. *Social Development*, *16*(3). https://doi.org/10.1111/j.1467-9507.2007.00398.x

Leonhardt, A., Könen, T., Dirk, J., & Schmiedek, F. (2016). How differentiated do children experience affect? An investigation of the within-and between-person structure of children's affect. *Psychological Assessment*, *28*(5). https://doi.org/10.1037/pas0000195

Li, S.-C., Schmiedek, F., Huxhold, O., Röcke, C., Smith, J., & Lindenberger, U. (2018). Working memory plasticity in old age: Practice gain, transfer, and maintenance. *Psychology and Aging, 23*(4), 731–742. https://doi.org/10.1037/a0014343

Linares, R., & Pelegrina, S. (2023). The relationship between working memory updating components and reading comprehension. *Cognitive Processing*, *24*(2). https://doi.org/10.1007/s10339-023-01127-3

Lorijn, S. J., Zwier, D., Laninga-Wijnen, L., Huisman, M., & Veenstra, R. (2024). A new school, a fresh start? Change and stability in peer relationships and academic performance in the transition from primary to secondary school. Journal of youth and adolescence, 53(9), 1987-2001.

Lupien, S. J., McEwen, B. S., Gunnar, M. R., & Heim, C. (2009). Effects of stress throughout the lifespan on the brain, behaviour and cognition. *Nature Reviews Neuroscience, 10*(6), 434–445. https://doi.org/10.1038/nrn2639

MacKinnon, D. P., Lockwood, C. M., & Williams, J. (2004). *Confidence limits for the indirect effect: Distribution of the product and resampling methods*. *Multivariate Behavioral Research, 39*(1), 99–128.

Marsh, H. W., & Craven, R. G. (2006). Reciprocal effects of self-concept and performance. *Perspectives on Psychological Science, 1*(2), 133–163.

Marsh, H. W., & Hau, K. T. (2003). Big-Fish-Little-Pond Effect on Academic Self-concept: A Cross-Cultural (26-Country) Test of the Negative Effects of Academically Selective Schools. *American Psychologist*, *58*(5). https://doi.org/10.1037/0003-066X.58.5.364

Marsh, H. W., & Parker, J. W. (1984). Determinants of student self-concept: Is it better to be a relatively large fish in a small pond even if you don't learn to swim as well? *Journal of Personality and Social Psychology*, *47*(1). https://doi.org/10.1037/0022-3514.47.1.213

Marsh, H. W., Seaton, M., Trautwein, U., Lüdtke, O., Hau, K. T., O'Mara, A. J., & Craven, R. G. (2008). The big-fish-little-pond-effect stands up to critical scrutiny: Implications for theory, methodology, and future research. *Educational Psychology Review*, *20*(3). https://doi.org/10.1007/s10648-008-9075-6

Maynard, B. R., Vaughn, M. G., Salas-Wright, C. P., & Vaughn, S. (2016). Bullying victimization among school-aged immigrant youth in the United States. *Journal of Adolescent Health*, *58*(3), 337-344.

McDougall, P., & Vaillancourt, T. (2015). Long-term adult outcomes of peer victimization. *Child Psychology and Psychiatry Review, 20*(4), 300–310.

McEwen, B. S., & Morrison, J. H. (2013). The brain on stress: Vulnerability and plasticity of the prefrontal cortex over the life course. Neuron, 79(1), 16–29

Meeus, W., Van De Schoot, R., Keijsers, L., Schwartz, S. J., & Branje, S. (2010). On the progression and stability of adolescent identity formation: A five-wave longitudinal study in early-to-middle and middle-to-late adolescence. Child development, 81(5), 1565-1581.

Mehl, M. R., & Wrzus, C. (2021). Ecological sampling methods for studying personality in daily life.

Miyake, A., & Friedman, N. P. (2012). The nature and organization of individual differences in executive functions. Psychological Review, 110(1), 49–100.

Molenaar, P. C. M. (2004). A manifesto on psychology as idiographic science. Measurement: Interdisciplinary Research & Perspective, 2(4), 201–218.

Molenaar, P. C. M., & Campbell, C. G. (2009). The new person-specific paradigm in psychology. *Current Directions in Psychological Science*, *18*(2). https://doi.org/10.1111/j.1467-8721.2009.01619.x

Moran, T. P. (2016). Anxiety and working memory capacity: A meta-analysis and narrative review. *Psychological Bulletin*, *142*(8). https://doi.org/10.1037/bul0000051

Muthén, B., & Muthén L. (2023). *Mplus*.

Neubauer, A. B., Dirk, J., & Schmiedek, F. (2019). Momentary working memory performance is coupled with different dimensions of affect for different children: A mixture model analysis of ambulatory assessment data. *Developmental Psychology*, *55*(4). https://doi.org/10.1037/dev0000668

Newcomb, A. F., Bukowski, W. M., & Pattee, L. (1993). Children's peer relations: A meta-analytic review. *Psychological Bulletin, 113*(1), 99–128.

Nezlek, J. B. (2012). Multilevel modeling analyses of diary-style data. Handbook of research methods for studying daily life, 676, 357-383.

Nezlek, J. B., Wesselmann, E. D., Wheeler, L., & Williams, K. D. (2015). Ostracism in Everyday Life: The Effects of Ostracism on Those Who Ostracize. *Journal of Social Psychology*, *155*(5). https://doi.org/10.1080/00224545.2015.1062351

Nurmi, J. E. (2004). Socialization and self-development: Channeling, selection, adjustment, and reflection. *Handbook of adolescent psychology*, 85-124.

Oberle, E., Schonert-Reichl, K. A., & Zumbo, B. D. (2011). Life satisfaction in early adolescence: Personal, neighborhood, school, family, and peer influences. Journal of youth and adolescence, 40(7), 889-901.

Parker, J. G., & Asher, S. R. (1987). Peer relations and later personal adjustment: Are low-accepted children at risk? Psychological Bulletin, 102(3), 357–389.

Pekrun, R. (2024). Control-value theory: From achievement emotion to a general theory of human emotions. Educational Psychology Review, 36(3), 83.

Pekrun, R., & Linnenbrink-Garcia, L. (2012). Academic emotions and student engagement. In S. Christenson, A. Reschly, & C. Wylie (Eds.), Handbook of research on student engagement (pp. 259–282). Springer. https://doi.org/10.1007/978-1-4614-2018-7_12

Pe, M. L., Raes, F., & Kuppens, P. (2013). The cognitive building blocks of emotion regulation: Ability to update working memory moderates the efficacy of rumination and reappraisal on emotion. PLOS one, 8(7), e69071.

Peng, P., Barnes, M., Wang, C. C., Wang, W., Li, S., Swanson, H. L., Dardick, W., & Tao, S. (2018). Meta-analysis on the relation between reading and working memory. *Psychological Bulletin*, *144*(1). https://doi.org/10.1037/bul0000124

Peper, J. S., & Dahl, R. E. (2013). The teenage brain: Surging hormones—Brain-behavior interactions during puberty. *Current directions in psychological science*, *22*(2), 134-139.

Pianta, R. C., Hamre, B. K., & Allen, J. P. (2012). Teacher–student relationships and engagement: Conceptualizing, measuring, and improving the capacity of classroom interactions. Handbook of Research on Student Engagement, 365–386.

Platt, B., Kadosh, K. C., & Lau, J. Y. F. (2013). The role of peer rejection in adolescent depression. In *Depression and Anxiety* (Vol. 30, Issue 9). https://doi.org/10.1002/da.22120

Preacher, K. J., Zyphur, M. J., & Zhang, Z. (2010). A general multilevel SEM framework for assessing multilevel mediation. *Psychological methods*, *15*(3), 209.

Raufelder, D., & Kulakow, S. (2021). The role of the learning environment in adolescents' motivational development. Motivation and Emotion, 45(3), 299-311.

Ragelienė, T. (2016). Links of adolescents identity development and relationship with peers: A systematic literature review. Journal of the Canadian Academy of Child and Adolescent Psychiatry, 25(2), 97.

Reyes, M. R., Brackett, M. A., Rivers, S. E., White, M., & Salovey, P. (2012). Classroom emotional climate, student engagement, and academic achievement. Journal of educational psychology, 104(3), 700.

Rowe, G., Hirsh, J. B., & Anderson, A. K. (2007). Positive affect increases the breadth of attentional selection. Proceedings of the National Academy of Sciences, 104(1), 383-388.

Rubin, K. H., Bukowski, W. M., & Bowker, J. C. (2015). Children in Peer Groups. In *Handbook of Child Psychology and Developmental Science*. https://doi.org/10.1002/9781118963418.childpsy405

Rudolph, K. D. (2008). Developmental influences on interpersonal stress generation in depressed youth. *Journal of abnormal psychology*, *117*(3), 673.

Rudolph, K. D., Ladd, G. W., & Dinella, L. (2007). Gender differences in the interpersonal consequences of early-onset depressive symptoms. Merrill-Palmer Quarterly, 53(3), 461-488.

Russell, J. A. (2003). Core affect and the psychological construction of emotion. *Psychological Review, 110*(1), 145–172.

Ryan, R. M., & Deci, E. L. (2000). Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. *American Psychologist*, *55*(1). https://doi.org/10.1037/0003-066X.55.1.68

Ryan, R. M., & Deci, E. L. (2017). Self-determination theory: Basic psychological needs in motivation, development, and wellness. The Guilford Press

Rytioja, M., Lappalainen, K., & Savolainen, H. (2019). Behavioural and emotional strengths of sociometrically popular, rejected, controversial, neglected, and average children. *European Journal of Special Needs Education*, *34*(5). https://doi.org/10.1080/08856257.2018.1560607

Schmeichel, B. J. (2007). Attention control, memory updating, and emotion regulation temporarily reduce the capacity for executive control. Journal of Experimental Psychology: General, 136(2), 241–255

Schmeichel, B. J., Volokhov, R. N., & Demaree, H. A. (2008). Working memory capacity and the self-regulation of emotional expression and experience. *Journal of Personality and Social Psychology, 95*(6), 1526–1540. https://doi.org/10.1037/a0013345

Schmidt, A., Dirk, J., Neubauer, A. B., & Schmiedek, F. (2021). Evaluating sociometer theory in children's everyday lives: Inclusion, but not exclusion by peers at school is related to within-day change in self-esteem. *European Journal of Personality*, *35*(5). https://doi.org/10.1177/0890207020962328

Schmidt, A., Dirk, J., & Schmiedek, F. (2019). The importance of peer relatedness at school for affective well-being in children: Between- and within-person associations. *Social Development*, *28*(4). https://doi.org/10.1111/sode.12379

Schmidt, A., Neubauer, A. B., Dirk, J., & Schmiedek, F. (2020). The bright and the dark side of peer relationships: Differential effects of relatedness satisfaction and frustration at school on affective well-being in children's daily lives. *Developmental Psychology*, *56*(8). https://doi.org/10.1037/dev0000997

Schweder, S., & Raufelder, D. (2024). Does changing learning environments affect student motivation? *Learning and Instruction*, *89*. https://doi.org/10.1016/j.learninstruc.2023.101829

Seaton, M., Marsh, H. W., & Craven, R. G. (2009). Earning Its Place as a Pan-Human Theory: Universality of the Big-Fish-Little-Pond Effect Across 41 Culturally and Economically Diverse Countries. *Journal of Educational Psychology*, *101*(2). https://doi.org/10.1037/a0013838

Sheldon, K. M., Ryan, R. M., & Reis, H. T. (1996). What makes for a good day? Competence and autonomy in the day and in the person. Personality and Social Psychology Bulletin, 22(12), 1270–1279. https://doi.org/10.1177/01461672962212007

Shields, G. S., Sazma, M. A., & Yonelinas, A. P. (2016). The effects of acute stress on core executive functions: A meta-analysis and comparison with cortisol. Neuroscience & Biobehavioral Reviews, 68, 651-668.

Shiffman, S., Stone, A. A., & Hufford, M. R. (2008). Ecological momentary assessment. *Annual Review of Clinical Psychology, 4*, 1–32.

Skinner, E. A., & Pitzer, J. R. (2012). Developmental dynamics of student engagement, coping, and everyday resilience. In Handbook of research on student engagement (pp. 21-44). Boston, MA: Springer US.

Skinner, E. A., & Zimmer-Gembeck, M. J. (2007). The development of coping. *Annu. Rev. Psychol.*, *58*(1), 119-144.

St Clair-Thompson, H. L., & Gathercole, S. E. (2006). Executive functions and achievements in school: Shifting, updating, inhibition, and working memory. In *Quarterly Journal of Experimental Psychology* (Vol. 59, Issue 4). https://doi.org/10.1080/17470210500162854

Suor, J. H., Sturge-Apple, M. L., & Skibo, M. A. (2017). Breaking cycles of risk: The mitigating role of maternal working memory in associations among socioeconomic status, early caregiving, and children's working memory. *Development and Psychopathology*, *29*(4). https://doi.org/10.1017/S095457941600119X

Troller-Renfree, S. V., Buzzell, G. A., & Fox, N. A. (2020). Changes in working memory influence the transition from reactive to proactive cognitive control during childhood. *Developmental Science*, *23*(6). https://doi.org/10.1111/desc.12959

Vandenbroucke, L., Spilt, J. L., Verschueren, K., & Baeyens, D. (2018). The effects of peer rejection, parent and teacher support on working memory performance: An experimental approach in middle childhood. *Learning and Individual Differences*, 67, 12–21.

van der Kaap-Deeder, J., Vansteenkiste, M., Soenens, B., & Mabbe, E. (2017). Children's daily well-being: The role of mothers', teachers', and siblings' autonomy support and psychological control. *Developmental Psychology*, *53*(2). https://doi.org/10.1037/dev0000218

Veenstra, R., & Laninga-Wijnen, L. (2022). Peer network studies and interventions in adolescence. Current Opinion in Psychology, 44, 157-163.

Vogel, E. K., & Awh, E. (2008). How to exploit diversity for scientific gain: Using individual differences to constrain cognitive theory. *Current Directions in Psychological Science, 17*(2), 171–176. https://doi.org/10.1111/j.1467-8721.2008.00569.x

Wang, M. T., & Eccles, J. S. (2012). Social support matters: Longitudinal effects of social support on three dimensions of school engagement from middle to high school. Child Development, 83(3), 877–895. https://doi.org/10.1111/j.1467-8624.2012.01745.

Wang, L. P., & Maxwell, S. E. (2015). On disaggregating between-person and within-person effects with longitudinal data using multilevel models. *Psychological methods*, *20*(1), 63.

Watson, D., & Tellegen, A. (1985). Toward a consensual structure of mood. Psychological Bulletin, 98(2), 219–235.

Wentzel, K. R. (1998). Social relationships and motivation in middle school: The role of parents, teachers, and peers. *Journal of Educational Psychology*, *90*(2). https://doi.org/10.1037/0022-0663.90.2.202

Wentzel, K. R., & Asher, S. R. (1995). The academic lives of neglected, rejected, popular, and controversial children. *Child Development, 66*(3), 754–763. https://doi.org/10.2307/1131948

Wentzel, K. R., & Caldwell, K. (1997). Friendships, peer acceptance, and group membership: relations to academic achievement in middle school. Child Development, 68(6), 1198–1209.

Wentzel, K. R., Barry, C. M., & Caldwell, K. A. (2004). Friendships in Middle School: Influences on Motivation and School Adjustment. Journal of Educational Psychology, 96(2), 195–203. https://doi.org/10.1037/0022-0663.96.2.195

Wentzel, K. R. (2017). Peer relationships, motivation, and academic performance at school. In A. J. Elliot et al. (Eds.), Handbook of Competence and Motivation (pp. 586–603). Guilford Press.

Wentzel, K. R., Russell, S., & Baker, S. (2016). Emotional support and expectations from parents, teachers, and peers predict adolescent competence at school. Journal of educational psychology, 108(2), 242.

Wigfield, A., Byrnes, J. P., & Eccles, J. S. (2006). Development during early and middle adolescence. In *Handbook of Educational Psychology* (pp. 87–113).

Yang, M. Y., Chen, Z., Rhodes, J. L. F., & Orooji, M. (2018). A longitudinal study on risk factors of grade retention among elementary school students using a multilevel analysis: Focusing on material hardship and lack of school engagement. *Children and Youth Services Review*, *88*. https://doi.org/10.1016/j.childyouth.2018.02.043

Yeager, D. S., & Dweck, C. S. (2012). Mindsets that promote resilience. *Educational Psychologist, 47*(4), 302–314

Yerkes, R. M., & Dodson, J. D. (1908). The relation of strength of stimulus to rapidity of habit-formation. Journal of Comparative Neurology and Psychology, 18(5), 459-482.

Yu, X., Wang, X., Zheng, H., Zhen, X., Shao, M., Wang, H., & Zhou, X. (2023). Academic achievement is more closely associated with student-peer relationships than with student-parent relationships or student-teacher relationships. Frontiers in psychology, 14, 1012701.

Zegers, M. A. J., Schuengel, C., van IJzendoorn, M. H., & Janssens, J. M. A. M. (2006). Attachment representations of institutionalized adolescents and their professional caregivers: Predicting the development of therapeutic relationships. *American Journal of Orthopsychiatry, 76*(3), 325–334. https://doi.org/10.1037/0002-9432.76.3.325

Supplementary Material

Supplementary Table 1. Unstandardized Regression Coefficients for the Prediction of WMU Performance and Perceived Academic Success From Peer Relatedness Satisfaction and Frustration (Studies 1 & 2)

Outcome	Study	Predictor	B	SE	95% CI	*p*
WMUP	1	Relatedness Satisfaction	0.041	0.037	[–0.029, 0.113]	.134
		Relatedness Frustration	–0.079	0.033	[–0.144, –0.013]	.010
WMUP	2	Relatedness Satisfaction	0.004	0.024	[–0.042, 0.056]	.422
		Relatedness Frustration	–0.032	0.022	[–0.075, 0.010]	.073
Perceived Academic Success	1	Relatedness Satisfaction	0.950	0.074	[0.803, 1.092]	<.001
		Relatedness Frustration	0.029	0.069	[–0.113, 0.163]	.338
Perceived Academic Success	2	Relatedness Satisfaction	0.684	0.068	[0.546, 0.814]	<.001
		Relatedness Frustration	0.146	0.059	[0.032, 0.263]	.005

Supplementary Table 2. Mediation of Peer Relatedness Satisfaction on Performance by Positive Affect (Study 1 and Study 2)

Study	Path	Unstandardised Estimate	Standard Error	95% Confidence Interval	p-value
Study 1	Peer Relatedness Satisfaction → Positive Affect	0.884	0.094	[0.710, 1.080]	< .001
Study 1	Positive Affect → WMUP	–0.057	0.076	[–0.203, 0.096]	0.227
Study 1	Peer Relatedness Satisfaction → WMUP (direct)	0.137	0.076	[–0.012, 0.287]	0.038
Study 1	Peer Relatedness Satisfaction → WMUP (indirect)	–0.051	0.023	[–0.106, 0.016]	0.149
Study 1	Peer Relatedness Satisfaction → WMUP (total)	0.086	0.078	[–0.016, 0.203]	0.122
Study 2	Peer Relatedness Satisfaction → Positive Affect	0.746	0.069	[0.611, 0.883]	< .001
Study 2	Positive Affect → WMUP	–0.059	0.059	[–0.179, 0.055]	0.144
Study 2	Peer Relatedness Satisfaction → WMUP (direct)	–0.012	0.052	[–0.108, 0.094]	0.410
Study 2	Peer Relatedness Satisfaction → WMUP (indirect)	–0.044	0.022	[–0.087, –0.001]	0.051
Study 2	Peer Relatedness Satisfaction → WMUP (total)	–0.056	0.058	[–0.170, 0.071]	0.389

Supplementary Table 3. Mediation of Peer Relatedness Frustration on Performance by Negative Affect (Study 1 and Study 2)

Study	Path	Unstandardised Estimate	Standard Error	95% Confidence Interval	p-value
Study 1	Peer Relatedness Frustration → Negative Affect	0.793	0.049	[0.696, 0.890]	< .001
Study 1	Negative Affect → WMUP	–0.059	0.059	[–0.179, 0.055]	0.144
Study 1	Peer Relatedness Frustration → WMUP (direct)	–0.012	0.052	[–0.108, 0.094]	0.410
Study 1	Peer Relatedness Frustration → WMUP (indirect)	–0.047	0.023	[–0.097, 0.002]	0.059
Study 1	Peer Relatedness Frustration → WMUP (total)	–0.059	0.058	[–0.171, 0.065]	0.369
Study 2	Peer Relatedness Frustration → Negative Affect	0.793	0.049	[0.696, 0.890]	< .001
Study 2	Negative Affect → WMUP	–0.059	0.059	[–0.179, 0.055]	0.144
Study 2	Peer Relatedness Frustration → WMUP (direct)	–0.012	0.052	[–0.108, 0.094]	0.410
Study 2	Peer Relatedness Frustration → WMUP (indirect)	–0.044	0.022	[–0.087, –0.001]	0.051
Study 2	Peer Relatedness Frustration → WMUP (total)	–0.056	0.058	[–0.170, 0.071]	0.389

Supplementary Table 4. Mediation of Peer Relatedness Satisfaction on Perceived Academic Success by Positive Affect (Study 1 and Study 2)

Study	Path	Unstandardised Estimate	Standard Error	95% Confidence Interval	p-value
Study 1	Peer Relatedness Satisfaction → Positive Affect	0.879	0.074	[0.735, 1.030]	< .001
Study 1	Positive Affect → Perceived Academic Success	0.133	0.165	[–0.199, 0.451]	0.212
Study 1	Peer Relatedness Satisfaction → Perceived Academic Success (direct)	0.880	0.169	[0.540, 1.203]	< .001
Study 1	Peer Relatedness Satisfaction → Perceived Academic Success (indirect)	0.278	0.190	[–0.084, 0.655]	0.068
Study 1	Peer Relatedness Satisfaction → Perceived Academic Success (total)	1.107	0.089	[0.933, 1.280]	< .001
Study 2	Peer Relatedness Satisfaction → Positive Affect	0.753	0.071	[0.617, 0.897]	< .001
Study 2	Positive Affect → Perceived Academic Success	0.546	0.109	[0.330, 0.759]	< .001
Study 2	Peer Relatedness Satisfaction → Perceived Academic Success (direct)	0.383	0.103	[0.181, 0.588]	< .001
Study 2	Peer Relatedness Satisfaction → Perceived Academic Success (indirect)	0.676	0.131	[0.425, 0.946]	< .001
Study 2	Peer Relatedness Satisfaction → Perceived Academic Success (total)	1.046	0.088	[0.880, 1.220]	< .001

Supplementary Table 5. Mediation of Peer Relatedness Frustration on Perceived Academic Success by Negative Affect (Study 1 and Study 2)

Study	Path	Unstandardised Estimate	Standard Error	95% Confidence Interval	p-value
Study 1	Peer Relatedness Frustration → Negative Affect	0.685	0.074	[0.540, 0.830]	< .001
Study 1	Negative Affect → Perceived Academic Success	–0.080	0.307	[–0.676, 0.535]	0.393
Study 1	Peer Relatedness Frustration → Perceived Academic Success (direct)	0.174	0.259	[–0.337, 0.684]	0.262
Study 1	Peer Relatedness Frustration → Perceived Academic Success (indirect)	–0.086	0.274	[–0.629, 0.458]	0.370
Study 1	Peer Relatedness Frustration → Perceived Academic Success (total)	0.880	0.089	[0.700, 1.052]	< .001
Study 2	Peer Relatedness Frustration → Negative Affect	0.796	0.052	[0.691, 0.898]	< .001
Study 2	Negative Affect → Perceived Academic Success	–0.077	0.332	[–0.748, 0.564]	0.401
Study 2	Peer Relatedness Frustration → Perceived Academic Success (direct)	0.104	0.289	[–0.470, 0.675]	0.365
Study 2	Peer Relatedness Frustration → Perceived Academic Success (indirect)	–0.199	0.353	[–0.918, 0.473]	0.276
Study 2	Peer Relatedness Frustration → Perceived Academic Success (total)	1.056			

CHAPTER 7

General Discussion

The studies described in the preceding chapters provided substantial evidence that peer exclusion exerts a significant influence on EFs and learning outcomes. In the opening section of this General Discussion, the main research questions addressed across the four empirical articles will be reviewed. Specifically, this section revisits the three central research questions examined in this dissertation: (1) the validity and suitability of an experimental paradigm for eliciting and studying peer exclusion in ecologically relevant ways, (2) the short-term cognitive effects of peer exclusion, and (3) the dynamic influence of daily peer relatedness experiences on WM and perceived academic success. Subsequently, the convergent and divergent results for the overarching themes of this dissertation will be reported. These themes are: firstly, the role of VR in assessing peer exclusion and the outcomes associated with different VR features across the studies; secondly, the effects of peer exclusion on WM and the differences observed among the studies; and thirdly, the main developmental differences in peer exclusion effects as assessed through both VR and ILDs. The ensuing two sections will address the theoretical and practical contributions of the overall work. Subsequent to this, specific reflections pertaining to the methodologies employed will be conducted, and, finally, limitations and future research directions will be reported.

Main Findings of the Research Questions

This dissertation investigated the interplay between peer exclusion and executive functioning in school-aged populations, with a particular focus on WM. Across four empirical chapters, the work addressed (1) how peer exclusion can be experimentally elicited and studied in ecologically valid ways, (2) its short-term cognitive consequences, and (3) its dynamic links with daily peer-relatedness experiences.

Research Question 1: Experimental assessment of peer exclusion

Chapters 3 and 4 provided complementary evidence for the validity and characteristics of a newly developed 3D VR classroom paradigm. Chapter 3 adopted a qualitative approach to compare

participants' subjective experiences of the 3D VR classroom with those of the established 2D Cyberball task. Via open-ended questions and debrief discussions, both children and adolescents in Italy reported that the VR paradigm convincingly reproduced the social dynamics of classroom-based peer exclusion, noting realistic interactions, spatial cues, and the gradual nature of exclusionary behaviour. Adolescents, in particular, produced richer and more emotionally nuanced narratives, suggesting developmental gains in social cognition and heightened salience of peer opinion. Children tended to focus on observable features (e.g., the virtual environment) rather than on underlying peer exclusion processes or intentions, reflecting developmental differences in perspective-taking and mentalising. Participants from different school grades (primary, lower secondary, and upper secondary) also offered constructive feedback to enhance ecological fidelity, including more naturalistic dialogue, improved facial animations, and context-appropriate conversational topics. This feedback was subsequently used to refine these specific elements of the VR paradigm, which was then employed in the following study.

Chapter 4 reported a quantitative study comparing the VR classroom and Cyberball paradigms in a within-subjects design in an Italian sample of children and adolescents. Both paradigms elicited robust declines in positive mood, increases in negative mood, and reductions in psychological needs. However, Cyberball produced stronger overall mood changes, whereas the VR paradigm was rated significantly higher in immersion, presence, involvement, and realism. These results indicate that Cyberball remains a potent tool for inducing socio-emotional distress in controlled settings, whereas the VR paradigm offers greater ecological validity and a closer approximation of the subtleties of real-life peer interactions, even if its immediate emotional impact is comparatively milder.

Age moderated these effects: adolescents experienced more pronounced mood and needs decrements in the VR condition compared to children, while Cyberball's effects did not vary by age. In addition to age, the study also explored secondary hypotheses concerning potential moderators such as gender, perceived social support, and history of peer rejection. Although these factors did not

yield strong or consistent interaction effects, some patterns suggested that higher perceived social support might buffer mood declines in Cyberball but not in VR, and that prior experiences of rejection could subtly heighten sensitivity to exclusion in Cyberball but not in VR. While not central to the main conclusions, these exploratory trends point to avenues for future research on individual differences in peer exclusion susceptibility.

Together, the qualitative and quantitative findings underscore the value of multi-method validation in selecting and refining experimental tools for peer exclusion research. Moreover, they underscore the value of the VR classroom as a high-validity paradigm that complements the established Cyberball one, with each offering distinct strengths for experimental research on peer exclusion.

Research Question 2: Immediate cognitive consequences of peer exclusion

Chapter 5 examined whether the manipulation of peer exclusion impairs WM performance. Using the validated VR classroom paradigm, participants completed mood assessments and two widely established WM tasks—Corsi Backwards (for visuospatial stimuli) and Digit Backwards (for verbal stimuli)—before and after a peer exclusion episode. The manipulation through the VR paradigm was successful in producing the expected emotional changes: positive mood declined, and negative mood increased. However, no significant changes in WM performance emerged at the overall sample level.

Moderation analyses revealed important individual differences. Age influenced the pattern of visuospatial WM change: children exhibited significant post-exclusion declines, whereas adolescents showed significant improvements, potentially reflecting different arousal–performance relationships or task strategies. Higher perceived teacher support and higher ratings of VR immersion and realism were associated with lower post-exclusion WM scores, suggesting that individuals who were more socially attuned or more absorbed in the VR scenario may have been more affected by peer exclusion.

Socio-economic status, baseline WM capacity, and problem behaviours also emerged as predictors of WM performance. These findings indicate that while manipulated peer exclusion does not uniformly impair WM, its effects are heterogeneous and contingent on developmental stage, contextual resources, and the depth of engagement with the social environment.

The mediation analyses provided additional insight into the relationship between emotional and cognitive responses. Although mood changes were strongly and consistently linked to the peer exclusion manipulation, neither the decline in positive mood nor the increase in negative mood significantly mediated the relationship between peer exclusion and WM performance. However, when the two broader mood dimensions were disentangled into specific emotions, reductions in happiness and increases in anger emerged as significant mediators of WM performance following peer exclusion on the overall sample. These findings highlight the importance of considering discrete emotions, rather than aggregated mood dimensions, in understanding how exclusion experiences influence cognition. Taken together, these findings suggest that the mechanisms by which peer exclusion may influence cognition are not solely, or even primarily, emotional in nature, and could involve attentional capture, cognitive load, or motivational changes. The absence of significant mediation across broader mood categories also aligns with the overall null effects on WM at the group level, reinforcing the conclusion that immediate cognitive decrease following peer exclusion is not inevitable and may depend on more complex individual and contextual factors.

Research Question 3: Daily peer relatedness and cognitive functioning

Chapter 6 extended the investigation into naturalistic settings using two 28-day ILD studies with children at the end of primary school (Grade 4) and at the start of secondary school (Grade 5) in Germany. Each day, participants reported their levels of peer-relatedness satisfaction and frustration, completed two psychometrically sound WMU tasks, and rated their positive and negative affect, as well as their perceived academic success. Bayesian multilevel models separated within-person (day-to-day fluctuations) from between-person (average levels) effects.

In the primary school cohort, within-person increases in peer-relatedness frustration were associated with same-day declines in WMU, and children who typically experienced higher peer-relatedness frustration also had lower average WMU scores. Peer-relatedness satisfaction was positively related to daily perceived academic success both within and between individuals, with positive affect partially mediating these associations. In contrast, peer-relatedness frustration was no related to same-day perceived academic success in primary school, and showed no between-person association.

In the secondary school cohort, the link between peer-relatedness frustration and WMU was not found anymore, but a more complex pattern emerged for perceived academic success: both higher average peer-relatedness satisfaction and higher average peer-relatedness frustration were positively associated with self-reported academic success. This suggests that, in the early secondary school context, competitive or comparative processes may enable some students to maintain a sense of achievement even when peer relations are strained. Across both cohorts, positive affect functioned as a partial mediator for the peer-relatedness satisfaction–success pathway, whereas negative affect did not consistently mediate peer-relatedness frustration effects.

Taken together, the findings show that the emotional–cognitive consequences of peer exclusion are best understood as context-dependent, developmentally moderated, and sensitive to the measurement timescale. The methodological contribution of validating a VR classroom paradigm offers researchers a tool that balances ecological realism with experimental control. The experimental studies reveal that peer exclusion robustly changes mood but does not inevitably impair WM, with individual differences shaping vulnerability. The ILD data underscore that in everyday school life, fluctuations in peer-relatedness frustration are meaningfully linked to cognitive performance, and that these links may evolve across educational transitions. These cross-national findings (Italy vs. Germany) should, however, be interpreted with caution, as cultural differences in peer relations may partly account for the observed developmental patterns.

Convergent and Divergent Outcomes across Studies

Across the four empirical chapters, several overarching trends emerged that converge on the key mechanisms linking peer exclusion, emotional processes, and cognitive functioning across development.

First, the dissertation demonstrates that VR can be a powerful and developmentally sensitive tool for simulating peer exclusion in school-aged groups. In Chapters 3 and 4, both the traditional Cyberball paradigm (Williams, 2001) and the new 3D VR classroom conversational paradigm successfully evoked the emotional effects of peer exclusion—lower positive mood, increased negative mood, and frustration of psychological needs (Abrams et al., 2011). However, some differences emerged. VR was consistently perceived as more immersive, realistic, and socially authentic, particularly by adolescents, who engaged with the scenarios on a deeper emotional and interpretative level. In contrast, children's reactions were more related to the visual and playful aspects of the simulation. Furthermore, the quantitative data and outcomes showed a high degree of correspondence, confirming the qualitative findings of the 3D VR paradigm. This was evidenced by adolescents reporting a heightened sense of exclusion compared to children. Conversely, children indicated higher levels of immersion, presence, involvement, and realism compared to their adolescent counterparts. These results suggest that immersive VR paradigms for modelling and examining social interactions are especially effective when developmental priorities shift towards increased social evaluation and perspective-taking, as observed in adolescence (Blakemore & Mills, 2014). In Chapter 5, the importance of a naturalistic experimental environment encompassing a high level of ecological validity was confirmed. Higher levels of realism felt within the VR simulation have been found to moderate and increase the negative impact of peer exclusion on WM. It is therefore imperative not only to develop but also to iteratively refine VR environments through user-centred and evidence-based design methods. Approaches such as participatory and co-design methodologies (Sanders & Stappers, 2014) and human–computer interaction frameworks for

educational research (Milani et al., 2022) can ensure that VR paradigms authentically reflect the dynamics of real classroom interactions. Incorporating qualitative feedback loops from students and teachers—as applied in the current work—enhances ecological fidelity and developmental appropriateness. Technological advances such as adaptive avatars, emotion-sensitive feedback systems, and AI-driven dialogue engines (Makransky & Wang, 2021) could further improve realism and interactivity. Methodologically, this refinement is necessary because highly immersive and socially credible VR contexts elicit psychological and behavioural responses that more closely mirror real-life exclusion experiences, thereby increasing construct validity. These improvements can help researchers and practitioners better evaluate socio-emotional mechanisms of exclusion and develop targeted interventions—a topic further elaborated in the section on practical implications below.

Second, concerning WM across both the experimental and ILD studies, Chapters 5 and 6 reveal that both brief and daily exclusion episodes can impair WM performance, especially in younger children. Negative mood and affect partially mediated the relationship between exclusion and WM decline in both chapters, supporting dual-process models in which social–emotional challenges compete with cognitive resource allocation (Eisenberger et al., 2003). In our own study, the ecological validity of the exclusion scenario modulated effect size: VR-based exclusion, by virtue of its immersive and socially rich context, was associated with both stronger emotional salience and measurable cognitive impact. Furthermore, our findings revealed that contextual factors play a significant role in moderating the adverse effects of peer exclusion on WM. In particular, the socio-economic level exerts a significant influence on the deleterious consequences of peer exclusion, particularly among students from lower socio-economic backgrounds. This pattern aligns with evidence that children from lower-SES contexts exhibit heightened physiological and emotional reactivity to social stressors, partly due to chronic exposure to environmental adversity and reduced access to cognitive scaffolding (Hackman et al., 2023; Ursache & Noble, 2016). Intriguingly, the perception of being positively supported by teachers has been shown to have a negative impact on

the experience of peer exclusion. This counterintuitive effect may reflect that teacher support increases students' emotional engagement and dependence on social evaluation, thereby heightening perceived discrepancy when peers act negatively (Roorda et al., 2017). In other words, strong teacher bonds may amplify sensitivity to social threat when peer support is lacking. The outcomes pertaining to WM were further moderated by individual differences, including baseline WM and behaviour problems, which in turn increased the negative impact of experiences of peer exclusion. This likely occurs because limited baseline WM resources and externalising tendencies reduce self-regulatory capacity under stress, leaving fewer cognitive resources available for task performance (Holmes et al., 2010). Altogether, these findings support Bronfenbrenner's ecological systems theory (2005), showing that both proximal (teacher–student, peer) and distal (SES) contexts jointly shape how children and adolescents process and recover from social stress. In the context of the overarching themes introduced here, this ecological framing provides a unifying theoretical basis for interpreting individual and contextual moderators of exclusion effects.

Third, this body of research highlights clear developmental differences in children's and adolescents' sensitivity to peer exclusion. This represents the third overarching theme of this dissertation. The four chapters addressing peer exclusion revealed both robust, age-invariant effects and developmentally specific patterns. In all cohorts, peer exclusion produced immediate emotional and affective costs, but its cognitive consequences were moderated by age. In all the experimental studies, adolescents reported more nuanced emotional interpretations and attributed greater negative impact to the VR experience, whereas children displayed stronger susceptibility to surface-level features. This conclusion is supported by the qualitative findings of Chapter 3 and by quantitative evidence in Chapters 4 and 5, where adolescents consistently exhibited stronger peer exclusion-related mood changes (larger declines in positive mood and increases in negative mood) compared to children. However, while adolescents demonstrated a heightened emotional response to peer exclusion in comparison to children, the two age groups exhibited divergent significant trends in their

cognitive responses. Specifically, children exhibited a substantial decrease in WM performance following the experience of peer exclusion, while adolescents demonstrated an increase in WM performance. From a developmental perspective, this pattern—also observed in Chapter 5—suggests that adolescents may mobilise compensatory cognitive control resources or motivational mechanisms (e.g., heightened arousal facilitating executive engagement; Somerville et al., 2018) when faced with social threat, whereas younger children experience greater resource depletion. In the study reported in Chapter 6, Grade 4 students showed declines in WMU following daily peer-relatedness frustration. In Grade 5, however, both peer relatedness satisfaction and frustration experiences correlated positively with perceived academic outcomes, a pattern plausibly reflecting the emergence of competitive peer dynamics during early adolescence (Marsh et al., 2008). These outcomes underscore the divergent cognitive resources and mechanisms employed by children and adolescents in their recovery from experiences of peer exclusion. Neurodevelopmental models emphasise that maturation of fronto-limbic circuitry during this period enables better emotional regulation (Crone & Dahl, 2012; Larsen & Luna, 2018). Furthermore, this developmental turning point may reflect the growing ability to reappraise social threat and redirect attention toward goal-directed tasks (Ahmed et al., 2015). The apparent shift between Grades 4 and 5 coincides with early adolescence, when social comparison and self-evaluative motives intensify, enabling some students to transform peer-related stress into motivational drive (Hollarek & Krabbendam, 2020). In sum, this transition marks a reorganisation of socio-cognitive functioning, moving from reactive to more controlled coping strategies.

In sum, the findings of this research indicate that experiences of peer exclusion may exert comparable effects irrespective of whether they are encountered with authentic school peers or simulated in a naturalistic and ecologically valid experimental environment employing non-real and unknown peers. Furthermore, findings emphasise significant developmental pathways and transitions from childhood to adolescence, which entail divergent emotional and cognitive outcomes between these two phases of life. The transition from childhood to adolescence thus represents not merely a

shift in sensitivity to peer exclusion but also a transformation in underlying regulation mechanisms, integrating emotional salience, social motivation, and cognitive control (Dahl et al., 2018; Blakemore, 2018). Additionally, our study outcomes highlight the countervailing forces of emotions and cognition during these developmental periods, providing new insight into how adolescents can harness social stress to maintain or even enhance executive functioning, while younger children remain more vulnerable to its cognitive costs.

Theoretical Contributions

This dissertation advances theoretical understanding of how peer exclusion influences emotional responses and cognitive functioning in childhood and adolescence by integrating three complementary levels of explanation: (1) theoretical backgrounds describing the ecological and attachment foundations of peer exclusion on cognition; (2) developmental perspectives highlighting age-related differences; (3) theoretical frameworks explaining the motivational, sociocultural, and emotion–cognition dynamics underlying peer exclusion effects. This structure reflects the multilevel nature of the findings and clarifies how the empirical work contributes to each domain.

At the theoretical background level, a core contribution of this work is the demonstration in Chapters 5 and 6 that peer exclusion can exert measurable cognitive costs, particularly under ecologically valid conditions, while also revealing the specific parameters under which such effects are absent or moderated. Prior literature has primarily examined the emotional consequences of peer exclusion (Abrams et al., 2011). Although in this dissertation not all analyses found significant WM impairments, the overall pattern of results across the two chapters indicates that both immediate and daily experiences of peer exclusion are associated with variations in WM performance (a central EF; Miyake et al., 2000; Baddeley, 2000). In Chapter 5, immediate WM decline in children was observed following experimentally induced exclusion in a 3D VR classroom context, whereas in Chapter 6, daily experiences of peer relatedness frustration predicted lower WMU performance across 28 school days. Together, these findings nuance the claim that peer exclusion impairs cognition by showing that

its impact depends on temporal scale and contextual specificity, rather than representing a uniform effect.

Within Bronfenbrenner's ecological systems theory (2005), these findings situate peer exclusion as a proximal process through which the immediate social environment influences cognitive functioning. Specifically, Chapter 5 focused on exclusion by unfamiliar peers in an experimental setting, whereas Chapter 6 examined experiences with familiar classmates within naturalistic school contexts. This distinction underscores the difference between situational levels (unfamiliar vs familiar peers) and temporal levels (immediate vs daily), both of which shape the cognitive impact of peer exclusion. Across both levels, the present dissertation demonstrates that the proximal social environment can influence WM independently of the quality or duration of existing social bonds. In this sense, the dissertation contributes to ecological theory by empirically validating the idea that proximal social interactions—whether transient or enduring—form a core mechanism linking the microsystem to cognitive outcomes.

From an Attachment Theory perspective (Bowlby, 1982; Greenberg, 1999), the findings further illustrate how disruptions in perceived social security translate into cognitive consequences. Previous literature has shown that attachment figures such as parents, teachers, and peers function as sources of emotional security that support exploration and learning (Allen, 2008; Gorrese & Ruggi, 2012). In line with these models, the current research found that peer exclusion—by threatening this secure base—triggered affective responses indicative of insecurity and heightened self-focus, which in turn coincided with reduced WM performance (Chapter 5). This finding corroborates prior evidence that insecure or unsupportive attachment contexts increase vigilance to social cues and thereby reduce cognitive resources available for academic tasks (Groh et al., 2014). At the same time, supportive and emotionally available relationships with peers, teachers, or parents are supposed to enhance emotion regulation and cognitive engagement (Mikulincer & Shaver, 2010). The present work corroborates the aforementioned assertions and the overarching theory by substantiating and

accentuating the pivotal role that peers and negative experiences with peers play in students' school wellbeing, cognitive performance, and academic perception. Moreover, although Chapter 5 did not reveal a statistically significant relationship between perceived social support from parents or previous negative peer experiences and the mitigation of peer exclusion, our findings highlight the role of teacher-provided social support. Specifically, teacher support was found to unexpectedly reduce cognitive performance immediately following exclusion. This pattern suggests that well-intended social buffering may, in some cases, increase self-awareness of peer exclusion rather than alleviate its effects. This finding opens new avenues for examining how different social agents (teachers vs. peers) dynamically modulate students' cognitive responses to peer exclusion in classroom settings. Together, these results expand attachment-based perspectives by identifying the classroom as a relational context in which secure-base and safe-haven mechanisms may operate dynamically across multiple attachment figures.

At the developmental perspective level, the dissertation shows that the impact of peer exclusion varies by age. Greater WM decrements in children suggest heightened cognitive susceptibility due to both immature prefrontal networks (Best & Miller, 2010) and less developed emotion regulation skills. As confirmed also in Chapter 5, adolescents, while cognitively more resilient, demonstrated richer emotional interpretation, indicating that developmental changes in cognitive robustness may coincide with deeper socioemotional engagement and potential long-term relational implications (Blakemore & Mills, 2014; Nelson et al., 2016). From a developmental perspective, these outcomes demonstrate that adolescents are more emotionally impacted by peer exclusion and report greater emotional distress (Will et al., 2016). However, these negative and stressful experiences also enhance their cognitive functioning (Sisk & Gee, 2022). This suggests the potential for expanding the field of developmental socio-cognitive research and theories. This work thus provides a concrete foundation for future research examining the mechanisms—such as

emotional salience, regulatory efficiency, and neural maturation—that make adolescents simultaneously more emotionally reactive and cognitively adaptive in peer contexts.

To integrate the aforementioned findings within the broader theoretical frameworks mentioned above, three frameworks are particularly relevant: Self-Determination Theory, Sociocultural Theory, and Cognitive Load Theory, complemented by social neuroscience and the emotion-cognition interplay model.

First, from a Self-Determination Theory perspective (Ryan & Deci, 2000), the need for relatedness is fundamental for motivation and learning. Peer exclusion frustrates this need, as evidenced in Chapters 3, 4, and 5 by reduced mood and WM following exclusion, and in Chapter 6 by day-to-day associations between low relatedness satisfaction and diminished WMU. These results demonstrate that frustrated relatedness not only affects emotional well-being but also directly constrains cognitive resources relevant to learning.

Second, in line with Vygotsky's Sociocultural Theory (2010), cognitive development is scaffolded through social interaction within the zone of proximal development. Peer exclusion removes opportunities for scaffolding, peer modelling, and collaborative problem-solving—mechanisms that are central to learning in school contexts. In this sense, the present work illuminates the essential role of peers in supporting learning by showing that negative peer experiences coincide with lower cognitive engagement, thereby reducing opportunities for optimal learning. The present findings (Chapters 5–6) empirically extend this theory by showing that the absence of such interactions—particularly exclusionary experiences—acts as an inhibitory social context that restricts cognitive engagement and learning efficiency. This resonates with recent evidence linking collaborative peer engagement with EF growth (Fitzpatrick et al., 2014; Perone et al., 2021).

Third, drawing on Cognitive Load Theory (Sweller, 1988; Paas et al., 2016) the results can be interpreted as showing that peer exclusion introduces additional emotional and regulatory demands

that occupy WM capacity. While this study did not directly test load mechanisms, the observed WM declines after exclusion (Chapter 5) and day-to-day WMU variability (Chapter 6) are consistent with the idea that social distress imposes an extraneous cognitive load, reducing resources available for learning-relevant processing (Sweller, 1988). Adopting this perspective, the present research corroborates the role of peer exclusion experiences in increasing the use of cognitive resources employed by students to reappraise and self-regulate following a stressful experience. This, in turn, has a consequential impact on the use of these cognitive resources for other academic tasks, thereby implying the employment of these cognitive functions. The observed WM decline following peer exclusion in Chapters 5 and 6 provides behavioural evidence for the detrimental impact of such extraneous load in authentic learning contexts.

Complementing these frameworks with social neuroscience, the findings also resonate with social-neuroscientific evidence linking peer exclusion to neural activation in affective and cognitive control networks. Social neuroscience evidence showed that peer exclusion recruits neural systems implicated in affective distress (e.g., anterior cingulate cortex, insula) and in executive control (e.g., ventrolateral prefrontal cortex), suggesting shared neurocognitive substrates for social pain and cognitive regulation (Eisenberger et al., 2003; Sebastian et al., 2010). Similar neural activation patterns have been documented in middle childhood, with studies showing that excluded children also exhibit heightened anterior cingulate and insula responses, indicating that the affective–cognitive coupling observed in adolescents is already present earlier in development (Crowley et al., 2010). By documenting behavioural performance decrements in naturalistic simulations in Chapters 3, 4, and 5, this thesis advances a dynamic, process-based view of executive functioning in which cognitive efficiency is permeable to moment-to-moment social–emotional experiences. Age-related patterns observed in the aforementioned chapters suggest adolescence as a sensitive period when the integration of social evaluation and cognitive control is particularly salient (Blakemore & Mills,

2014). Adolescents' more elaborate emotional narratives and higher realism ratings for VR scenarios may reflect maturational gains in social cognition alongside increased salience of peer opinion.

Finally, this dissertation contributes to theoretical models of emotion–cognition interplay. The findings empirically support affective–cognitive competition models (Inzlicht & Gutsell, 2007) in which social exclusion-induced negative affect competes with, and diminishes, cognitive resources for concurrent tasks. However, the findings also highlight emotional regulation as a potential protective mechanism for preserving cognitive performance under socially adverse conditions. The demonstration of two contrasting trends in reacting to experiences of peer exclusion in Chapter 5 (i.e. both a significant decrease and an increase, depending on the triggered emotions) highlights the significance of specific negative moods and emotions' activations, which in turn may have different and opposite cognitive outcomes. These findings are consistent with dual-process models of emotion–cognition interaction (Pessoa, 2013), which proposes that emotion can either hinder or facilitate cognition depending on motivational relevance. In this dissertation, negative affect partially mediated WM decline (Chapter 5), whereas certain emotional activations corresponded with improved performance, highlighting emotion specificity. Accordingly, future theoretical models should integrate this emotion specificity by distinguishing between discrete affective states—such as anger, sadness, or anxiety—and their differential cognitive consequences. Such models could employ multi-component measurement (both self-report and physiological) and dynamic network analysis to capture real-time emotion–cognition coupling in educational settings.

Methodological Reflections

Strengths of the present work lie in the utilisation of diverse methodologies across the four chapters. The integration of qualitative, quantitative, experimental, and ILD methodologies proved invaluable for capturing the multifaceted nature of peer exclusion. Qualitative analysis enriched interpretation by revealing how students perceived and appraised the peer exclusion scenarios, providing insight into subjective realism and emotional resonance. Experimental designs allowed for

causal inference regarding the immediate effects of peer exclusion on mood and WM, while the ILD method revealed the temporal dynamics and within-person variability of peer influence, providing a developmental perspective on social–cognitive links. This triangulation aligns with recommendations in developmental science to combine between- and within-person approaches for a complete understanding of context–behaviour interactions (Hamaker et al., 2015).

The development and use of a 3D VR experimental paradigm imply a fundamental methodological strength. The immersive VR classroom paradigm represents a methodological advance in operationalising peer exclusion through realistic, conversation-based interactions rather than abstract tasks. This improves ecological validity while preserving experimental control, allowing for precise manipulation of situational variables such as peer relationships, classroom dynamics, and other related topics (Parsons, 2015). It also permits examination of nonverbal and paralinguistic cues—eye contact, turn-taking, intonation—that are integral to real-world exclusion but absent from traditional paradigms. By enabling systematic variation in both situational and temporal dimensions of peer exclusion, the VR tool opens new avenues for experimental investigation into the very contextual factors identified in this thesis as central to the social–cognitive link. Future research could further extend this approach by using immersive VR to simulate a broader range of social dynamics—such as inclusion, bullying, or bystander behaviour—allowing for controlled yet naturalistic exploration of how children and adolescents navigate complex peer interactions in real time. These possibilities are further elaborated in the Practical Implications and Future Directions section.

An important methodological reflection concerns the specific design and scenarios of the newly developed VR classroom paradigm. Unlike traditional laboratory-based exclusion tasks such as Cyberball, the VR paradigm was specifically designed to approximate the natural flow and complexity of peer interactions in classroom settings. Interestingly, although participants rated the VR condition higher in terms of immersion, presence, and ecological realism, the emotional impact it produced was comparatively weaker than those elicited by Cyberball. This pattern was consistent

across both children and adolescents, although adolescents showed a relatively stronger emotional response to VR exclusion than younger children. This paradox underscores the possibility that more naturalistic peer exclusion experiences may exert a lower immediate impact precisely because they mirror the ambiguous, gradual, and socially embedded features of real-life peer dynamics, rather than the exaggerated and overt manipulation typical of experimental paradigms. In this sense, the VR classroom may provide a more ecologically valid estimate of the effects of peer exclusion, which could explain the attenuation of mood decrease observed in relation to Cyberball. Similar concerns have been raised in social psychology, where the trade-off between ecological validity and experimental potency remains a central methodological tension (Parsons, 2015; Prendergast & Schubert, 2020). Thus, the development of VR paradigms not only advances methodological innovation but also calls for a reconsideration of how experimental designs balance control with ecological fidelity in the study of social processes.

The ILD used in this dissertation offers a uniquely sensitive perspective to observe the fluctuations of peer interactions in the classroom. By tracking experiences of peer relatedness across multiple time points within the same individuals, the data show that these social dynamics are not fixed but change significantly from day to day, exerting subtle influences on students' WMU and perceived academic outcomes. In students, such fluctuations indicate that the classroom functions as a socially charged environment where competitive and comparative mechanisms may develop alongside collaborative ones, shaping motivation in complex ways (Darnon et al., 2007; Festinger, 1954). This methodological approach therefore demonstrates the importance of detailed, within-person data for moving beyond simple binary views of peer influence, towards models that can explain the bidirectional and context-dependent effects of social interactions on learning. In future work, integrating VR experiments with ILDs could be made feasible by embedding short, repeated VR-based exclusion tasks within classroom or lab sessions across several days. This would allow researchers to capture immediate emotional and cognitive responses while simultaneously tracking

daily variations in peer-related experiences, providing a richer and temporally precise understanding of how peer exclusion dynamics unfold (Schmidt et al., 2019).

Practical Implications

The empirical findings of this thesis have significant implications for educational practice, school-based interventions, and policy design. They demonstrate that peer exclusion is not merely a socio-emotional challenge but also a cognitive and academic risk factor.

From an applied perspective, even brief episodes of social exclusion can have measurable impacts not only on students' emotional well-being but also on their cognitive functioning—specifically, WM—which is essential for learning and academic success. Evidence from Chapter 5 showed that short-lived episodes of peer exclusion significantly impaired WM in both children and adolescents, underscoring the importance of fostering inclusive peer climates within schools. Cooperative learning structures, peer-assisted learning strategies, and social–emotional learning (SEL) curricula (Durlak et al., 2011) can reduce the impact of peer exclusion when they explicitly incorporate inclusion goals and teacher monitoring. When properly implemented, such programmes help students develop empathy, cooperative norms, and social awareness that counteract exclusionary dynamics. For instance, teachers who actively structure group roles and ensure equitable participation can prevent marginalisation and strengthen classroom belonging (Wentzel, 2017).

Teachers can be trained to recognise subtle exclusion behaviours, such as conversational ignoring, nonverbal signalling, group ignoring, or digital exclusion, which often go unnoticed but have significant developmental consequences (Abrams & Killen, 2014), and to facilitate social repair through guided group tasks, peer mediation, or structured turn-taking activities. Evidence suggests that teacher-facilitated peer mediation and cooperative problem-solving can enhance inclusion and improve classroom social climate (Farmer et al., 2019; Spilt et al., 2012). Building on this, educational strategies should place stronger emphasis on teachers' social diagnostic skills—recognising exclusion

patterns early, creating inclusive norms, and intervening constructively to re-engage isolated students—rather than solely identifying at-risk children after difficulties arise. These strategies extend beyond the descriptive findings of this dissertation by emphasising how educators can transform awareness into effective, daily classroom practices. Creating inclusive and emotionally safe environments may act as a protective factor by buffering students against the negative consequences of peer exclusion.

Another important practical implication of the present findings is the need to identify and support those students who are most vulnerable to the cognitive consequences of peer exclusion. The results from both the experimental study in Chapter 5 and the ILD study in Chapter 6 indicate that developmental stage, perceived social support, socio-economic background, and the degree of immersion and relatedness in peer interactions can modulate the extent to which exclusion disrupts WM and related academic processes. For example, younger students and those reporting high internalising and externalising problems or strong engagement with the school social environment may be more susceptible to cognitive performance decrements following peer exclusion events. Schools could implement brief, low-stigma monitoring tools that assess fluctuations in social connectedness, emotion regulation, and classroom engagement (Papadopoulos et al., 2021; Roberts et al., 2025). These findings could guide selective support measures—such as social skills training, resilience-building programmes, or structured peer support initiatives—designed to buffer cognitive costs following negative peer experiences. Embedding such efforts within school routines could help ensure that students' cognitive resources remain available for learning, even in the face of transient social challenges (Jia et al., 2024).

In this regard, literature has shown that supportive classroom climates can enhance cognitive and emotional resilience, particularly in vulnerable youth (Blair & Cybele Raver, 2015). This is especially crucial for students with heightened emotional reactivity, those undergoing sensitive developmental transitions (e.g., late childhood), or those exposed to contextual risks such as low SES

or previous social rejection (Mikami et al., 2010). Findings from Chapters 3, 4, and 5 demonstrated that adolescents displayed stronger emotional reactivity to exclusion (e.g., more pronounced negative mood changes) than children, and that, across both age groups, emotional responses moderated cognitive outcomes. While adolescents experienced mood deterioration coupled with improved WM performance—possibly due to arousal-based cognitive activation—children showed declines. This pattern suggests that the interplay between mood changes and cognitive outcomes varies by age and mood type, and interventions should account for this heterogeneity. Accordingly, developmentally sensitive SEL interventions should be tailored to emotion regulation profiles. Evidence shows that programmes embedding differentiated emotion regulation strategies (e.g., cognitive reappraisal for older students, attention redirection for younger ones) are more effective than uniform approaches (Brackett & Rivers, 2014; Reyes et al., 2012). Integrating these adaptive modules can help align interventions with students' developmental and emotional needs, thereby enhancing both emotional balance and learning outcomes.

School psychologists can integrate VR-based peer exclusion simulations into social–emotional skills programmes, using them to both assess and train peer inclusion behaviours. Because VR provides an immersive, emotionally engaging experience, it can create a powerful bridge between awareness-raising and behavioural change (Lin et al., 2024). Although VR-based social skills and empathy training tools already exist (e.g., Schultze-Krumbholz et al., 2016; Liu et al., 2025), applied research will be necessary to adapt the current paradigm for intervention use and to rigorously test its effectiveness beyond traditional non-VR approaches. This includes iterative co-design with teachers and students, development of adaptive feedback systems, and longitudinal testing to assess whether VR-based inclusion training yields sustained behavioural and cognitive improvements. The VR paradigm developed here offers a versatile platform for school-based interventions. It could be adapted for empathy training (allowing students to experience both the target's and the bystander's perspectives during peer exclusion events, thereby enhancing emotional understanding and prosocial

intentions; Schultze-Krumbholz et al., 2016); social skills rehearsal (enabling students to practise conflict resolution, inclusion strategies, and supportive peer responses within controlled, repeatable scenarios; Liu et al., 2025); teacher professional development (equipping educators with first-person insight into peer exclusion dynamics, thereby informing their classroom management strategies; Bailenson, 2018).

At the policy level, these findings should be interpreted with caution but can inform educational priorities. Policymakers could support evidence-based investments in SEL curricula and digital inclusion tools by funding pilot projects that evaluate their cognitive as well as socio-emotional benefits. Specifically, policies might promote teacher professional development in early exclusion detection and inclusion facilitation, and incentivise schools to adopt validated, ecologically grounded prevention frameworks. By doing so, educational systems can progressively create safer and cognitively supportive peer environments—an aim consistent with, though not directly proven by, the present findings.

Limitations and Future Directions

While this work offers novel empirical insights and methodological innovations, several limitations must be acknowledged to guide cautious interpretation and to inform future research. Looking ahead, several future research directions emerge from these limitations.

A first conceptual limitation is that the present research has focused mainly on negative peer interaction dynamics, namely peer exclusion, without investigating the immediate potential cognitive and emotional benefits of positive peer experiences. Interactions characterised by acceptance, inclusion, and mutual support may engage different neurocognitive pathways, potentially enhancing executive functions and learning outcomes (Hoorn et al., 2016). By neglecting this positive dimension, the current work cannot speak to whether peer inclusion and peer exclusion are symmetrical in their effects or whether they operate through qualitatively distinct mechanisms

(Caprara et al., 2000). Future research should adopt a more balanced approach that incorporates both negative and positive peer dynamics to provide a complete account of the social ecology of learning.

A second limitation relates to the conceptualisation of mood in the present work, which was operationalised primarily through the bipolar dimensions of positive versus negative mood and affect. While this distinction is informative, it does not capture the specificity of discrete emotions—such as anger, sadness, embarrassment, or pride—which may differ in their antecedents, neural correlates, and cognitive consequences. For example, peer exclusion-induced anger might mobilise approach-oriented responses, whereas sadness could lead to withdrawal, each with distinct implications for WM and overall learning outcomes (Nook et al., 2018). Importantly, one study within this dissertation (Chapter 5) did include an exploratory differentiation of discrete emotions in the supplementary analyses, revealing that reductions in happiness and increases in anger mediated the effects of peer exclusion on WM performance. This partial evidence supports the notion that specific emotions, rather than global mood dimensions, may drive distinct cognitive consequences. Integrating such fine-grained emotion analyses more systematically across future studies would therefore provide valuable mechanistic insight. Incorporating fine-grained emotion measures, possibly through multimodal assessments combining self-report, behavioural observation, and physiological indices, would allow for a more differentiated understanding of the affective mechanisms linking peer interactions to cognitive performance (Hohensee et al., 2025). Future work should also investigate the role of emotional context in moderating peer exclusion effects. By systematically varying emotional states—such as high versus low arousal or positive versus negative affect—researchers could determine the boundaries of peer exclusion's impact on cognition and identify conditions under which its effects are amplified or attenuated (Pekrun et al., 2002). For this purpose, a promising avenue could be the integration of physiological and neurological measures—such as heart rate variability, electroencephalography (EEG), or functional magnetic resonance imaging (fMRI)—to capture the underlying biological processes that mediate the link between peer exclusion and

cognition (Lim et al., 2024). Such multimodal approaches could illuminate the temporal dynamics of affective and cognitive responses and clarify whether certain neural patterns are predictive of resilience or vulnerability.

Another important conceptual limitation lies in the focus on WM and WMU as the primary cognitive outcomes. Although WM is a central component of executive functioning and critical for learning, other executive processes—such as inhibition and cognitive flexibility (Miyake et al., 2000)—were not directly assessed. Also, as students come into adolescence, they start to develop more advanced executive functions, like problem-solving, planning, reasoning, and decision-making (Tervo-Clemmens et al., 2023). However, these functions have not been sufficiently considered concerning their social contexts within schools (Holmes et al., 2009). Moreover, a conceptual distinction must be made between WM and WMU, the latter representing the continuous monitoring and manipulation of information in response to changing environmental demands. While Chapter 5 investigated immediate WM changes following acute exclusion, Chapter 6 examined daily fluctuations in WMU as a more dynamic and ecologically sensitive indicator of cognitive adaptation. Future research should therefore integrate both constructs within unified designs to capture how exclusion affects both transient WM capacity and moment-to-moment WMU in real-world settings. It is plausible that peer exclusion impacts a broader set of cognitive systems, each with its own sensitivity to social–emotional disruption (Jia et al., 2024). Future studies incorporating a more comprehensive model of EF tasks will allow for a richer understanding of peer exclusion's cognitive impact. Indeed, broadening the field to include other EFs and attentional processes would enable a more nuanced understanding of how social adversity interacts with cognitive systems. Examining inhibition and cognitive flexibility, as well as problem solving, planning and decision making, together with WM could yield a multidimensional profile of peer exclusion's effects, better informing interventions aimed at mitigating its impact on learning.

As for the methodological limitations, a first limitation concerns the characteristics of the sample. Participants were drawn from two culturally and geographically specific contexts (i.e., an Italian and a German city). This geographic focus was advantageous for maintaining experimental control but inevitably limits the generalisability of the findings to broader populations (Killen & Rutland, 2011). Cultural norms regarding peer relationships, classroom competition and cooperation vary substantially, and these differences could modulate both the experience of peer exclusion and its cognitive consequences (Killen et al., 2002). Specifically, cross-national differences between Cesena (Italy) and Frankfurt (Germany) may reflect distinct cultural and educational frameworks. According to Hofstede's cultural dimensions, Italy is characterised by relatively higher collectivism and uncertainty avoidance, whereas Germany exhibits greater individualism and long-term orientation (Hofstede, 2011). In classroom settings, Italian schools often emphasise relational warmth and collaborative engagement, while the German system tends to promote autonomy and performance-based evaluation (Baumann & Krskova, 2016). These cultural and institutional contrasts may partly explain differences in how students interpret social exclusion, experience teacher support, and link peer relations to academic outcomes. Expanding future research to more diverse cultural and socio-economic contexts will be crucial for testing the universality of the observed mechanisms.

A second methodological limitation related to the sample concerns the developmental scope of the ILD study presented in the final manuscript. Although the aim to investigate the transition from primary to secondary school has been widely emphasised, the daily assessment of peer-relatedness and WMU was conducted exclusively among children aged 9–11 years, thereby excluding adolescents, who constituted a focal group in the earlier experimental studies of this thesis. As adolescence is a period marked by heightened sensitivity to peer evaluation and increasingly complex social-cognitive processing (Blakemore & Mills, 2014), the absence of adolescents' data precludes conclusions about whether the daily cognitive consequences of peer exclusion follow similar patterns across developmental stages. It is plausible that the social salience of peer exclusion during

adolescence would amplify daily fluctuations in working memory and academic self-perceptions, potentially diverging from the trajectories observed in late childhood (Crone & Dahl, 2012). Future research should therefore extend intensive longitudinal designs to adolescent cohorts, in order to capture developmental continuity and discontinuity in the social–cognitive consequences of peer exclusion. This would align with broader lifespan perspectives, emphasising the importance of developmental timing in shaping the impact of social experiences on cognitive functioning (Steinberg & Morris, 2025).

A third methodological limitation is the temporal gap between data sources: the ILD data underpinning Chapter 6 were collected in 2018, whereas the remainder of the thesis draws on data gathered between 2023 and 2024. Given ongoing social and educational changes—such as changes in digital communication, classroom dynamics, and post-pandemic peer relations—the findings from 2018 may not fully generalise to the present context (Viner et al., 2022). Future research should prioritise the collection of new ILD data to verify whether the patterns observed in earlier cohorts persist today.

A fourth methodological limitation concerns the exclusive focus on typically developing students, without the inclusion of participants with neurodevelopmental disorders, learning disabilities, or other clinical conditions. While this choice allowed for greater experimental control and homogeneity, it limits the applicability of the findings to populations for whom peer exclusion may be particularly frequent. Evidence suggests that children with conditions such as attention-deficit/hyperactivity disorder (ADHD), autism spectrum disorder (ASD), or specific learning disorders are at increased risk for peer rejection and victimisation, which can have compounding effects on both socio-emotional and cognitive functioning (e.g., Humphrey & Hebron, 2015; Papadopoulos et al., 2021). Future research should extend the present work to clinical and atypical developmental groups, examining whether the mechanisms identified here operate similarly or whether additional vulnerabilities and resilience factors emerge. Such studies would be especially

valuable for informing targeted interventions in educational settings where diverse developmental profiles are present.

A fifth methodological limitation relates to the VR technology. Although the VR paradigm offered enhanced ecological validity, certain technical challenges remain: avatar realism (limited naturalism in facial expressions and voice synthesis occasionally reduced immersion; Liu et al., 2025); cybersickness (while incidence was low, some participants may have experienced some discomfort, requiring content and delivery optimisation; Chang et al., 2020); hardware requirements (despite decreasing costs, VR hardware availability in schools is uneven, potentially limiting large-scale deployment; Brown et al., 2020). Another factor that must be considered is the novelty effect (Southgate et al., 2019); as VR is still a relatively unfamiliar tool for many students, initial exposure may trigger heightened curiosity, excitement, or distraction, potentially influencing engagement or emotional responses in ways that are not solely attributable to the experimental manipulation. Over time, as novelty diminishes, the same VR scenarios may elicit different patterns of emotion and cognition, raising questions about the stability and generalisability of findings. However, despite the limitations, this dissertation represents an early but crucial step toward the standardisation of VR exclusion paradigms. Standardised protocols would enable cross-study comparability, replication, and meta-analytic synthesis. Validation should be extended to different cultural, linguistic, and educational contexts, as peer norms and exclusion behaviours vary across societies (Killen & Rutland, 2011).

A final methodological limitation related to the VR methodology involves the duration and intensity of peer exclusion episodes in the experimental paradigm. The VR scenarios simulated relatively brief and acute exclusion experiences. While such episodes are ecologically valid for many classroom interactions, they do not fully capture the sustained and repeated exclusion that some students endure over weeks or months (Bailenson, 2018). Chronic exclusion may exert cumulative or qualitatively distinct effects on emotional well-being, executive functioning, and academic

engagement (Ladd et al., 2017). Longitudinal designs that combine VR simulations with real-world tracking of persistent exclusion episodes could clarify these differences. This combined approach was implemented in the present dissertation through the integration of both experimental paradigms and ILDs, enabling the examination of peer exclusion effects across controlled and naturalistic contexts. However, individual studies that relied on only one of these approaches may still be limited in capturing the full temporal and contextual dynamics of peer exclusion experiences.

Final Conclusions

This dissertation makes a contribution to developmental and educational psychology by demonstrating that peer exclusion—whether simulated in VR or occurring in everyday contexts—can have immediate and daily effects on WM and academic success.

Methodologically, it pioneers the use of an immersive VR classroom conversation paradigm that overcomes the ecological limitations of traditional paradigms such as Cyberball, allowing for realistic yet controlled manipulation of peer exclusion events. This innovation opens new pathways for both fundamental research and applied intervention, enabling educators and psychologists to explore peer dynamics in authentic, emotionally engaging contexts.

Theoretically, the work offers a sequential interpretation of the findings through the complementary lenses of Self-Determination Theory, Attachment Theory, Vygotsky's Sociocultural Theory, Ecological Systems Theory, and Cognitive Load Theory, each of which helps to elucidate how social–emotional disruptions can translate into cognitive costs. It also refines developmental and neuroscientific perspectives by showing that children and adolescents differ in both vulnerability and interpretative engagement with peer exclusion experiences.

Practically, the findings underscore the importance of fostering inclusive peer climates in schools and highlight the potential of VR as a promising exploratory tool for studying and supporting socio-emotional learning. While the present evidence does not yet establish its efficacy for empathy-

building or training interventions, it suggests that immersive technologies could serve as a valuable foundation for developing and evaluating such applications in future work. They also provide policymakers with evidence to support socio-emotional education as a means of safeguarding cognitive resources and promoting equitable learning outcomes.

In sum, this dissertation underscores a central principle: cognitive development and academic performance cannot be disentangled from the social contexts in which they unfold. By bridging rigorous experimental control with ecological authenticity, the present work offers both a richer understanding of the exclusion–cognition link between peers at school and a practical toolkit for addressing it in real-world educational environments.

References

Abrams, D., & Killen, M. (2014). Social Exclusion of Children: Developmental Origins of Prejudice. *Journal of Social Issues*, *70*(1). https://doi.org/10.1111/josi.12043

Abrams, D., Weick, M., Thomas, D., Colbe, H., & Franklin, K. M. (2011). On-line ostracism affects children differently from adolescents and adults. *British Journal of Developmental Psychology*, *29*(1). https://doi.org/10.1348/026151010X494089

Ahmed, S. P., Bittencourt-Hewitt, A., & Sebastian, C. L. (2015). Neurocognitive bases of emotion regulation development in adolescence. Developmental Cognitive Neuroscience, 15, 11–25. https://doi.org/10.1016/j.dcn.2015.07.006

Allen, J. P. (2008). The attachment system in adolescence. In J. Cassidy and P. R. Shaver (Eds.), Handbook of attachment: Theory, research, and clinical applications (pp. 419-435). Guilford Press.

Baddeley, A. (2000). The episodic buffer: A new component of working memory? In *Trends in Cognitive Sciences* (Vol. 4, Issue 11). https://doi.org/10.1016/S1364-6613(00)01538-2

Bailenson, J. (2018). Experience on Demand: What Virtual Reality Is, How It Works, and What It Can Do. In *National Defense*.

Baumann, C., & Krskova, H. (2016). School discipline, school uniforms and academic performance. *International Journal of Educational Management*, 30(6), 1003-1029.

Best, J. R., & Miller, P. H. (2010). A Developmental Perspective on Executive Function. In *Child Development* (Vol. 81, Issue 6). https://doi.org/10.1111/j.1467-8624.2010.01499.x

Blair, C., & Cybele Raver, C. (2015). School readiness and self-regulation: A developmental psychobiological approach. *Annual Review of Psychology*, *66*. https://doi.org/10.1146/annurev-psych-010814-015221

Blakemore, S.-J. (2018). Inventing ourselves: The secret life of the teenage brain. Doubleday.

Blakemore, S. J., & Mills, K. L. (2014). Is adolescence a sensitive period for sociocultural processing? In *Annual Review of Psychology* (Vol. 65). https://doi.org/10.1146/annurev-psych-010213-115202

Bowlby, J. (1982). Attachment and loss: Attachment (Vol. 1). In *Attachment* (Vol. 1).

Brackett, M. A., & Rivers, S. E. (2014). Transforming students' lives with social and emotional learning. In *International Handbook of Emotions in Education*. https://doi.org/10.4324/9780203148211

Bronfenbrenner, U. (2005). Making human beings human: Bioecological perspectives on human development. In *British Journal of Developmental Psychology* (Vol. 23, Issue 1).

Brown, M., McCormack, M., Reeves, J., Brooks, C., & Grajek, S. (2020). 2023 EDUCAUSE Horizon Report. Teaching and Learning Edition. In EDUCAUSE Horizon Report Review (Vol. 55, Issue 1)Caprara, G. V., Barbaranelli, C., Pastorelli, C., Bandura, A., & Zimbardo, P. G. (2000). Prosocial foundations of children's academic achievement. *Psychological Science*, *11*(4). https://doi.org/10.1111/1467-9280.00260

Chang, E., Kim, H. T., & Yoo, B. (2020). Virtual Reality Sickness: A Review of Causes and Measurements. *International Journal of Human-Computer Interaction*. https://doi.org/10.1080/10447318.2020.1778351

Crone, E. A., & Dahl, R. E. (2012). Understanding adolescence as a period of social-affective engagement and goal flexibility. *Nature Reviews Neuroscience*, *13*(9). https://doi.org/10.1038/nrn3313

Crowley, M. J., Wu, J., Molfese, P. J., & Mayes, L. C. (2010). Social exclusion in middle childhood: Rejection events, slow-wave neural activity, and ostracism distress. *Social Neuroscience*, *5*(5). https://doi.org/10.1080/17470919.2010.500169

Dahl, R. E., Allen, N. B., Wilbrecht, L., & Suleiman, A. B. (2018). Importance of investing in adolescence from a developmental science perspective. Nature, 554(7693), 441–450. https://doi.org/10.1038/nature25770

Darnon, C., Butera, F., & Harackiewicz, J. M. (2007). Achievement goals in social interactions: Learning with Mastery vs. Performance goals. *Motivation and Emotion*, *31*(1). https://doi.org/10.1007/s11031-006-9049-2

Durlak, J. A., Weissberg, R. P., Dymnicki, A. B., Taylor, R. D., & Schellinger, K. B. (2011). The Impact of Enhancing Students' Social and Emotional Learning: A Meta-Analysis of School-

Based Universal Interventions. *Child Development*, *82*(1). https://doi.org/10.1111/j.1467-8624.2010.01564.x

Eisenberger, N. I., Lieberman, M. D., & Williams, K. D. (2003). Does rejection hurt? An fMRI study of social exclusion. *Science*, *302*(5643). https://doi.org/10.1126/science.1089134

Farmer, T. W., Hamm, J. V., Dawes, M., Barko-Alva, K., & Cross, J. R. (2019). Promoting inclusive communities in diverse classrooms: Teacher attunement and social dynamics management. Educational Psychologist, 54(4), 286-305.

Festinger, L. (1954). A Theory of Social Comparison Processes. *Human Relations*, *7*(2). https://doi.org/10.1177/001872675400700202

Fitzpatrick, C., McKinnon, R. D., Blair, C., & Willoughby, M. T. (2014). Do preschool executive function skills explain the school readiness gap between advantaged and disadvantaged children? Learning and Instruction, 30, 25–31. https://doi.org/10.1016/j.learninstruc.2013.11.003

Gorrese, A., & Ruggieri, R. (2012). Peer attachment: A meta-analytic review of gender and age differences and associations with parent attachment. Journal of youth and adolescence, 41(5), 650-672.

Greenberg, M. T. (1999). Attachment and psychopathology in childhood. In The Guilford Press (Ed.), *J. Cassidy & P. R. Shaver (Eds.), Handbook of attachment: Theory, research, and clinical applications* (pp. 469–496).

Groh, A. M., Fearon, R. M. P., Bakermans-Kranenburg, M. J., van IJzendoorn, M. H., Steele, R. D., & Roisman, G. I. (2014). The significance of attachment security for children's social competence with peers: A meta-analytic study. Attachment & Human Development, 16(2), 103–136. https://doi.org/10.1080/14616734.2014.883636

Hackman, D. A., Gallop, R., Evans, G. W., & Farah, M. J. (2015). Socioeconomic status and executive function: Developmental trajectories and mediation. Developmental science, 18(5), 686-702.

Hamaker, E. L., Kuiper, R. M., & Grasman, R. P. P. P. (2015). A critique of the cross-lagged panel model. *Psychological Methods*, *20*(1). https://doi.org/10.1037/a0038889

Hofstede, G. (2011). Dimensionalizing cultures: The Hofstede model in context. *Online readings in psychology and culture*, 2(1), 8.

Hohensee, N., Joormann, J., & Gadassi-Polack, R. (2025). Examining the association among adolescents' emotional clarity, emotion differentiation, and the regulation of negative and positive affect using a daily diary approach. *Emotion*, *25*(1), 144–157. https://doi.org/10.1037/emo0001424

Hollarek, M., Lee, N. C., & Krabbendam, L. (2020). The effect of social feedback from peers on adolescent cognitive control. Journal of Adolescence, 85, 12-20.

Holmes, J., Gathercole, S. E., & Dunning, D. L. (2009). Adaptive training leads to sustained enhancement of poor working memory in children. *Developmental Science*, *12*(4). https://doi.org/10.1111/j.1467-7687.2009.00848.x

Holmes, J., Gathercole, S. E., Place, M., Dunning, D. L., Hilton, K. A., & Elliott, J. G. (2010). Working memory deficits can be overcome: Impacts of training and medication on working memory in children with ADHD. Applied cognitive psychology, 24(6), 827-836.

Hoorn, J. Van, Dijk, E. Van, Güroğlu, B., & Crone, E. A. (2016). Neural correlates of prosocial peer influence on public goods game donations during adolescence. *Social Cognitive and Affective Neuroscience*, *11*(6). https://doi.org/10.1093/scan/nsw013

Humphrey, N., & Hebron, J. (2015). Bullying of children and adolescents with autism spectrum conditions: A 'state of the field' review. *International Journal of Inclusive Education*, *19*(8). https://doi.org/10.1080/13603116.2014.981602

Inzlicht, M., & Gutsell, J. N. (2007). Running on empty: Neural signals for self-control failure. *Psychological Science*, *18*(11). https://doi.org/10.1111/j.1467-9280.2007.02004.x

Jia, W., Huang, C., Hu, N., & Cai, D. (2024). The association between school bullying and executive functions in children and adolescents: A three-level meta-analysis. In *Journal of Adolescence* (Vol. 96, Issue 8, pp. 1713–1726). John Wiley and Sons Inc. https://doi.org/10.1002/jad.12397

Killen, M., Lee-Kim, J., Mcglothlin, H., Stangor, C., & Helwig, C. C. (2002). How Children and Adolescents Evaluate Gender and Racial Exclusion. *Source: Monographs of the Society for Research in Child Development*, *67*(4).

Killen, M., & Rutland, A. (2011). Children and Social Exclusion: Morality, Prejudice, and Group Identity. In *Children and Social Exclusion: Morality, Prejudice, and Group Identity*. https://doi.org/10.1002/9781444396317

Ladd, G. W., Ettekal, I., & Kochenderfer-Ladd, B. (2017). Peer victimization trajectories from kindergarten through high school: Differential pathways for children's school engagement and achievement? *Journal of Educational Psychology*, *109*(6). https://doi.org/10.1037/edu0000177

Larsen, B., & Luna, B. (2018). Adolescence as a neurobiological critical period for the development of higher-order cognition. Neuroscience and Biobehavioral Reviews, 94, 179–195. https://doi.org/10.1016/j.neubiorev.2018.09.005

Lim, L., Talozzi, L., & Howells, H. (2024). Atypical brain structural connectivity and social cognition in childhood maltreatment and peer victimisation. *BMC Psychiatry*, *24*(1). https://doi.org/10.1186/s12888-024-05759-3

Lin, H. L., Wang, Y. C., Huang, M. L., Yu, N. W., Tang, I., Hsu, Y. C., & Huang, Y. S. (2024). Can virtual reality technology be used for empathy education in medical students: a randomized case-control study. *BMC Medical Education*, *24*(1). https://doi.org/10.1186/s12909-024-06009-6

Liu, C., Meng, S., Zheng, W., & Zhou, Z. (2025). Research on the impact of immersive virtual reality classroom on student experience and concentration. *Virtual Reality*, *29*(2). https://doi.org/10.1007/s10055-025-01153-w

Makransky, G., & Wang, A. I. (2021). The cognitive affective model of immersive learning (CAMIL): A theoretical research-based model of learning in immersive virtual reality. Educational Psychology Review, 33(3), 937–958. https://doi.org/10.1007/s10648-020-09586-2

Marsh, H. W., Seaton, M., Trautwein, U., Lüdtke, O., Hau, K. T., O'Mara, A. J., & Craven, R. G. (2008). The big-fish-little-pond-effect stands up to critical scrutiny: Implications for theory,

methodology, and future research. Educational Psychology Review, 20(3). https://doi.org/10.1007/s10648-008-9075-6

Mikami, A. Y., Lerner, M. D., & Lun, J. (2010). Social context influences on children's rejection by their peers. *Child Development Perspectives*, *4*(2). https://doi.org/10.1111/j.1750-8606.2010.00130.x

Mikulincer, M., & Shaver, P. R. (2010). Attachment in adulthood: Structure, dynamics, and change. Guilford Publications.

Milani, A. S., Cecil-Xavier, A., Gupta, A., Cecil, J., & Kennison, S. (2022). A systematic review of human–computer interaction (HCI) research in medical and other engineering fields. International Journal of Human–Computer Interaction. https://doi.org/10.1080/10447318.2022.2116530

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The Unity and Diversity of Executive Functions and Their Contributions to Complex 'Frontal Lobe' Tasks: A Latent Variable Analysis. *Cognitive Psychology*, *41*(1). https://doi.org/10.1006/cogp.1999.0734

Nelson, E. E., Jarcho, J. M., & Guyer, A. E. (2016). Social re-orientation and brain development: an expanded and updated view. Dev. Cogn. Neurosci. 17, 118–127.

Nook, E. C., Sasse, S. F., Lambert, H. K., McLaughlin, K. A., & Somerville, L. H. (2018). The Nonlinear Development of Emotion Differentiation: Granular Emotional Experience Is Low in Adolescence. *Psychological Science*, *29*(8). https://doi.org/10.1177/0956797618773357

Paas, F. P., Renkl, A. R., & Sweller, J. S. (2016). Cognitive Load Theory and Instructional Design: Recent Developments. In *Educational Psychologist: A Special Issue of educational Psychologist: Volume 38* (Vol. 38). https://doi.org/10.4324/9780203764770-1

Papadopoulos, A., Seguin, D., Correa, S., & Duerden, E. G. (2021). Peer victimization and the association with hippocampal development and working memory in children with ADHD and typically-developing children. *Scientific Reports*, *11*(1). https://doi.org/10.1038/s41598-021-95582-7

Parsons, T. D. (2015). Virtual reality for enhanced ecological validity and experimental control in the clinical, affective and social neurosciences. *Frontiers in Human Neuroscience*, *9*(DEC). https://doi.org/10.3389/fnhum.2015.00660

Pekrun, R., Goetz, T., Titz, W., & Perry, R. P. (2002). Academic emotions in students' self-regulated learning and achievement: A program of qualitative and quantitative research. In *Educational Psychologist* (Vol. 37, Issue 2). https://doi.org/10.1207/S15326985EP3702_4

Perone, S., Simmering, V. R., & Buss, A. T. (2021). A dynamical reconceptualization of executive-function development. Perspectives on Psychological Science, 16(6), 1198–1208. https://doi.org/10.1177/1745691620966792

Pessoa, L. (2013). The cognitive-emotional brain: From interactions to integration. In *The cognitive-emotional brain: From interactions to integration.*

Prendergast, C. N., & Schubert, T. (2020). Investigating Reflexive Responses to Explicit and Implicit Forms of Social Exclusion Using Immersive Virtual Environment Technology. *Frontiers in Psychology*, *11*. https://doi.org/10.3389/fpsyg.2020.575783

Reyes, M. R., Brackett, M. A., Rivers, S. E., White, M., & Salovey, P. (2012). Classroom emotional climate, student engagement, and academic achievement. Journal of Educational Psychology, 104(3), 700–712. https://doi.org/10.1037/a0027268

Roberts, E., Francesconi, M., & Flouri, E. (2025). The effect of peer victimisation on cognitive development in childhood: evidence for mediation via inflammation. *Social Psychiatry and Psychiatric Epidemiology*. https://doi.org/10.1007/s00127-025-02836-0

Roorda, D. L., Jak, S., Zee, M., Oort, F. J., & Koomen, H. M. (2017). Affective teacher–student relationships and students' engagement and achievement: A meta-analytic update and test of the mediating role of engagement. School Psychology Review, 46(3), 239–261. https://doi.org/10.17105/SPR-2017-0035.V46-3

Ryan, R. M., & Deci, E. L. (2000). Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. *American Psychologist*, *55*(1). https://doi.org/10.1037/0003-066X.55.1.68

Sanders, E. B. N., & Stappers, P. J. (2014). Probes, toolkits and prototypes: Three approaches to making in codesigning. CoDesign, 10(1), 5–14. https://doi.org/10.1080/15710882.2014.888183

Schmidt, A., Dirk, J., & Schmiedek, F. (2019). The importance of peer relatedness at school for affective well-being in children: Between- and within-person associations. *Social Development*, *28*(4). https://doi.org/10.1111/sode.12379

Schultze-Krumbholz, A., Schultze, M., Zagorscak, P., Wölfer, R., & Scheithauer, H. (2016). Feeling cybervictims' pain-The effect of empathy training on cyberbullying. *Aggressive Behavior*, *42*(2). https://doi.org/10.1002/ab.21613

Sebastian, C., Viding, E., Williams, K. D., & Blakemore, S. J. (2010). Social brain development and the affective consequences of ostracism in adolescence. In *Brain and Cognition* (Vol. 72, Issue 1). https://doi.org/10.1016/j.bandc.2009.06.008

Sisk, L. M., & Gee, D. G. (2022). Stress and adolescence: vulnerability and opportunity during a sensitive window of development. Current Opinion in Psychology, 44, 286-292.

Somerville, L. H., Sasse, S. F., Garrad, M. C., Drysdale, A. T., Abi Akar, N., Insel, C., & Wilson, R. C. (2017). Charting the expansion of strategic exploratory behavior during adolescence. Journal of experimental psychology: general, 146(2), 155.

Southgate, E., Smith, S. P., Cividino, C., Saxby, S., Kilham, J., Eather, G., Scevak, J., Summerville, D., Buchanan, R., & Bergin, C. (2019). Embedding immersive virtual reality in classrooms: Ethical, organisational and educational lessons in bridging research and practice. *International Journal of Child-Computer Interaction*, *19*, 19–29. https://doi.org/10.1016/j.ijcci.2018.10.002

Spilt, J. L., Koomen, H. M., Thijs, J. T., & Van der Leij, A. (2012). Supporting teachers' relationships with disruptive children: The potential of relationship-focused reflection. Attachment & human development, 14(3), 305-318.

Steinberg, L., & Morris, A. S. (2025). *ADOLESCENT DEVELOPMENT* (Vol. 17). www.annualreviews.org.

Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive Science*, *12*(2). https://doi.org/10.1016/0364-0213(88)90023-7

Tervo-Clemmens, B., Calabro, F. J., Parr, A. C., Fedor, J., Foran, W., & Luna, B. (2023). A canonical trajectory of executive function maturation from adolescence to adulthood. *Nature Communications*, *14*(1). https://doi.org/10.1038/s41467-023-42540-8

Ursache, A., & Noble, K. G. (2016). Neurocognitive development in socioeconomic context: Multiple mechanisms and implications for measuring socioeconomic status. Psychophysiology, 53(1), 71-82.

Viner, R., Russell, S., Saulle, R., Croker, H., Stansfield, C., Packer, J., Nicholls, D., Goddings, A. L., Bonell, C., Hudson, L., Hope, S., Ward, J., Schwalbe, N., Morgan, A., & Minozzi, S. (2022). School Closures during Social Lockdown and Mental Health, Health Behaviors, and Well-being among Children and Adolescents during the First COVID-19 Wave: A Systematic Review. In *JAMA Pediatrics* (Vol. 176, Issue 4). https://doi.org/10.1001/jamapediatrics.2021.5840

Vygotsky, L. S. (2010). Mind in society: Development of higher psychological processes. In *Boston Studies in the Philosophy and History of Science* (Vol. 287).

Wentzel, K. R. (2017). Peer relationships, motivation, and academic performance at school. In A. J. Elliot, C. S. Dweck, & D. S. Yeager (Eds.), Handbook of competence and motivation (2nd ed., pp. 586–603). Guilford Press.

Will, G. J., van Lier, P. A. C., Crone, E. A., & Güroğlu, B. (2016). Chronic Childhood Peer Rejection is Associated with Heightened Neural Responses to Social Exclusion During Adolescence. *Journal of Abnormal Child Psychology*, 44(1).

Williams, K. D. (2001). *Ostracism: the power of silence. (Emotions and social behavior)*. Guilford.