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Can virtual reality improve social-emotional learning among adolescents? An experimental study

Qinna Feng [a], Gege Li [a], Yanbei Chen [b], Feng Zhang [a], Wenhao Li [a,*], Heng Luo [a,**]

[a] Faculty of Artificial Intelligence in Education, Central China Normal University, China
[b] Department of Instructional Design, Development, and Evaluation, Syracuse University, USA

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ABSTRACT

The potential of virtual reality (VR) to support social-emotional learning (SEL) has been widely acknowledged, but design precedents for VR-based SEL interventions are still lacking in the literature. The effectiveness of such interventions also remains uncertain due to insufficient empirical evidence. To bridge this research gap, the present study adopted a between-subjects design to explore the impact of a VR-based intervention on enhancing SEL and learning experience. A total of 297 seventh-grade students in China were randomly assigned to one of three conditions: VR (n = 101), face-to-face (n = 107), and control (n = 89). Participants in both the VR and face-to-face conditions engaged in collaborative tasks designed to promote SEL, while the control condition received no such intervention. The findings revealed significant improvement in overall social-emotional competencies in the VR condition, especially in the subscales of task performance, collaboration, and engagement with others. The VR intervention also promoted a stronger sense of group cohesion and enriched social experiences. These findings offer practical implications for the design and implementation of VR-based SEL interventions in formal education settings.

1. Introduction

Social-emotional learning (SEL) is widely recognized as a crucial component of 21st-century skill development (UNESCO, 2019), which is an effective way to promote social-emotional competences (SECs). SECs are known as non-cognitive or psychosocial competence, encompassing the multifaceted strategies and abilities that individuals employ to effectively navigate and adeptly manage emotions, maintain positive relationships, and achieve personal goals (Collie, 2022). SECs have been strongly associated with academic and professional success (Dowling et al., 2019; Kasikci & Ozhan, 2021; OECD, 2024; Wang et al., 2019) and are significant predictors of personal well-being (Bierman et al., 2010; Jones et al., 2015), healthy interpersonal relationships (Weissberg et al., 2015), and overall societal harmony (You et al., 2023). This growing recognition underscores the need to explore how SECs can be effectively nurtured across diverse developmental stages.

Compared to adults, children and adolescents are facing more challenges in SEC development due to factors such as increased academic pressure (Kleinkorres et al., 2023), limited life experience (Naz et al., 2021), vulnerable developmental stage (Povey et al.,

* Corresponding author. 152 Luoyu Street, Central China Normal University, Wuhan, 430079, China.
** Corresponding author. 152 Luoyu Street, Central China Normal University, Wuhan, 430079, China.
E-mail addresses: whenhowlee@ccnu.edu.cn (W. Li), luoheng@ccnu.edu.cn (H. Luo).

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2022), and high family expectations (Zhang, 2024). These challenges are known to cause prevalent social-emotional issues such as disruptive behavior, depression, anxiety, and eating disorders (Ogundele, 2018; Potterton et al., 2022). Leaving these issues unattended can cause serious consequences such as bullying, aggression, suicide, and antisocial behaviors among young people (Di Stasio et al., 2016; Neth et al., 2020).

Previous studies claimed that digital-game is effective for enabling children and adolescents to develop SECs (Shoshani et al., 2021; Toh & Kirschner, 2023), such as *Emotion Detectives* (Koivula et al., 2017) and *Zoo U* (DeRosier & Thomas, 2017). As highlighted in the literature by Toh & Kirschner, 2023, video games facilitate the development of SECs such as emotional regulation, prosocial behaviors, and relationship management, by allowing students to experience and reflect on social interactions in a controlled and safe space. However, video games often lack the sensory richness and embodied presence necessary to simulate authentic social contexts, which limits players' ability to engage in realistic emotional and interpersonal exchanges (Chen et al., 2024; Parsons & Cobb, 2011; Toh & Kirschner, 2023). This limited realism can reduce the transferability of skills acquired in-game to real-life social situations.

Virtual reality (VR) has emerged as a promising technology to support game-based SEL by offering immersive, interactive, safety and emotionally engaging spaces that can simulate complex social situations with high fidelity (Mosher & Carreon, 2021; Tan et al., 2023). First, VR can create diverse immersive and multisensory real-life scenarios that provide students with individualized experiences to practice behavioral and emotional skills rather than a generic experience delivered in a classroom or school setting (Veling et al., 2014). Second, VR environments enable more social opportunities for leaners through natural communications and real-time interactions with avatars and peers (Arts et al., 2023). Third, VR can provide a controlled and safe environment with minimal real-world consequences (Yu et al., 2023), such as victimization, rejection, embarrassment, or other risks often encountered in real-life settings (Didehbani et al., 2016).

Several studies have indicated that VR program can develop essential SECs, such as social behaviors and emotion expression and regulation (Bailey et al., 2019; Beidel et al., 2021; Ip et al., 2018). Existing VR programs mainly simulate specific real-life scenarios for specific skill, such as emotional recognition, social communication, and social adaptation training (Chen et al., 2024). These VR interventions often replicate structured scenarios, such as classroom scenes (Ke et al., 2020), bus stop (Cheng et al., 2015), pedestrian crossing scene (Vidhusha et al., 2019), particularly those with autism spectrum disorder (ASD), develop the ability to understand emotions and practice appropriate social behaviors (Parsons & Cobb, 2011). However, most studies focused on single-user VR experiences (Ip et al., 2018; Johnson et al., 2021; Lorenzo et al., 2013; Stavroulia & Lanitis, 2023), which, while beneficial for specific skill acquisition, do not fully replicate the dynamic nature of real-world social interactions. There are currently comparatively few empirical studies investigating the effect of collaboration in VR environments to promote SEL, although earlier research has suggested that social-emotional interactions are most likely to occur in collaborative learning situations (Huang & Lajoie, 2023). Furthermore, most of these studies have been implemented in the context of special education (Zhang et al., 2024), highlighting the urgent need to investigate VR-based instructional interventions for the general student population.

To address these research gaps, we designed and developed an immersive and collaborative VR program to support the development of SECs among adolescents and conducted an experiment in a regular middle school in China to determine the effectiveness of this VR program. The experiment comprised two treatment groups (SEL interventions in VR and face-to-face settings) and a control group (no intervention). The control group is used to isolate the intervention effect by keeping all extraneous variables constant between groups, so that possible threats to internal validity such as history and practice effects can be minimized. The face-to-face treatment group serves as an important reference that might reveal unique benefits and limitations of VR as a technology-enhanced learning space for SEL. Particularly, the following questions guided our investigation.

1. Can the collaborative VR program improve SECs among adolescents in regular education?
2. Compared to a face-to-face SEL program, is the VR program more effective in improving SECs? How does this effect vary among different SEC subscales?
3. How do learning experiences differ between SEL programs conducted in VR versus face-to-face settings?

2. Literature review

2.1. SEL

There is no one-size-fits-all definition of SEL. However, it has been comprehensively defined at different levels: At a macro-level, SEL involves learning and applying social, emotional, behavioral, and character skills essential for success in school, the workplace, relationships, and citizenship (Jones et al., 2019, pp. 18–24). At a meso level, SEL can be defined as "the process through which all young people and adults acquire and apply the knowledge, skills, and attitudes to develop healthy identities, manage emotions and achieve personal and collective goals, feel and show empathy for others, establish and maintain supportive relationships, and make responsible and caring decisions" (Collaborative for Academic, Social, and Emotional Learning [CASEL], 2020). According to the leading framework, CASEL, SEL can be further identified at a micro-level in terms of several specific skills and capacities, such as self-awareness, self-management, social awareness, relationship skills, and responsible decision-making.

As the objective of SEL, SEC serves as an umbrella term that refers to a range of capabilities that enable individuals to express, regulate, and understand their thoughts, emotions, and behaviors in daily interactions and adopt to changing situations. SECs are also known under different terms, such as non-cognitive or soft skills, personality characteristics, character, virtues, or 21st-century skills (Duckworth & Yeager, 2015). SECs are conceptually different from academic abilities and subject-matter achievement; rather, SECs emerge from reciprocal interactions between biological predispositions and environmental factors and develop progressively as

children mature. SECs can be shaped through various socialization experiences and learning opportunities in both formal and informal settings; they are thus malleable and responsive to interventions. Though often viewed as stable traits, SEC vary across contexts and evolve over time, contributing significantly to educational success, lifelong well-being, and socio-economic outcomes (De Fruyt et al., 2015).

OECD proposed a framework of assessing SECs based on the Big Five Personality Traits Model (Chernyshenko et al., 2018), which provided a comprehensive and evidence-based approach for understanding the individual skills and characteristics essential for personal and professional development. This framework encompasses six domains of SECs: task performance, emotional regulation, collaboration, open-mindedness, engaging with others, and compound skills. Task performance focuses on achieving goals, taking responsibility, and demonstrating persistence (Collie, 2022). Emotional regulation involves managing stress, maintaining optimism, and practicing emotional control. Collaboration emphasizes empathizing with others, building mutual trust, and collaborating effectively during teamwork (Huang & Lajoie, 2023). Open-mindedness means cultivating curiosity, practicing tolerance, and promoting creativity. Engaging with others includes sociability and energy in interpersonal interactions (Chernyshenko et al., 2018). Compound skills combine multiple homogeneous skills, such as self-efficacy, critical thinking/independence, and self-reflection/meta-cognition. These skills predict important outcomes by integrating multiple characteristics into an overall composite. Compared to CASEL, which primarily relies on self-reported measures, SECs as assessed with the framework can also be observed in classroom settings by teachers and researchers (Susanne et al., 2012), which makes it particularly suitable for the younger student population. This study therefore adopted this framework to assess SECs of the study participants who were seventh-grade students.

2.2. Approaches for SEL

SEL approaches are traditionally grounded in play-based curricula or collaborative activities, such as small group lessons (Gatzke-Kopp et al., 2015), instructional practices (Sutherland et al., 2018), social skill instruction, or support embedded in play or activities with peers (Stanton-Chapman et al., 2014). Lin et al. (2023) investigated commonly used SEL programs, such as the framework for recognizing, understanding, labeling, expressing, and regulating emotions, the promoting alternative thinking strategies program, Sanford harmony, second step, zones of regulation, and semi-structured block play. These programs provide SEL curricula that require active engagement and encourage social interactions among children, who are also enabled to apply SECs in a natural and complex social process, which benifits holistic development (Bodrova et al., 2023; Devlin et al., 2023; Domitrovich et al., 2007) when implemented faithfully (Durlak et al., 2011). However, these traditional approaches have some limitations. For example, these methods often require considerable resources, such as sufficient staffing, training, and materials, which may not be feasible in all educational settings. Moreover, the effectiveness of these interventions can vary widely depending on implementation fidelity and individual differences among children (Hunter et al., 2022; Weisberg et al., 2016).

The role of technology in promoting SEL is growing, extending SEL beyond traditional curricula. Interactive tools, such as virtual agents (e.g., Self-Talk with Superhero Zip), robots (Ihamäki & Heljakka, 2020) and digital games (Toh & Kirschner, 2023), offer engaging and personalized environment for learners to practice emotional management skills (Fu et al., 2023), mediate interpersonal conflict (Shen et al., 2018), and augment positive mood (Crossman et al., 2018). Games, in particular, provide meaningful opportunities for social interaction, feedback, and emotional decision-making, making them a promising approach for SEL (Nikolayev et al., 2016).

However, while these technologies can yield positive outcomes, their application often lacks high-level immersion and embodied design, which are crucial for effective SEL implementations (Durlak et al., 2011; Hunter et al., 2022). This limitation suggests the need for more immersive and tailored technological solutions, such as VR. The affordances of VR include authentic and immersive experiences (Parsons, 2016), characterized by natural interactions that allow learners to react and respond in virtual worlds in a manner similar to real-world interactions, thereby immersing them in the computer-mediated environment. Additionally, VR can provide students with customized experience based on their preference, interests, and physiological or psychological characteristics (Marougkas et al., 2024). The choices of scenarios, avatars, and the mission complexity in turn, shape students' SEL experience within the VR program.

2.3. VR as an SEL approach

VR has been shown to be an effective intervention for promoting SEL among children and adolescents (Zhang et al., 2023). For example, Lorenzo et al. (2013) found that students improved in executive functions and social skills after experiencing simulated classroom interactions, peer conversations, and emotional comprehension. Similarly, Ip et al. (2018) reported significant improvements in children's emotional expression, emotion regulation and social-emotional reciprocity following a VR-based training program. Kolk et al. (2023) designed a VR training program that simulated authentic social settings, such as cinemas and school canteens, to provide personalized social skills training. The results demonstrated that children showed significant gains in communication, social attention, and conflict resolution. Additionally, prior studies suggest that even short-term immersive VR interventions can enhance SECs. For example, Parong and Mayer (2021) designed an immersive VR lesson lasting approximately 12 min and found that short-term VR interventions can induce a positive and highly arousing affective state. Similarly, Dong et al. (2025) reported increased empathy after a 10–15-min VR game. Bailey et al. (2019) found that although children were only exposed to a short VR experience, they demonstrated improvements in sharing behavior with minimal physical and emotional distress.

Although current VR-based SEL programs have demonstrated positive effects, they are predominantly grounded in simulations of

real-world environments—such as classrooms, supermarkets, or public spaces (Cheng et al., 2015; Ip et al., 2018). These simulations typically aim to recreate specific contexts with high fidelity, offering learners structured scenarios to practice predefined skills, particularly among populations with ASD (Zhang et al., 2023). However, such simulations often lack elements of agency, challenge, and feedback dynamics that are central to game-based learning. As highlighted by Merchant et al. (2014) in their meta-analysis, game-based learning environments are more effective than simulations, as they encourage active decision-making, strategic thinking, and emotional engagement. VR games, by integrating competition, collaboration, and narrative-driven roles, can create emotionally engaging experiences that more authentically mirror the complexity of interpersonal relationships (Toh & Kirschner, 2023). Additionally, it is noteworthy that most existing studies on VR's facilitation of SEL primarily concentrate on children with neurodevelopmental disorders, particularly ASD (Zhang et al., 2023). There is limited research examining its impact on typically developing children, which constitutes a research gap in this domain.

Furthermore, most current research on VR-based SEL has focused on single-user VR experiences (Ip et al., 2022; Ke & Im, 2013). However, as technology advances rapidly, novel multi-user VR spaces, such as the metaverse, are gaining prominence. These multi-user VR environments exhibit significant potential for facilitating collaborative activities (Parsons, 2015), which presents novel avenues for SEL education. First, social interactions in a multi-user VR are more authentic and natural. Unlike single-user VR experiences, multi-user VR enables real-time interactions within a virtual environment while collaborating on tasks with real persons (Liang et al., 2019). In this immersive context, learners can intuitively observe their peers' expressions, gestures, and body language intuitively (Oh et al., 2023), which can foster a deeper understanding of social cues. Second, multi-user VR allows instructors to implement diverse collaborative activities (Dalgarno & Lee, 2010) and tailor teaching activities to varying degrees of complexity and formats, aligning with pedagogical goals and student needs. For instance, instructors can organize challenging tasks or role-playing scenarios in virtual settings (Feng et al., 2024; Olteanu et al., 2014), during which students must work together to solve problems, thus practicing collective decision-making and social skills (Zhao et al., 2024). Therefore, this study aims to examine whether a short-term multi-user collaborative VR game can have an impact on adolescents' SECs.

2.4. Theoretical background of VR as an SEL approach

The potential of VR-based multi-user collaborative games to foster the development of SECs is supported by theoretical assumptions of collaborative learning and game-based learning, with additional affordances provided by VR technology. Fig. 1 illustrates the theoretical framework underpinning this approach. Collaborative learning posits that social interactions during group activities provide opportunities for students to develop SECs such as emotional regulation, communication, empathy, and teamwork (Rogat & Adams-Wiggins, 2015). An effective collaborative design for fostering SECs must account for four essential dimensions: shared goals, positive independence, active communication, and role assignment (Johnson et al., 1984). Specifically, through shared tasks and mutual goal achievement, students navigate diverse perspectives and learn to build constructive relationships (Chang et al., 2017). In

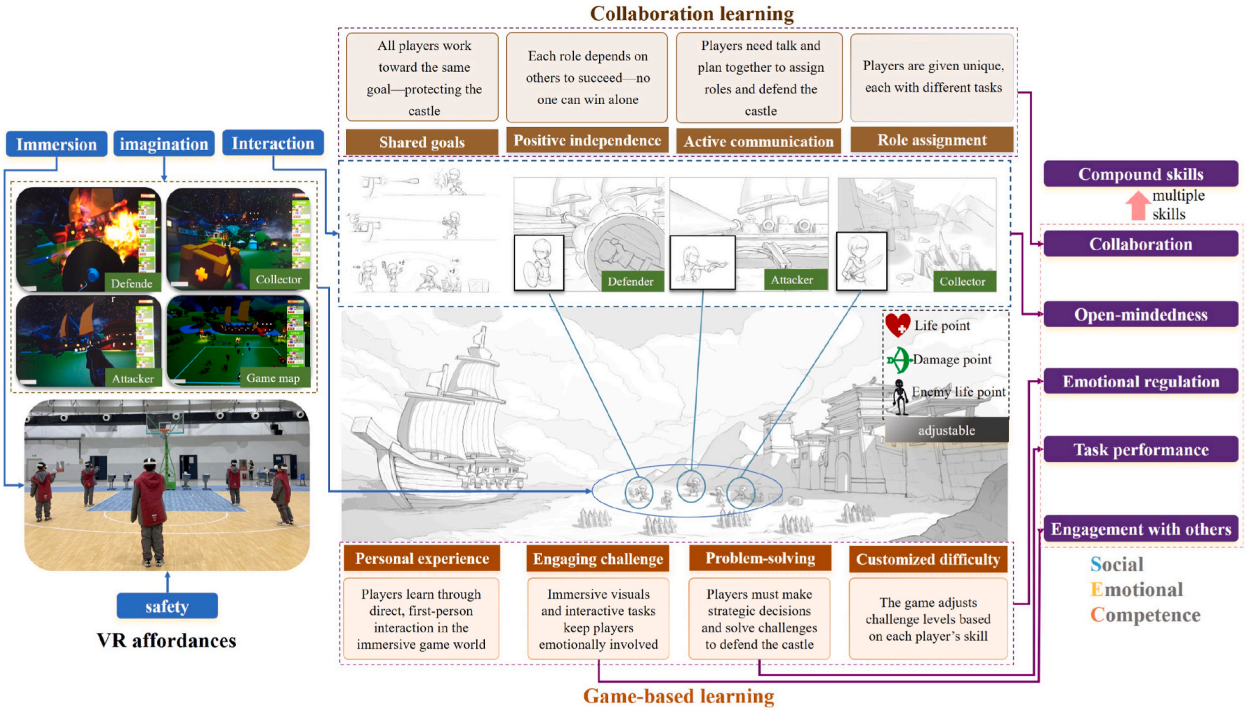

Fig. 1. The theoretical framework for promoting SECs in VR collaborative game.

this study, the shared goal was for each five-member team to protect the castle from being destroyed while defeating incoming enemies, which required coordinated efforts toward a common outcome. Positive interdependence was embedded in the game mechanics: defenders had to block enemy fire to protect teammates, attackers had to eliminate enemies, and collectors had to secure resources and health points for the group, making success contingent on every member's active contribution. Active communication was also essential, as players needed to negotiate strategies and coordinate actions in real time to progress. Finally, role assignment was realized through three distinct roles with non-overlapping functions, further encourage group members to cultivate interpersonal skills, and mutual trust within the group. VR extends the scope of collaborative learning by creating immersive and interactive environments that simulate real-world scenarios while reducing barriers to participation. Multi-user VR programs enable learners to engage in authentic and dynamic social interactions with peers in a psychologically safe space, where the absence of direct face-to-face interactions can alleviate social anxiety and awkwardness (Yu et al., 2023). The immersive nature of VR heightens the sense of presence and engagement, allowing students to practice and refine SECs in a controlled yet realistic environment (Chheang et al., 2020)

Additionally, studies have shown that games are effective for SEC training (Shoshani et al., 2021; Toh & Kirschner, 2023) since the games feature clear rules that allow students to solve social challenges while practicing SECs. In this study, four game-based learning principles were embedded in the VR game design. First, personal experience was ensured by adopting a first-person perspective within an immersive virtual environment, allowing students to directly engage with the task. Second, games often present challenges in the form of obstacles, bosses, or puzzles that require players to apply compound skills for problem-solving (Granic et al., 2014; Hromek & Roffey, 2009). The game provided an engaging challenge: students needed to remain focused as vivid visual effects and interactive mechanics in VR simulated an ongoing battle, sustaining their motivation and enthusiasm. Third, the task in this game required students to collaboratively solve the problem of defending the castle wall from enemies, thereby operationalizing the principle of problem-solving through the processes of strategizing, executing, and completing the mission together. Finally, well-designed games also allow for customized difficulty based on individual traits, ensuring that games remain challenging without becoming too frustrating, and thus afford an engaging and personalized experience for each player (Zohaib, 2018). VR can serve as a powerful platform to enhance game-based learning experience, amplifying emotional presence and social realism through embodied interaction and sensory cues (Alfadil, 2020). When combined with intentional game mechanics, VR-based games can create dynamic and emotionally engaging contexts for learners to experiment with social strategies, reflect on outcomes, and receive feedback (Zhang et al., 2024). Moreover, the virtual nature of the environment enables safe experimentation with different strategies for emotional and social engagement without real-world repercussions.

2.5. Assessment of SECs

There are two primary methods for assessing SECs: indirect and direct assessment (Martinez-Yarza et al., 2023; von der Embse et al., 2023). Indirect assessment typically involves self-reporting by students or reports from teachers and caregivers (Mantz et al., 2018; Murano et al., 2021); this approach predominantly uses instruments such as the Likert-type rating scale. It requires raters to possess a professional level of ability to evaluate SECs, which may present challenges for elementary and middle school students. Due to the subjectivity of reporters and the social desirability effects (LeBuffe et al., 2018; McKown, 2019), self-reported outcomes also tend to be disparate from actual competences. Direct assessment, on the other hand, refers to the use of trained observers to assess students' SECs in real-life settings, including classrooms, social situations, or required tasks or simulations (e.g., role-playing scenarios, problem-solving activities, or decision-making exercises) that require SECs (Martinez-Yarza et al., 2023). For example, Susanne et al. (2012) observed preschoolers' performance in different forms of play and interaction to assess their emotional expression, emotion regulation, and prosocial behavior. DeRosier and Thomas (2017) required pupils to make decisions in six SEC assessment scenes and evaluated their SECs through menu-based scores and in-game behavior. This method of assessing SECs can be standardized and applied consistently across different observers and settings, which enhances reliability and minimizes the subjectivity inherent in self-reporting. Additionally, direct assessment could capture subtle behavioral and emotional changes during authentic tasks that may be missed by self-report, especially after short-term interventions. Therefore, to precisely evaluate SECs, this study selected to observe students' performance in a collaborative task that involved presenting a dramatic interpretation of a Chinese poem. The assessment framework referred to the one proposed by OECD (Chernyshenko et al., 2018), which is suitable for assessing SECs through observation during collaborative tasks.

3. Methods

3.1. Research design

This study employed a randomized controlled trial with a between-subjects design to assess the impacts of a VR-based SEL intervention versus a face-to-face SEL intervention on SECs. Given the potential confounding effect (i.e., repeated exposure to SEL assessments), an untreated control group was included to establish a baseline for evaluating intervention effectiveness. We used random function of excel to assign the list of students obtained in advance into three groups. Therefore, participants were randomly assigned to one of three conditions: VR ($n = 101$), face-to-face ($n = 107$), and control ($n = 89$).

Participants in the VR condition were organized into five-person teams to engage in an immersive VR collaborative game called "The League of Castle Defenders." The game lasted 10–15 min and was implemented as a VR-based SEL interventions. Players were required to negotiate and assign three roles—defender, attacker, and collector—to defend the enemy and achieve victory. The short-

duration VR-based SEL intervention was informed by two considerations: pilot results showed that 10–15 min was sufficient for task completion without inducing cybersickness, and school schedule constraints made longer sessions impractical. This design enhances the feasibility and relevance of the findings for real-world school settings.

Participants in the face-to-face condition were also divided into five-person teams to play a traditional collaborative game, Charade, in a classroom setting. Similarly, in the face-to-face intervention, players were required to collectively allocate the roles of performer and guesser with the aim of making more accurate guesses. The intervention also lasted 10–15 min. After intervention, all participants received VR-based SEL intervention as compensatory.

Participants in the control condition did not receive any SEL intervention but completed the same pre- and post-assessments as the treatment groups, providing a critical reference point for interpreting intervention effects beyond practice effects. According to Miller et al. (2020), using a control group in an experimental design is essential to determine whether any observed changes are due to the intervention, as all groups are exposed to the same environmental trends. A compensatory VR-based SEL intervention was arranged for participants in control conditions after the experiment to ensure ethical considerations and equitable access to SEL training opportunities.

By comparing pre- and post-intervention assessments between the treatment and control groups, any observed differential improvements can more accurately attributed to the interventions rather than extraneous factors, such as repeated testing effects. Since our SEL assessments required participants to engage in collaborative activities rather than simply self-reporting their SECs, including a control group helped control for potential practice effects inherent in the assessment format. Additionally, a non-intervention control group was included could eliminate potential novelty effects, as repeated assessment of SECs through collaborative tasks may yield declining post-test performance unrelated to actual ability changes.

3.2. Participants

The participants were recruited from five seventh-grade classes at a middle school located in a county-level city in central China. We initially recruited 304 participants; however, students who did not complete the SEC posttest were excluded. Consequently, 297 participants (136 boys and 161 girls) were involved in the entire experimental process. The average age of the participants was 12.20 years old (SD = 0.42), ranging from 11 to 14. We recruited participants exclusively from the seventh grade for two reasons. First, as first-year middle school students, they tended to be more anxious due to the transition from primary to middle school, which entails adjusting to new social dynamics and a new learning environment. Second, selecting participants from a single grade level minimizes confounding effects of varying educational levels and age differences. Participants' demographic information was obtained via questionnaire and interview, along with their susceptibility to motion sickness, to ensure that those in the VR condition would not experience dizziness, because most students had limited exposure to VR. Furthermore, all participants had normal or corrected-to-normal eyesight. Before the experiment, all participants were properly informed about the study's aims and procedures, and informed consent was obtained. The research protocol received approval from the Institutional Review Board (IRB) of Central China Normal University (IRB No. CCNU-IRB-202306002a) and was reviewed and endorsed by the local school administration.

3.3. SEL interventions

3.3.1. VR collaboration game

The VR-based SEL intervention was a collaborative virtual game named "The League of Castle Defenders," inspired by ancient Chinese culture. This game features three different hero roles (defender, attacker, and collector), who defend their home castle from enemies aboard a warship equipped with cannons, as shown in Fig. 2. The enemies use cannons to besiege the castle walls and players. Each participant had to select a hero when entering the game and work with the other four members of their team to protect the castle while eliminating enemies. Mission victory was achieved if the castle remains intact and at least one hero survives. Each role has a unique function: the defender uses a shield to block artillery fire, the attacker employs a crossbow to damage enemies, and the collector gathers arrows and life points from the game field, where supplies automatically regenerate in random spots. The VR game was

Fig. 2. Illustration of the game scenes: (a) the third perspective of the VR game scene; (b) the first perspective of the defender role.

developed by the research team. For further details about the game design and technical specifications, please refer to the design case by Feng et al. (2024).

The social and collaborative nature of the VR game makes it an appropriate SEL intervention for children and adolescents. The game requires a cohesive team effort from the five students, each assuming a different virtual role. Before entering the VR environment, players are required to negotiate the allocation of the three roles and discuss gaming strategies. This process requires that students have a clear self-awareness of their strengths and weaknesses, effectively express their preferences and rationales, listen to different opinions and perspectives, and make fast decisions under pressure. This fosters a sense of shared responsibility among group members for collaborative decision-making. The game also involves continuous enemy artillery fire directed at the castle walls, resulting in frequent player hits and eliminations. This dynamic element tests the players' ability to manage stress and maintain focus under pressure.

We used inside-out tracking technology to enable synchronous co-located interactions among multiple participants in the VR collaboration game. This is a spatial positioning technology and relies on the cameras integrated into the head-mounted display (HMD) to detect environmental changes. The VR collaboration game employed SLAM (simultaneous localization and mapping) algorithms and depth cameras to ascertain the precise position of the HMD in space. The sharing of SLAM data allows for the accurate location of multiple users in a virtual space, thereby enhancing social immersion through synchronized interactions and immersive virtual scenes. The technical setup was built with Unreal Engine 4.26.2 using a combination of C++ programming and Blueprint visual scripting, compiled via Microsoft Visual Studio. Additionally, this study employed the Oculus Quest 2 (approx. USD 300–400 per headset) that offers 360° head and gesture tracking, and its controllers support various action-based interactions, such as opening supply boxes when acting as the collector. Before the formal VR game, facilitators required basic training in VR operation, calibration, and session management.

Furthermore, students were able to select from three prespecified virtual avatars with distinctive hero skills. The anonymity enabled by the virtual avatars also creates a sense of psychological safety during collaboration, as students were shielded from face-to-face awkwardness, and mistakes made in the virtual environment did not carry real-world consequences. Therefore, the VR game afforded a highly imaginative, immersive, interactive, and psychological safety collaborative environment. Table 1 summarizes VR affordances, game functions, and technical requirements of the VR collaboration game.

3.3.2. Face-to-face collaboration game

Charade is a face-to-face game that promises to promote the development of SECs by fostering interaction and communication, empathy and understanding, emotion management and expression, and social skills. The game is typically played in teams, with some team members acting out the clues while the others attempt to guess them within a set time limit. The game emphasizes non-verbal communication and creativity, promoting teamwork and offering a collaborative activity that support SEL development. First, players must have clear self-awareness of their strengths in acting or interpreting non-verbal cues. Second, Charades enhances empathy and emotional understanding by prompting players to express and interpret emotions without words. Third, teamwork and communication are strengthened as players collaborate to guess the mimed words or phrases. Fourth, Charades encourages creative thinking and problem-solving, as players devise innovative ways to represent complex ideas without words. Finally, the game typically involves guessing within a limited time frame, which tests players' ability to perform under time constraints.

3.3.3. Comparison of VR and face-to-face interventions

The League of Castle Defenders and Charade were selected as SEL interventions for VR and face-to-face conditions, respectively. Despite their difference in environment conditions, the two interventions share many similarities in terms of collaboration mechanism and activities: (1) they both require students to strategically choose roles based on the assessment of skills, efficacy, and personality (Toh & Kirschner, 2023; Gee, 2007), thereby fostering self-awareness (e.g., recognizing one's strengths and weakness) and responsible decision-making in role assignment; (2) they both involve collaborative tasks that require students to actively interact with group members through verbally and kinetically, which cultivates relationship skills such as communication, perspective-taking, and cooperation; (3) they both impose stressful and time-pressured challenges that enhance social bonding and emphasize certain SECs such self-control, stress resistance, and optimism. Consequently, both VR and face-to-face interventions in this study offer comparable SEL opportunities for students, contributing to the development of SECs. The relationship between SEC subscales and intervention affordances are summarized in Table 2.

Table 1
Description of the functions and technical requirements of VR collaboration game.

Affordances	Functions	Technical requirements
Imagination	• Choose a virtual character in a fantastical realm • Become an ancient soldier defending the castle	High-fidelity graphics rendering, Oculus Quest 2
Immersion	• Engage in game scenarios without being limited by physical space • Experience co-presence and social presence through real time negotiation	Oculus Quest 2, SLAM algorithms
Interaction	•Check health points or arrows by observing the status bar •Move freely in space, shoot arrows, open the supply boxes, lift shields	Oculus Quest 2, VR controllers
Safety	• Create a psychological safety through anonymity • Allow for productive failure without real-world consequences	Customizable virtual identity

3.4. Procedure

The formal experiment comprised three steps, as shown in Fig. 3. In the first step, the SEC pretest was conducted. The participants were randomly assigned to groups of 4–5 members and instructed to complete a task within 15 min. This task required each group to negotiate to select and perform one of 12 ancient Chinese poems, while one member of the group shooting a video using an iPad. The entire process was recorded by two cameras: one fixed camera positioned at the front to capture the overall setting, and another handheld by a researcher to track and record details such as participants' emotions, expressions, and conversations during the task completion.

In the second step, participants were randomly assigned to one of three experimental conditions: the VR condition, the face-to-face condition, and the control condition. Participants in the VR and face-to-face conditions were further randomly divided into groups of five to complete either the VR collaborative game or the face-to-face collaborative game, respectively. Prior to the formal intervention, participants in the VR condition received equipment training, while all participants in both the VR and face-to-face conditions also observed the preceding group's gameplay, during which roles and tasks were assigned. Each formal intervention session lasted 10–15 min. After that, they were required to fill in the learning experience questionnaire regarding their perception of the collaborative game. Participants in the control condition were not required to complete the questionnaire because they did not receive any intervention.

In the third step, participants in three conditions took part in the SEC posttest. Like the pretest, the posttest also required group collaboration to perform a selected Chinese poem and film the performance. The same test activity ensured the consistency of the research instruments for measuring SECs. However, to eliminate the threat of practical effects due to repeated measurements, the ancient Chinese poems used in the posttest were different from those used in the pretest. After the experiment, the participants in the face-to-face and control conditions also experienced VR collaborative game.

3.5. Data collection and analysis

The independent variable in this study was the type of SEL intervention (VR intervention vs. face-to-face intervention vs. no intervention). The dependent variables were SEC levels and learning experiences during the SEL interventions. Due to the subjectivity of reporters and the social desirability effects, we chose direct assessment and video-recorded their performance during both the pretest and posttest to enable objective, post hoc external ratings. A total of 304 videos were collected, with 152 captured from fixed camera positions and 152 from handheld cameras to provide comprehensive coverage of participant performance. The rating of participants' SEC levels was informed by the assessment framework proposed by the OECD (Chernyshenko et al., 2018), which includes six scales: task performance, emotional regulation, collaboration, open-mindedness, engagement with others, and compound skills. Each scale is classified into three subscales with 5 points for each subscale. The overall score for each scale was calculated by averaging the scored of its subscales. The complete rating protocol is provided in Appendix A.

To ensure the reliability of the SEC rating results, we required two raters to evaluate each video, and used the average of their rating as the final score if satisfactory inter-rater relatability was achieved. A total of 20 graduate students were recruited and divided into 10 dyads. Each dyad received 15–16 videos for evaluation. Prior to the formal rating, all raters received two weeks training, during which they tentatively evaluated 10 % of the videos and discussed inconsistencies in weekly meeting until a consensus was reached about the rating criteria. During the weekly meetings, all raters engaged in discussions with experts in the field of SEC to address issues and uncertainties encountered during the rating process. At the end of the formal rating, the inter-rater reliability, measured by Pearson's r, was high across all dyads, ranging from 0.872 to 0.945. To ensure the validity of rating results, we followed the recommendation of Birenbaum (2007), who advocated that evidence of assessment quality can be obtained by expert judgement. Therefore, we purposefully selected 12 participants who received high or low SEC ratings and asked a professor of child psychology to provide expert ratings. The high correlation between the expert and dyad ratings ($r = 0.853$) indicates good measurement validity.

We also administered a questionnaire to measure learning experiences among participants in the VR and face-to-face intervention conditions. The learning experience questionnaire (LEQ) was adapted from a well-established questionnaire in the literature (Vidergor, 2021) and comprised 20 items rated on a 5-point Likert scale (three items for group cohesiveness, five items for collective efficacy, four items for group effectiveness, and eight items for social experience). The details about the LEQ are included in Appendix B. A total of 208 questionnaires were collected, with 196 deemed valid after excluding those with incomplete data. The Cronbach's α for the LEQ was 0.934, and the α values for the subscales ranged between 0.854 and 0.936, indicating high reliability.

To determine the effectiveness of the VR-based SEL intervention, we used the Wilcoxon signed-rank test to compare pre- and post-

Table 2
The relationship between SEC subscales and intervention affordances.

SECs	VR intervention	Face-to-face intervention
Self-awareness	Choose the right role based on self-preference and evaluation	Decide whether they are skilled in performing or guessing
Social awareness	Pay attention to others' statuses, emotions, needs, and gameplay	Recognize teammates' social cues and subtle changes in emotion and actions
Sociability	Real-time communication and virtual collaboration to ensure game victory	Constant verbal and gestural interactions to perform and guess the correct words
Responsible decision-making	Make decision collectively (e.g., roles, formation strategy) to ensure game victory	Make decision collectively (e.g., roles, skip or persist) to maximize correct guesses
Stress resistance	Sustain stress of being attacked by constant fire and castle fall	Sustain stress of guessing more words in the limited time

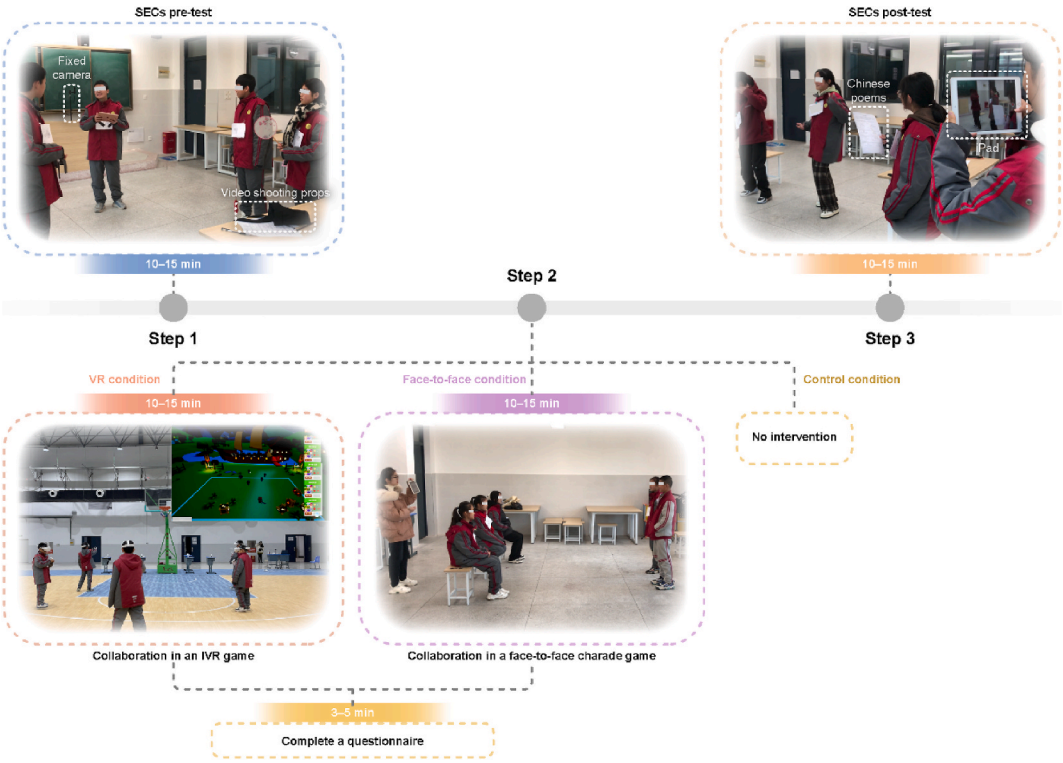

Fig. 3. Experimental procedure for this study.

intervention SEC rating scores within each conditioned group. The Kruskal–Wallis test was employed to examine the between-group differences. The Scheirer-Ray-Hare test was used to explore the effect of gender on the two types of interventions. We used non-parametric tests because the rating scores for most SEC subscales did not follow a normal distribution, as indicated by Shapiro–Wilk normality test results (all $W > 0.943$, $p < 0.000$). Additionally, a *t*-test was conducted to compare the LEQ ratings between the VR and face-to-face conditions to explore difference in learning experiences across the two SEL interventions. The Wilcoxon signed-rank and Kruskal–Wallis test analyses were conducted using IBM SPSS software (version 26), while the Scheirer-Ray-Hare test analysis was performed using RStudio software.

4. Results

4.1. Descriptive SEC results

Table 3 presents the descriptive statistics results for the SEC and subscale scores at pretest across the three conditions. The Kruskal–Wallis signed-rank test results revealed no statistically significant differences among the three conditions on any of the subscales at pretest (all $p > 0.05$). Table 4 displays the posttest results for SECs. The VR condition exhibited the highest SEC total scores (mean = 21.30), followed by the face-to-face condition (mean = 20.70), and the control condition showed the lowest score (mean = 19.97). Furthermore, the VR condition demonstrated higher scores on the subscales of SEC compared to the other conditions.

Table 3
Descriptive statistics: Pretest.

Variables	VR condition (n = 101)		Face-to-face condition (n = 107)		Control (n = 89)	
	Mean (SD)	M (P_{25}, P_{75})	Mean (SD)	M (P_{25}, P_{75})	Mean (SD)	M (P_{25}, P_{75})
SEC total score	20.53(2.36)	20.5(18.7,22.3)	20.83(2.65)	20.83(18.8,22.7)	20.54(2.83)	20.33(18.7,22.2)
Task performance	3.57(0.57)	3.67(3.2,4.0)	3.72(0.67)	3.67(3.3,4.0)	3.67(0.71)	3.67(3.2,4.2)
Emotional regulation	3.34(0.47)	3.33(3.0,3.7)	3.38(0.45)	3.33(3.0,3.7)	3.35(0.54)	3.33(3.0,3.7)
Collaboration	3.35(0.40)	3.33(3.0,3.7)	3.41(0.35)	3.33(3.2,3.7)	3.37(0.44)	3.33(3.0,3.7)
Open-mindedness	3.30(0.39)	3.33(3.0,3.5)	3.37(0.40)	3.33(3.0,3.7)	3.32(0.38)	3.33(3.0,3.5)
Engagement with others	3.61(0.64)	3.67(3.0,4.0)	3.58(0.67)	3.67(3.0,4.0)	3.50(0.70)	3.33(3.0,4.0)
Compound skills	3.35(0.55)	3.33(3.0,3.7)	3.37(0.65)	3.17(3.0,3.8)	3.32(0.66)	3.33(3.0,3.7)

Table 4
Descriptive statistics: Posttest.

Variables	VR condition (n = 101)		Face-to-face condition (n = 107)		Control (n = 89)	
	Mean (SD)	M (P_{25}, P_{75})	Mean (SD)	M (P_{25}, P_{75})	Mean (SD)	M (P_{25}, P_{75})
SEC total score	21.30(1.80)	21.33(19.9,22.5)	20.70(2.07)	21.00(19.0,22.2)	19.97(2.21)	19.67(18.2,21.5)
Task performance	3.86(0.53)	3.83(3.3,4.3)	3.70(0.59)	3.67(3.3,4.0)	3.56(0.63)	3.67(3.0,4.0)
Emotional regulation	3.47(0.36)	3.33(3.3,3.7)	3.41(0.42)	3.33(3.0,3.7)	3.31(0.39)	3.33(3.0,3.5)
Collaboration	3.52(0.29)	3.67(3.3, 3.7)	3.51(0.27)	3.5(3.3,3.7)	3.35(0.42)	3.33(3.0,3.7)
Open-mindedness	3.25(0.29)	3.17(3.0,3.3)	3.19(0.26)	3.17(3.0,3.3)	3.12(0.27)	3.00(3.0,3.3)
Engagement with others	3.86(0.54)	4.00(3.4,4.3)	3.65(0.63)	3.67(3.3,4.0)	3.47(0.67)	3.33(3.0,4.0)
Compound skills	3.35(0.46)	3.33(3.0,3.7)	3.24(0.52)	3.00(3.0,3.7)	3.15(0.50)	3.00(3.0,3.3)

4.2. Within-group differences in SECs among the three conditions

The results presented in Table 5 illustrate the within-group differences in SECs across the VR, face-to-face, and control conditions. Significant improvements in the total SEC score ($p = 0.001$, $r = 0.323$) were observed following the VR intervention, especially in subscales such as task performance ($p < 0.001$, $r = 0.539$), collaboration ($p = 0.002$, $r = 0.320$), and engagement with others ($p = 0.000$, $r = 0.413$), highlighting the potential of VR for promoting collaborative and task-oriented skills. In the face-to-face condition, improvements were noted in both the SEC total score and the collaboration subscale, with a significant increase observed for collaboration ($p = 0.012$, $r = 0.244$). However, the score of participants in the face-to-face condition exhibited a notable decrease in open-mindedness ($p = 0.000$, $r = 0.357$) and compound skills ($p = 0.042$, $r = 0.197$). The control condition showed a decrease in SEC total score, with a significant drop in task performance, open-mindedness, and compound skills.

4.3. Between-group differences in SECs among the three conditions

To investigate significant differences in the SECs among the three conditions following the interventions, a series of Kruskal–Wallis signed-rank tests were performed on the posttest scores. As shown in Table 6, the results revealed statistically significant differences in total SEC scores across the three conditions ($H = 20.098$, $p < 0.001$, $\eta_p^2 = 0.061$). Additionally, significant differences were found in several SEC subscales, particularly task performance ($H = 11.427$, $p = 0.003$, $\eta_p^2 = 0.032$), collaboration ($H = 10.245$, $p = 0.006$, $\eta_p^2 = 0.028$), engagement with others ($H = 16.947$, $p < 0.001$, $\eta_p^2 = 0.051$), and compound skills ($H = 9.714$, $p = 0.008$, $\eta_p^2 = 0.026$).

To further compare the differences among the three conditions, a series of post-hoc tests were conducted. As illustrated in Fig. 4, participants in the VR condition attained significantly higher SEC scores than those in the face-to-face (MD = 0.60, $p = 0.039$) and

Table 5
Wilcoxon signed rank test results for within-group differences in SECs.

	Median change (pre–post)	Signed rank test statistic (Z)	*p*	*r*
VR condition (n = 101)				
SEC total score	−0.833	3.252	0.001[b]	0.323
Task performance	−0.617	5.414	0.000[c]	0.539
Emotional regulation	0.000	3.245	0.001[b]	0.323
Collaboration	−0.333	3.216	0.002[b]	0.320
Open-mindedness	0.167	1.268	0.205	0.126
Engagement with others	−0.333	4.150	0.000[c]	0.413
Compound skills	0.000	0.060	0.952	0.006
Face-to-face condition (n = 107)				
SEC total score	−0.167	1.121	0.262	0.108
Task performance	0.000	0.622	0.508	0.060
Emotional regulation	0.000	1.098	0.272	0.106
Collaboration	−0.167	2.523	0.012[a]	0.244
Open-mindedness	0.167	3.689	0.000[c]	0.357
Engagement with others	0.000	0.820	0.412	0.079
Compound skills	0.167	2.036	0.042[a]	0.197
Control condition (n = 89)				
SEC total score	0.667	2.485	0.013[a]	0.263
Task performance	0.000	1.999	0.046[a]	0.212
Emotional regulation	0.000	0.149	0.881	0.016
Collaboration	0.000	0.858	0.391	0.091
Open-mindedness	0.333	4.167	0.000[c]	0.442
Engagement with others	0.000	0.769	0.442	0.081
Compound skills	0.333	2.326	0.020[a]	0.246

Note.
[a] $p < 0.05$.
[b] $p < 0.01$.
[c] $p < 0.001$.

Table 6
Kruskal–Wallis signed-rank test results for between-group differences in SECs.

Variables	Kruskal-Wallis *H*	*df*	*p*	η_p^2
SEC total score	20.098	2	0.000[c]	0.061
Task performance	11.427	2	0.003[b]	0.032
Emotional regulation	9.029	2	0.011[a]	0.024
Collaboration	10.245	2	0.006[b]	0.028
Open-mindedness	8.319	2	0.016[a]	0.021
Engagement with others	16.947	2	0.000[c]	0.051
Compound skills	9.714	2	0.008[b]	0.026

Note.
[a] $p < 0.05$.
[b] $p < 0.01$.
[c] $p < 0.001$.

control conditions (MD = 1.33, $p < 0.001$). Additionally, the face-to-face condition also had a significant effect on SEC scores compared to the control condition (MD = 0.73, $p = 0.011$). Regarding the SEC subscales, participants in the VR condition exhibited significant differences from those in the control condition across all subscales (all $p < 0.05$), but differed from the face-to-face condition only on the engagement with others subscale (MD = 0.21, $p = 0.026$), as shown in Fig. 5. Significant differences were observed between the face-to-face and control conditions in collaboration (MD = 0.16, $p = 0.010$) and engagement with others (MD = 0.18, $p = 0.044$) subscales, as depicted in Fig. 5 (c) and (e).

4.4. Between-group differences in learning experiences for VR and face-to-face conditions

A series of *t*-tests were performed to determine differences in the participants' learning experience between the VR and face-to-face conditions. As shown in Table 7, the VR condition exhibited higher mean values across all four subscales compared to the face-to-face condition. The *t*-test results revealed significant differences in group cohesiveness ($t = 3.376$, $p < 0.05$) and social experience scores ($t = 2.730$, $p < 0.05$) between the two conditions, with participants from the VR condition reporting higher ratings than those in the face-to-face condition.

4.5. Role of gender in moderating SEL intervention effects

To explore whether gender moderated the effects of the intervention (VR vs. face-to-face) on SECs, a Scheirer-Ray-Hare test was conducted using gender and intervention group as between-subjects factors, as shown in Table 8. No significant interaction effect between gender and intervention was found for the overall SECs score ($H = 0.639$, $p = 0.424$). However, a significant main effect of intervention group was observed ($H = 4.294$, $p = 0.038$), suggesting that participants in VR conditions showed higher scores in overall SECs, regardless of gender. Regarding the SEC subscales, a significant main effect of gender was observed in task performance ($H = 4.296$, $p = 0.038$), indicating that girls outperformed the boys both interventions, as shown in Table 8. Additionally, both a significant main effect of gender ($H = 4.265$, $p = 0.039$) and interaction effect between gender and interventions ($H = 4.283$, $p = 0.038$) were found for open-mindedness. The boys gained higher scores in VR condition and girls gained more higher scores in face-to-face

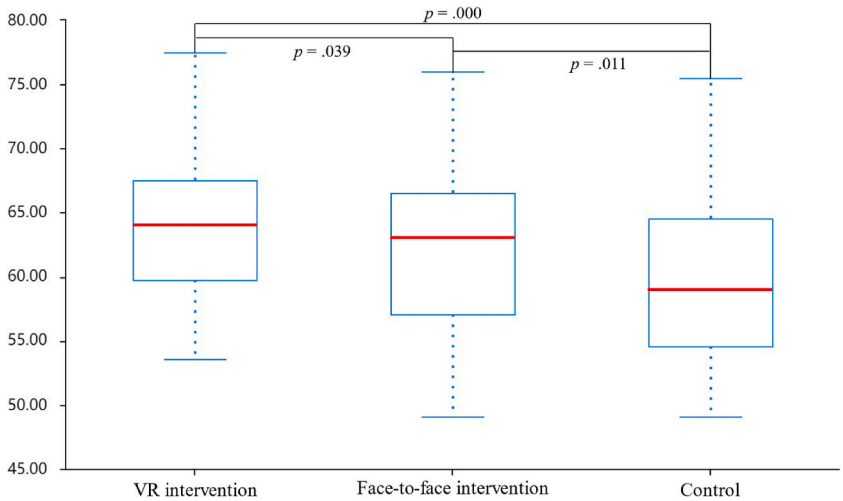

Fig. 4. Boxplot of SEC scores among three conditions.

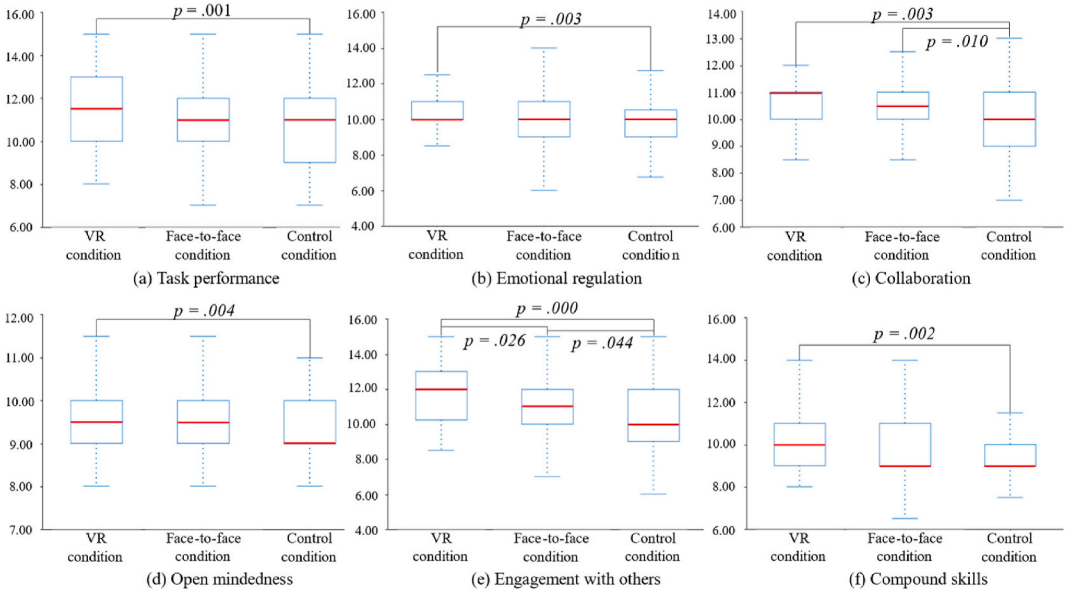

Fig. 5. Boxplots of the six SEC subscales among three conditions.

Table 7
T-test results for learning experiences in VR and face-to-face conditions.

Variables	VR intervention (n = 96)		Face-to-face intervention (n = 100)		*t*	*p*
	Mean	SD	Mean	SD		
Group cohesiveness	4.31	0.69	3.96	0.77	3.376	0.001**
Collective efficacy	4.40	0.79	4.18	0.76	1.948	0.053
Group effectiveness	4.23	1.18	4.02	0.84	1.412	0.160
Social experience	4.58	0.61	4.33	0.68	2.730	0.007**

Note: *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

Table 8
Scheirer-Ray-Hare test results for between interventions and gender.

Variables	*df*	*SS*	*H*	*p*
SECs				
Gender	1	391	0.108	0.742
Group	1	15539	4.294	0.038*
Gender*group	1	2313	0.639	0.424
Task performance				
Gender	1	15260	4.296	0.038*
Group	1	11124	3.131	0.077
Gender*group	1	904	0.254	0.614
Open mindedness				
Gender	1	14097	4.265	0.039*
Group	1	5574	1.687	0.194
Gender*group	1	14156	4.283	0.038*

Note: *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

condition.

5. Discussion

5.1. Positive effects of VR collaboration game on adolescents' SECs development

The findings indicated that VR-based intervention significantly improved SECs, especially in the subscales of *task performance, emotional regulation, collaboration, and engagement with others*. Consistent with previous studies showing that VR programs effectively enhance SECs in children with ASD (Cheng et al., 2015; Ip et al., 2022; Parsons, 2015), this study examined that VR program can also

had a positive impact on adolescents in regular school. These findings suggest that immersive virtual environments can effectively support the development of SECs by offering dynamic, emotionally engaging contexts in which learners can safely practice social behaviors (Bailey et al., 2019; Tsai et al., 2021; Zhang et al., 2023). The VR program in this study, characterized by its meticulous design (e.g., collaboration, role, task) that mandates active participation from all students, offers an equitable and engaging environment for SECs development.

Interestingly, the results revealed that although the VR condition showed no significant improvement in the subscales of *open mindedness and compound skills* between pre- and post-tests, the control condition, which did not receive any intervention, exhibited a significant decrease in these two subscales. One possible reason is that the pre- and post-test tasks used to measure SECs were similar, which may have induced student fatigue or disengagement during the posttest (Marsden & Torgerson, 2012). It also suggests that despite the use of the similar testing tasks, students in the VR intervention were able to maintain their enthusiasm for repeated collaborative tasks following the intervention.

5.2. Differences in learning effects between VR-based and face-to-face SEL

The results of this study also indicate that the VR intervention was more effective than the face-to-face intervention, as demonstrated by a randomized-controlled experiment. Students in the VR condition achieved higher overall SEC scores in the posttest, especially in the subscale of *engagement with others*. One possible reason for this may be that the VR intervention provided students with a greater immersive experience and a deeper sense of presence (Tan et al., 2023), evoking psychological and physical reactions identical to those experienced in similar real-life situations (Alghamdi et al., 2017; Arts et al., 2023). Additionally, student interactions in the VR intervention were enabled through virtual avatars, which are known to reduce psychological pressure and negative affects among youth during social events (Spano et al., 2023). Collaboration in virtual environments also affords a sense of anonymity and security, which can mitigate the embarrassment and rejection often encountered in face-to-face collaboration (Didehbani et al., 2016). This may have allowed participants to focus more on interacting with others rather than being anxious about interpersonal relationships.

While the VR condition appeared to outperform the face-to-face condition in SEC development for adolescents, no significant differences emerged in in certain SEC subscales, such as *open-mindedness and emotional regulation*. One possible reason is that these subscales involve trait-like qualities (Fortes & De Brasi, 2023; Jenks, 2011), which are challenging to alter in a short period of time (Bleidorn et al., 2021; Brandt et al., 2023). Another reason may be that the learning task in the VR intervention was collaborative in nature (Feng et al., 2024), focusing on social communication and interaction rather than fostering social emotions such as curiosity and empathy. However, although no significant differences were detected in these subscales, the VR group consistently showed higher scores, suggesting potential benefits of VR that may not have reached significance due to the limit duration of the intervention. Evidence from longitudinal research indicate that repeated VR-based SEL sessions over several weeks can yield stronger and more differentiated improvements across SEC subscales (Ip et al., 2018).

Notably, students in the face-to-face significantly improved in overall SEC scores and *collaboration* subscale. As Hromek and Roffey (2009) argued, games are a powerful approach for developing SEC in young people due to its interactive nature. Game design for delivering SEL typically incorporates strategies such as multiple challenges, positive discussions, and creative problem solving to engage students in resolving social conflicts while practicing their SECs simultaneously (Hadley et al., 2022). Moreover, collaborative activities have been found to enhance SECs by fostering emotional regulation, interdependence, and peer interaction (Rogat & Adams-Wiggins, 2015; Shoshani et al., 2021).

Furthermore, gender differences were evident in specific SEC subscales. Girls consistently outperformed boys in *task performance* across both interventions. This result aligns with studies suggesting that girls generally exhibit better self-regulation and task-oriented behaviors in educational settings (Duckworth & Yeager, 2015; Huang et al., 2022). Interestingly, the results revealed a significant interaction between gender and intervention type for *open-mindedness*. Boys benefited more from the VR intervention, whereas girls showed greater gains in the face-to-face setting. This pattern may be attributable to differences in learning preferences or social engagement styles. Prior studies have found that boys are often more responsive to digital, interactive, and game-based environments that allow for autonomy and spatial exploration (Li & Tsai, 2013; Liu et al., 2024). Conversely, girls may benefit more from face-to-face interactions that emphasize verbal communication and relational connectedness—factors often linked with empathy and openness in social learning contexts (Rose & Rudolph, 2006).

5.3. Enhanced level of group cohesiveness and social experience in VR-based SEL

Students in the VR condition reported higher levels of *group cohesiveness and social experience* than those in the face-to-face condition. This finding that VR collaboration enhanced group cohesion aligns with existing findings in the VR literature (Bozanta et al., 2016; Chheang et al., 2020). One possible explanation is that the fantasy challenge in the VR intervention required students to act in unison toward a common goal under stress, which is known to strength group identity and foster a sense of belonging (Davis et al., 2022). Regarding the observed increase in social experience, it may be postulated that the VR intervention featured a synchronous and co-located collaboration task, which enabled students to perceive a high level of co-presence and social presence through real-time communication and shared experience. This can lead to enhanced social experience (Feng et al., 2024; Zhang et al., 2023). Several researchers have also argued that such experiences tend to be more immersive in VR and closer to a state of flow (Bian et al., 2023; Oubibi & Hryshayeva, 2024). However, it is worth noticing that the game task in the VR condition is different from that in the face-to-face condition, despite the similar collaboration mechanism, such a difference might also contribute to the variance in learning

experiences.

Additionally, the findings revealed no significant differences between the VR and face-to-face conditions in terms of student's perceived *collective efficacy and group effectiveness*. Regarding to the collective efficacy, previous studies have suggested that it is largely influenced by task design, such as task independence (Alavi & McCormick, 2008; Men et al., 2022), positive conflict and acceptance communication (McLean et al., 2020). Both the VR-based and the face-to-face SEL interventions in this study were similar, designed to promote interdependence, role assignment, and time-constrained group problem solving—key components known to foster collective efficacy. Given the strong correlation between collective efficacy and group effectiveness (Ganotice et al., 2022), the absence of significant differences in group effectiveness between the VR and face-to-face groups may be attributed to their comparable levels of collective efficacy.

5.4. Implications

Based on our research findings, we propose several implications for designing and implementing SEL programs. First, educators could consider incorporating VR programs into future SEL curricula, because the results indicate that VR collaboration may yield better performance and experience than traditional collaboration. Additionally, the findings suggest that students exhibit greater engagement with others after experiencing a VR collaborative program. Therefore, if the educational goal is to foster learners' interactions with others, developing interesting and challenging collaborative VR programs may be a suitable option. However, if the educational goal is to have students develop and regulate certain emotions, VR developers should explore other tasks or scenarios that involve mindfulness or other meditation exercises. Moreover, the short duration and low technical complexity in this study suggest that such programs are feasible for integration into regular school settings. Notably, this VR program is explicitly designed for collaborative learning, enabling multiple participants to engage in team-based activities simultaneously, which enhances its feasibility in real-world educational settings by optimizing hardware usage and shared space requirements. Finally, in the absence of the affordable VR equipment and appropriate VR program, face-to-face collaborative games could be used as a versatile and cost-effective alternative for developing SEL in K-12 schools.

6. Limitations and future research

Despite our best efforts, this study still has several limitations. First, this study was conducted in a single school setting, which may limit the generalizability of the results. Since the results indicated that gender moderated the effects of the VR-based and face-to-face interventions on SECs, future studies could consider diverse factors such as various age groups, regions, and cultural backgrounds to validate these findings in different educational contexts. Second, although this study examined the effectiveness of VR-based intervention, the whole process and the intervals between pre- and post-tests were relatively short. Longer term studies should therefore be conducted to assess the sustainability of the improvements in SECs and to examine the long-term impact of VR-based SEL programs. Third, while both games in this study were designed to incorporate comparable collaborative mechanic, their differing game content introduced a potential confounding variable, possibly influencing participants' engagement or emotional responses beyond the delivery modality. Future research should design highly comparable game content to explore VR intervention effectiveness. Finally, this study also did not include qualitative data and analysis. Future studies could consider using qualitative methods to generate qualitative results for data triangulation and meaningful interpretation, such as interviews, students' reflections and virtual ethnography.

7. Conclusions

This article presented an experimental study exploring the effectiveness of a VR-based SEL program to promote SECs in adolescents. We examined whether the VR program could improve SECs and compared the outcomes across three different groups to determine if the VR-based intervention was more effective overall or whether it was better in certain subscales than face-to-face or no interventions. The results showed that VR-based SEL intervention can be a practical approach for improving SECs, especially in task performance, collaboration, and engaging with others. The face-to-face collaboration condition also showed significant improvement in SECs compared to the control condition. Additionally, the effectiveness of two interventions was moderated by gender. Participants in the VR condition also reported a better learning experience, especially in terms of group cohesiveness and social experience. These findings emphasize the potential of VR in SEL development for adolescents and highlight the importance of integrating technology in education. When designed and used appropriately, VR can offer engaging, immersive, and personalized environments that provide meaningful and effective learning experiences aligned with adolescents' developmental needs and learning preferences. As VR technology continues to evolve and become more accessible, it offers valuable opportunities for enhancing educational outcomes, particularly in the domain of SEL.

CRediT authorship contribution statement

Qinna Feng: Writing – original draft, Visualization, Investigation, Formal analysis. **Gege Li:** Investigation, Formal analysis, Data curation. **Yanbei Chen:** Writing – original draft. **Feng Zhang:** Writing – original draft, Investigation. **Wenhao Li:** Supervision, Methodology, Funding acquisition. **Heng Luo:** Writing – review & editing, Funding acquisition, Conceptualization.

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Declaration of interest statement

There is no potential conflict of interest.

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Appendix A. Skills Included in the Study on Social and Emotional Skills (SSES)

FRAMEWORK	SKILLS	DESCRIPTION	BEHAVIORAL EXAMPLES
Task Performance (Conscientiousness)	Achievement Orientation	Setting high standards for oneself and working hard to meet them	Enjoys reaching a high level of mastery in some activity. Opposite: uninterested in career development
	Responsibility	Able to honor commitments, and be punctual and reliable	Arrives on time for appointments, chores get done right away. Opposite: doesn't follow through on agreements/promises
	Self-Control	Able to avoid distractions and focus attention on the current task in order to achieve personal goals	Doesn't rush into things, is cautious and risk averse. Opposite: is prone to impulsive shopping or binge drinking
Emotional Regulation (Emotional stability)	Stress Resistance	Effectiveness in modulating anxiety and able to calmly solve problems (is relaxed, handles stress well).	Is relaxed most of the time, performs well in high-pressure situations. Opposite: worries about things, difficulties sleeping.
	Optimism	Positive and optimistic expectations for self and life in general	Generally, in good mood. Opposite: often feels sad, tends to feel insecure.
	Emotional Control	Effective strategies for regulating temper, anger and irritation in the face of frustrations	Controls emotions in situations of conflict. Opposite: gets upset easily; is moody.
Collaboration (Agreeableness)	Empathy	Kindness and caring for others and their well-being that leads to valuing and investing in close relationships.	Consoles a friend who is upset, sympathizes with the homeless. Opposite: Tends to disregard other person's feelings.
	Trust	Assuming that others generally have good intentions and forgiving those who have done wrong	Lends things to people, avoids being harsh or judgmental. Opposite: is suspicious of people's intentions.
	Co-operation	Living in harmony with others and valuing interconnectedness among all people.	Finds it easy to get along with people, respects decisions made by a group. Opposite: has a sharp tongue, is not prone to compromises.
Open-Mindedness (Openness to experience)	Curiosity	Interest in ideas and love of learning, understanding and intellectual exploration; an inquisitive mindset.	Like to read books, to travel to new destinations. Opposite: dislikes change, is not interested in exploring new products.
	Tolerance	Is open to different points of view, values diversity, is appreciative of foreign people and cultures	Have friends from different backgrounds. Opposite: dislikes foreigners
	Creativity	Generating novel ways to do or think about things through exploring, learning from failure, insight and vision	Having original insights is good at the arts. Opposite: seldom daydreams, dresses conventionally
Engagement With Others (Extraversion)	Sociability	Able to approach others, both friends and strangers, initiating and maintaining social connections	Skilled at teamwork, good at public speaking. Opposite: avoids large groups, prefers one-to-one communication
	Assertiveness	Able to confidently voice opinions, needs, and feelings, and exert social influence	Takes charge in a class or team. Opposite: waits for others to lead the way, keeps quiet when disagrees with others
	Energy	Approaching daily life with energy, excitement and spontaneity	Is always busy, work long hours. Opposite: get tired easily

(*continued on next page*)

(*continued*)

FRAMEWORK	SKILLS	DESCRIPTION	BEHAVIORAL EXAMPLES
Compound Skills	Self-efficacy	The strength of individuals' beliefs in their ability to execute tasks and achieve goals	Remains calm when facing unexpected events. Opposite: avoids challenging situations
	Critical thinking/ independence	The ability to evaluate information and interpret it through independent and unconstrained analysis.	Good at solving problems, at ease in new and unknown situations. Opposite: dependent on others' guidance.
	Self-reflection/ metacognition	Awareness of inner processes and subjective experiences, such as thoughts and feelings, and the ability to reflect on and articulate such experiences	Good exam preparation strategies, able to master skills more effectively. Opposite: over- or underestimates time needed for exam preparation or project completion

Note. From "Social and emotional skills for student success and well-being: Conceptual framework for the OECD study on social and emotional skills", by O. Chernyshenko, M. Kankaraš and F. Drasgow, 2018, *OECD Education Working Papers*, No. 173, OECD Publishing, Paris, https://doi.org/10.1787/db1d8e59-en.

Appendix B

Learning experience questionnaire

Group Cohesiveness

The students in my group were friends.
I felt that the people in my group knew how to solve problems.
Students in my group were focused on completing the task.

Collective-Efficacy

This group could pull itself out of difficult situations.
I believed that failure would make our group try harder.
My group members worked harder than expected.
My group members worked hard to fulfill the group's assignments.
My group was effective in finishing the assignments.

Group Effectiveness

My group did a good job in getting things done.
My group was effective in meeting task requirements.
My group accomplished its goals successfully.
My group completed its task successfully.

Social Experience

I felt I was not alone.
I felt the group members supported me.
I felt I had someone to work with in my group.
I felt like a member of my group.
I felt connected to others in my group.
I felt it was a social experience to work with my group.
I felt I could share things with members of my group.
The game influenced me because it had group work.

Data availability

Data will be made available on request.

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