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From gaming to reality: effectiveness of skills transfer from competitive sandbox gaming environment to near and far contexts

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Abstract

Esports or competitive video gaming has been increasingly utilized to enhance essential twenty-first century skills. However, there is limited evidence on the extent to which the skills acquired from a gaming environment can be transferred to other settings. This study employed an experimental design to investigate the effectiveness of a competitive sandbox game environment in enabling the transfer of the 4Cs skills to both near and far tasks, in contrast with a non-game environment. A cohort of 110 students from a university were randomly allocated to both conditions for the 4Cs skills training. The skills transferability was measured through self-reports, observations, and interviews. The findings indicated no significant differences in the transfer of creativity, critical thinking, and communication skills in near and far settings following both training environments. Interestingly, a competitive gaming environment significantly facilitated the transfer of collaboration skills to near tasks evidenced by performance-based assessments. Moreover, although the hypotheses 1c and 3c were not statistically supported, the small to medium effect size suggests that there were practical differences between the groups in self-reported collaboration skills in near and far tasks. Additionally, analysis of individual interviews with 41 participants indicated that the successful transference was attributed to an array of scaffolds (i.e., mentorship, collaborative problem-solving environment, autonomy, and guided checklists) while the failure to detect positive effects was explained by various constraints (i.e., unfamiliarity with game rules, limited time, lack of practice, and established cognitive patterns). These findings add new insights into the literature on game-based learning and transfer of learning and inform researchers to further investigate the longitudinal effect of skills transfer and retention in both academic and professional spheres.

Keywords: 4Cs skills, Esports, Sandbox game, Competitive gaming environment, Skills transfer, Experimental design

Introduction

Esports or electronic sports, also known as competitive video gaming (Jenny et al., 2017) has caught enormous scholarly interest in recent years (Scholz, 2020). Different from educational games that often face criticism for simple designs that are narrowly focused

on academic content and target low-level literacy (Lester et al., 2014; Qian & Clark, 2016; Villalta et al., 2011), esports games present new opportunities for research. Compared with educational games, esports provide an array of affordances characterized by a good combination and balance of game mechanic features—discovery, rewards, tasks, narratives, competition, and collaboration—which support more effective and authentic situated learning (Squire, 2003; Zhong et al., 2024a, b). This interactive environment provides a space for players to develop skills naturally and holistically (González et al., 2018).

Recent studies highlighted the promising potential of esports as a medium for skills development (e.g. González et al., 2018; Zhong et al., 2022). Much evidence has supported the effectiveness of competitive video gaming in developing crucial knowledge and transferrable soft skills, such as creativity and critical thinking (e.g., Chang et al., 2020; Duncan, 2020; Kao et al., 2017; Mao et al., 2022; Qian & Clark, 2016; Yeh et al., 2019). However, the current literature has focused on how video games are being used to teach particular skills or subject-matter knowledge of the curriculum (Beserra et al., 2019; Rosas et al., 2003; Shute et al., 2015). Much of this research has highlighted the immediate consequences of using games to develop specific areas of skills (e.g., Lei et al., 2022; Lester et al., 2014; Lu et al., 2023; Squire, 2003). Unfortunately, far less attention has been paid to the extent to which the knowledge and skills acquired through gaming can be transferred to a range of situations. While the acquisition of knowledge and skills is essential, the fundamental and enduring goal of education, however, lies in skills transfer—applying and adapting what has been acquired to diverse contexts both within and outside the classroom (Barnett & Ceci, 2002; Lobato, 2006).

The urge to improve skill transferability, particularly in higher education has been driven by the need for a versatile workforce in the twenty-first century and the expectations from employers and students for graduates to immediately add value in any job situation (Billing, 2007; Botke et al., 2018; Haskell, 2000; Kemp & Seagraves, 1995). Despite the growing importance of transferrable skills, the prevailing education characterized by rote learning and overemphasis on academic content within the traditional structure of school subjects has led to unsatisfactory skills development and transfer (Billing, 2007; Voogt & Roblin, 2010). Students are less likely to transfer their skills if they are not explicitly taught and socially supported (Billing, 2007; Comfort & Timms, 2018). While esports gaming provides a social context for skills development (Zhong et al., 2022), there is an absence of robust understanding in the available research regarding the differences in the effectiveness of skills transfer following traditional teaching methods and socially rich game-based learning approaches. Moreover, understanding of skills transfer is largely framed by the choice of measures. Some available studies solely rely on qualitative measures (e.g., interviews) to capture the nuances of skill transfer to various contexts (e.g., Kendellen & Camiré, 2020; Thianthai & Sutamchai, 2022). A few studies quantitatively examined the impact of the gaming environment on skills transfer (e.g., Liu & Jeong, 2022; Nietfeld, 2020). Given the complexity and multifaceted nature of skills transfer, it necessitates the use of multiple methods to triangulate findings and draw more reliable conclusions.

In this study, we utilized an experimental design combining both quantitative and qualitative methods to investigate the effectiveness of skills transfer to both near and

far settings beyond the immediate competitive gaming environment compared to the non-gaming environment. By exploring the transference of skills cultivated through both environments, this study contributes to the existing literature by providing valuable insights into the conditions under which transfer of learning occurs and practically informing effective skills transfer in diverse situations.

Literature review

Concepts of 21st Century Skills: the 4Cs

The term "twenty-first century skills" emerged with the digital age, which is characterized by unprecedented technological growth and information explosion which have fundamentally changed social, economic, and academic lives (Beers, 2011; van Laar et al., 2020). The changes of the new century required individuals to possess a new mix of prominent skills that enable people to face challenges in the increasingly challenging world, which are mostly referred to as twenty-first century skills (Bağcı et al., 2019). Synonyms for describing the skills necessary for the twenty-first century included employability skills (De Fruyt et al., 2015), core competencies (Gooderham, 2014; Wahyuni & Sugihartini, 2021), social-emotional skills (Corcoran et al., 2018; Weissberg et al., 2015), generic or transferrable skills (Mawarti et al., 2020; Virtanen & Tynjälä, 2019), soft skills (Alex, 2009; Short & Keller-Bell, 2021), and life skills (Kivunja, 2015). While there has been an international consensus on the prominent need for various skills, the definition of '21st Century Skills' has lacked clarity and conformity in the academic community.

Several terminologies have been adopted to categorize 21st Century Skills, and they conceptualize the approach to a more convenient, resourceful, and result-oriented performance framework (Joynes et al., 2019).The global economy has become significantly knowledge-based, providing a perspective into the increased value attached to creativity, critical thinking, communication, and collaboration, known as the 4Cs. The aforementioned skillsets have a significant position in the current organizational landscape since they constitute a policy-friendly operational model (National Education Association, 2011). Based on the studies that have been undertaken by authoritative players like industry and independent researchers, the 4Cs can be considered the most effective skill sets that can contribute to holistic competence and professional efficacy (National Education Association, 2011).

According to Binkley et al. (2012), creativity encompasses the generation of new and valuable ideas, the refinement and evaluation of these ideas, the ability to work creatively with others, and the persistence to implement and promote these ideas despite obstacles and failures. Critical thinking is the disciplined process of effective reasoning, systematically analyzing, and evaluating evidence to make reasoned judgments, solve problems, and draw conclusions, while being open to new information, alternative viewpoints, and self-correction (Binkley et al., 2012). Communication is the multifaceted ability to effectively convey and interpret messages in various forms and contexts, utilizing a strong command of language, an understanding of cultural nuances, and the deployment of verbal and nonverbal cues to engage in clear, constructive, and culturally sensitive dialogue (Binkley et al., 2012). Collaboration refers to the coordinated effort of individuals to interact effectively, respect and integrate diverse perspectives, manage projects, guide

teams with integrity, and achieve common goals through active listening, clear communication, and responsible, ethical leadership (Binkley et al., 2012).

Skills transfer in the gaming environment

Transfer of learning, which involves the application of knowledge, skills, and behaviors learned from one context to another, context, is a well-studied phenomenon in psychology (Galoyan & Betts, 2021; Jackson, 2016). Transfer of learning is crucial as it empowers individuals to leverage previously learned knowledge and skills to solve new problems (Mayer & Wittrock, 1996; Rebello et al., 2017; Voss, 1987). It also supports the concept of lifelong learning, making the educational process perpetual and relevant to different life stages and aspects (Illeris, 2009). Traditional educational methods frequently come under scrutiny for not creating the necessary conditions for either reflexive or mindful transfer of learning (Perkins & Salomon, 1992). Consequently, the quest for innovative instructional approaches to facilitate the transfer of knowledge and skills has been a key focus for educators and researchers. Skills transfer by game-based learning environments is crucial for validating games as educational tools, aiming to extend in-game learning to real-world contexts (Thianthai & Sutamchai, 2022). A substantial body of research has indicated that digital games can improve critical thinking, creativity, communication, and collaboration (e.g., Behnamnia et al., 2020; David et al., 2022; Duncan, 2020; Michalski et al., 2019; Sala & Gobet, 2017; Schroeder & Kirkorian, 2016). For instance, in a study by Hsiao et al. (2014), researchers investigated the effects of game-based learning on fostering creativity among 51 students and observed that students demonstrated a positive increase in creativity while engaging in knowledge acquisition and task resolution within a DGBL environment. Mao et al. (2022) performed a meta-analysis involving 21 effect sizes from 20 studies with 1947 participants to explore the overall impact of game-based learning on students' critical thinking. The analysis indicated a substantial positive effect on overall critical thinking ($g = 0.863$, $k = 21$), with the impact on critical thinking disposition ($g = 1.774$, $k = 4$) being stronger than that on critical thinking skills ($g = 0.661$, $k = 17$).

Despite considerable research on how game-based learning affects skills development, limited evidence has been found on the transferability of these skills from gaming environments to real-world scenarios. Some available evidence showed transfer effects, such as enhanced communication skills from gaming transferring to real-world interactions (Nielsen and Hanghøj (2019), and significant improvement in cognitive skills (Parong et al., 2020). However, studies indicated that the process of transferring skills from one context to another is often challenging. For instance, in a study by Liu and Jeong (2022), no significant differences were observed in the near transfer of computational skills through game-based learning primarily because of the different dosages of cognitive support. While some evidence has indicated that transfer is possible, the mixed findings on the effectiveness of gaming environment on skills transfer suggested that transferability depends on various factors. Individual factors that impact transferability include prior knowledge and motivation (Fryer et al., 2021; Pierce et al., 2017), where engaged and intrinsically motivated players show better skill application in reality (Lohse et al., 2013). Game design also matters, with clear goals and feedback improving transfer (Lieberman et al., 2014; Serge et al., 2013). Additionally, contextual factors and

the timing of learning activities, ranging from minutes (e.g., a 60-min arts course), and months (e.g., a three-month football season); to generations (e.g., long-standing societal events) play a role (Lee & Martinek, 2013). As an illustration, a study conducted by McDonald (2017) demonstrated that playing the Coffee Shop game leads to short-term gains in critical thinking. These insights reflect the complex nature of transferring skills through the gaming context and provide guidance for designing game-based instruction to optimize skills transfer.

Conceptualizing skills transfer for the present study

The existing literature presents a range of theories to explain the phenomena of learning transfer. Each theory provides a different perspective and has embraced both merits and criticism. One classical theory, Thorndike's common elements theory (Thorndike, 1906), suggests transfer effectiveness is based on recognizing similarities across contexts. This theory facilitates the identification of transferrable knowledge and skills by underscoring the specific elements that need to be common in both original and new tasks. However, this faced criticism for its experimental design and potential bias towards the experimenter's expectations (Evans, 1998; Lobato, 2003a; Von Bastian et al., 2022). Another prominent theory, the situated cognition theory, proposes that learning and transfer are innately tied to context, making it difficult to separate knowledge from the environment in which it is applied (Lave & Wenger, 1991). Engle (2006) additionally advocated for linking learning contexts over time to enhance transfer. This approach helps students understand that their current tasks contribute to future learning and build upon previous knowledge. As an addition to traditional theories, alternative perspectives on transfer, such as the actor-oriented transfer (AOT) approach, deviate from classic transfer models by emphasizing practical generalizations within specific performance frameworks and highlighting the significance of accurate execution in transfer tasks. Under this approach, qualitative methods are frequently adopted to understand how students apply previous learning to new situations, capturing transfer from the learner's perspectives (Lobato, 2003b, 2006, 2014). Despite varied academic views on skill transfer's nature and mechanisms, these theories collectively contribute to a comprehensive understanding of the nature of transfer, the extent to which it occurs, and the nature of its underlying mechanisms (Barnett & Ceci, 2002).

This study conceptualized skills transfer by integrating multiple theories, considering the perspectives of participants, observers, and the context of the transfer activity. As shown in Fig. 1, this study integrated several theoretical perspectives on skills transfer. It began with the situated cognition approach, which posits that learning is contextually based and that skills development is part of the learning activity within specific contexts (Brown et al., 1989). In game-based learning environments, social interactions and problem-solving tasks were embedded in a narrative that players find meaningful and contextually rich (Chen et al., 2018). During the gameplay, players were presented with problems that were deeply embedded in a specific context, governed by rules (influenced by the content constraints), along with a rich array of interactive components and cognitive tools that encouraged players to independently discover paths to solutions (Adcock et al., 2011). This design could ensure that learning occurred in a social context, mirroring the 'community of practice' (Britt & Britt, 2021) where learners observed and

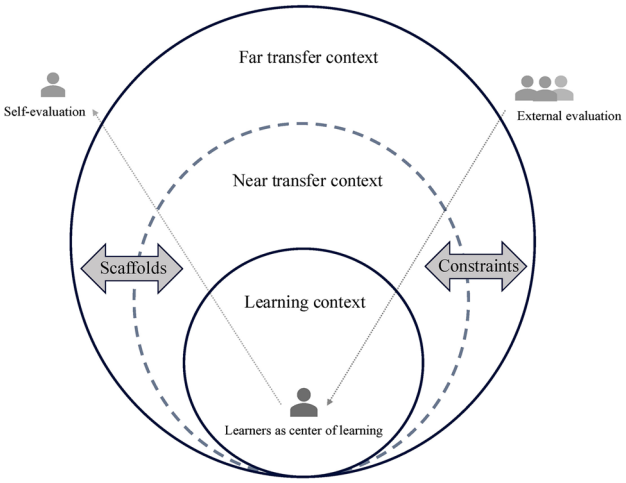

Fig. 1 A holistic perspective of skills transfer

monitored the consequences of their decisions and were continuously challenged to overcome knowledge gaps and developed multiple skills through problems that involve drawing on prior knowledge (Van Eck, 2007). For instance, during gameplay, learners discussed strategies and reflected on their actions, which not only enhanced immediate game performance but also built a foundation for transferring these reflective, communicative, and collaborative practices to external environments (Pivec, 2009).

Following the exposures to learning environments, the classical perspective suggests that transfer happens when learning and transfer situations share common elements; skills transfer can be 'near' (in similar contexts) or 'far' (across dissimilar contexts) (Thorndike, 1906). Near transfer is typically easier, while far transfer requires abstracting and applying knowledge to novel situations (Bigand & Tillmann, 2022; Detterman & Sternberg, 1993; Kassai et al., 2019). Learners benefit from engaging with multiple situations to build abstract representations that facilitate transfer (Chen & Daehler, 2000; Gentner et al., 2003).

Furthermore, transfer was traditionally assessed by observers, like teachers, who evaluate how well learners apply skills in new contexts. Apart from the expert's perspective, this study took into account learners' self-reflection on their ability to apply skills, their confidence, and their experiences with transfer (Lobato, 2014). Additionally, this study aligned with the theory that framing learners as active 'authors' in an intellectual conversation enhances transfer, particularly in the gaming context (Özhan & Kocadere, 2020). By drawing various insights from multiple theories, this study advocated a multi-dimensional approach of integrating participant and observer perspectives with careful design of activities in various contexts to understand skills transfer.

The objectives of the present research

The objective of the present research was to investigate the effectiveness of skills transfer to near and far tasks following a competitive Sandbox gaming learning environment in comparison to a non-game learning environment. Previous studies using digital games for learning and skills transfer yielded mixed results (Liu & Jeong, 2022; Parong et al.,

2020). Many studies indicated that near transfer can be more easily observed in gaming contexts. The skills required are closely related and thus transfer is more direct and likely to be more effective (e.g., Liu & Jeong, 2022). Far transfer, such as applying problem-solving skills from games to real-life strategic tasks, is less consistent, with studies showing varied results on its effectiveness (e.g., Bainbridge et al., 2022; Liu & Jeong, 2022). Based on the existing studies, we constructed the following research questions and exploratory hypotheses. Hypotheses a through d in each research question correspond to the transferability of critical thinking (hypothesis a), creativity (hypothesis b), collaboration (hypothesis c), and communication (hypothesis d) respectively:

RQ 1. Is a competitive sandbox game learning environment (CSG) more effective in the transferability of the 4Cs skills to near tasks than a nongame instructional (NG) approach?

Hypothesis 1a–d: The 4Cs (critical thinking, creativity, collaboration, and communication) skills acquired in CSG were expected to be more effectively transferred to near tasks compared to NG conditions, as assessed by self-reported measures.

Hypothesis 2a–d: The 4Cs skills acquired in CSG were expected to be more effectively transferred to near tasks compared to NG conditions, as measured by performance-based assessment.

RQ 2. Is CSG more effective in the transferability of the 4Cs skills to far tasks than NG method?

Hypothesis 3a–d: The 4Cs skills acquired in CSG were more effectively transferred to far tasks compared to NG condition, as assessed by self-reported measures.

Hypothesis 4a–d: The 4Cs skills acquired in CSG were more effectively transferred to far tasks compared to NG condition, as measured by performance-based assessment.

RQ 3. What are the differences in the transferability of the 4Cs skills learned through CSG to near tasks compared to far tasks?

Hypothesis 5a–d: The 4Cs skills acquired in a gaming environment will be more effectively transferred to the near task than the far task, as assessed by self-reported measures.

Hypothesis 6a–d: The 4Cs skills acquired in a gaming environment will be more effectively transferred to the near task than the far task, as measured by performance-based assessment.

RQ 4. How do the participants engaged in CSG perceive scaffolds and constraints in the transferability of the 4C skills to near and far settings?

Methodology

Research design

This study was preregistered at open science (https://osf.io/fgw3t/). This study utilized a comparative research design to investigate the 4Cs skills transfer following different instructional methods (Fig. 2). Participants were randomly assigned to either the competitive sandbox gaming environment (CSG Group) or the non-game environment (NG Group). This random assignment ensured that any differences observed between the groups could be attributed to the instructional method rather than participant characteristics. The pre-tests were administered to measure their proficiency in the 4Cs before the instructional interventions began. After the intervention, participants from both

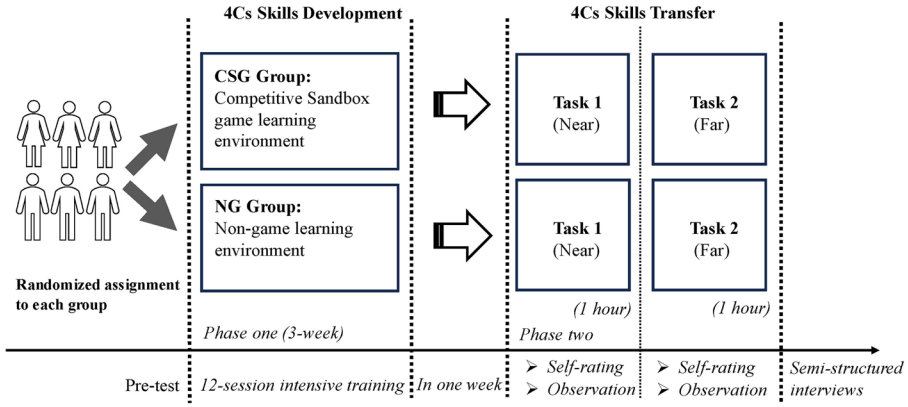

Fig. 2 An overview of research design

groups were invited to the follow-up near and far tasks to examine their skills transfer. Participants self-rated their 4Cs skill transfer in the respective tasks. Observations were conducted to record participants' performance in applying the 4Cs skills in both transferring settings. Additionally, semi-structured self-interviews facilitated by computers were conducted with participants to gather their perspectives on their transferability of skills to different contexts.

The follow-up assessment in the current study was performed one week after the training intervention. The rationale for assessing skills transfer within a short duration after intervention was to effectively measure the immediate retention and transfer following the initial effectiveness of the training. This short interval helped to measure how well participants can recall and apply what they have learned without the longer-term influences of memory consolidation and forgetting that occur over months (Walsh et al., 2014). Another reason was that a one-week interval minimizes the impact of external factors that could influence the participants' performance on the follow-up tasks (Seamon, 2004). Longer periods could introduce variability from other life experiences, additional training, or education that might confound the results. Additionally, short-term follow-ups benefited from higher participant engagement and lower dropout rates (Sauers-Ford et al., 2021).

Sandbox game for intervention: Shadow of Doubt

A detective sandbox game named *Shadow of Doubt* was utilized for skills training. Set in an alternate hyper-industrial version of the 1980s, the game requires players to adopt the role of detectives, using a range of tools to gather evidence like private investigators and solve cases to earn commissions. The game was selected for the intervention because it centers on the investigation and solving of intriguing cases as a detective and thus requires a variety of skills, making it suitable for developing the 4Cs competencies. Specifically, in detective gaming scenarios, players are presented with complex mysteries and puzzles that demand creative solutions. This encourages them to think outside the box and devise innovative strategies for solving puzzles or interpreting clues. Second, critical thinking is at the core of detective games. Players must analyze information, deduce connections, evaluate the relevance and

reliability of clues, use logical reasoning and make decisions based on incomplete or misleading evidence or clues in the games. Third, the game that involves teams can significantly enhance collaboration skills. Players need to work together to discuss and analyze various evidence, pooling their collective knowledge to form a consensus or solve the case. Finally, effective communication is essential in the game, where players must share findings and learn to communicate complex ideas succinctly and clearly to ensure all team members understand the situation and the proposed solutions. Convincing team members to follow a particular line of investigation requires persuasive communication, especially when opinions diverge.

Skills development program

The CSG Group was involved in skills training through sandbox game-based experiential learning activities. The teaching process followed a structured learning cycle that includes stages of experience, reflection, connection, and application. The instruction started with sandbox gaming competitions, where players were working in teams to find evidence to solve the case. After initial gaming experience, students reflected on the 4Cs competencies observed during the gameplay. In this phase, the teacher guided students in reflecting on their gameplay and how it connected to the competencies. Following that, students connected concepts by engaging with course materials that had been prepared by the teachers. Similarly to the prior phase, the teacher helped facilitate learning by directing students to connect these materials with the skills and concepts being taught. Students acquired understanding and strategies for each competence. Once they understood the 4Cs competencies, they returned to the game to apply what they had learned. During the competitive sandbox gaming environment, students were encouraged to participate actively, ask questions, and lead discussions to facilitate the skills acquisition.

In comparison, NG Group received nongame skills training, where the students were passive recipients of knowledge, following instructions presented by the teacher. The teacher served as the primary authority in student learning. The teacher began with warm-up exercises, followed by an introduction to the topic via a prepared PowerPoint presentation. The teacher continued by helping students acquire conceptual knowledge of the 4Cs and strategies for developing these competencies using prepared learning materials, facilitated group discussions and reflections, and concluded with feedback from the teacher.

The primary difference between the groups was that the CSG group was centered around student needs and interests, promoting autonomy and exploration, whereas the NG instruction was tightly structured, with the teacher guiding activities and enforcing strict rules. Nonetheless, both groups had learning instructions that were comparable in terms of content and duration. The training for each group extended across 3 weeks, consisting of four modules, with each module being divided into three 50-min sessions. Both groups followed the same learning content and timeframe. The learning materials were sourced from recognized skills training programs and existing university courses (Bellis, 2023; Broomfield, 2023; FutureLearn, 2023; Kruse et al., 2023).

Skills transfer context

After skills training, participants engaged in tasks designed for skills transfer, with one hour dedicated to a near transfer task and another hour to a far transfer task. In the near transferring scenario, students put into practice the skills developed from their earlier training. The CSG Group took part in a detective game that was similar to a detective sandbox game, requiring them to work together in teams, share information, discuss thoughts, and coordinate their efforts to solve the mystery. The NG Group engaged in a group task supported by videos, which echoed the contents they had previously studied. For the far transfer context, both groups were assigned an identical group task: to create a business strategy, a task not included in their prior training. In completing the task, students were required to analyze the specific situation, exercise critical thinking, share and discuss ideas, collaborate with their team members effectively, and formulate creative solutions.

Participants

A priori power analysis was conducted using G*Power version 3.1.9.6 software to estimate the sample size needed to test hypotheses. Results showed that 88 participants (44 for each group) were required to achieve a statistical power of 95% for a two-tailed independent t-test, with a 0.05 alpha level (Faul et al., 2009). Thus, the obtained sample of $N=110$ was sufficient to test the hypotheses. The participants involved second-year students (comprising 44 males and 66 females) from five faculties at a privately run, mid-sized university in mainland China were involved in the study. University administrators assisted in recruitment by posting research posters on campus and sharing details through the university's communication channels. The study, approved by the Human Research Ethics Committee of the university where the study was affiliated (Anonymized Reference Number), ensured participants were informed about its goals, methods, and their rights to confidentiality and withdrawal (Brooks et al., 2014). Informed consent was obtained before participation.

The study randomly assigned students to either the CSG group or the NG group using a random number generator (Kang & Tian, 2018), with each group including 55 participants. Four participants in the CSG group completed the initial knowledge test and survey but later withdrew due to scheduling conflicts. After skills training, the remaining students completed near and far transfer tasks and were then invited to follow-up interviews. Table 1 presents the demographic information of participants engaged at various stages of the study.

Data collection

Phase one: pre-intervention skills assessment

Participants completed a questionnaire that included demographic information (e.g., age and gender) and self-reported measures of the 4C skills (creativity, critical thinking, collaboration, and communication). The items used to measure each competency were sourced from established assessments developed by Kelley et al. (2019) but were slightly rephrased to suit the context of this study. Respondents assessed their competency levels using a cumulative scale ranging from level 1 (Novice/beginner) to level 5

Table 1 Demographic information of participants involved in different phases of the study

Phases	Groups	Total	Gender		Age (18–22)	
			Female	Male	Mean	SD
Pretest (*Self-rating*)	CSG group	55	33	22	19.60	0.71
	NG group	55	33	22	19.40	0.85
Near task (*Self-rating*)	CSG group	50	31	19	19.56	0.70
	NG group	54	32	22	19.52	0.91
Near task (*Performance*)	CSG group	51	31	20	19.59	0.73
	NG group	54	33	21	19.43	0.84
Far task (*Self-rating*)	CSG group	50	31	19	19.56	0.70
	NG group	51	29	22	19.46	0.86
Far task (*Performance*)	CSG group	50	31	19	19.56	0.70
	NG group	51	29	22	19.46	0.86
Follow-up interviews	CSG group	41	26	15	19.59	0.74

(Expert/Mastery). This assessment provides a baseline understanding of where each participant stands in terms of skill development. Confirmatory factor analysis was performed to refine the measurement model. Items were considered for exclusion if they had factor loadings below 0.5 or significant cross-loadings, as suggested by Brown (2015) and Tabachnick et al. (2013). As a result, we yielded 16 items, with each skill set consisting of 4 items. Various fit indices were applied in determining the adjusted model's fit for verifiability and authority. A Root Mean Square Error of Approximation (RMSEA) value of 0.056, with a 90% confidence interval ranging from 0.035 to 0.085, signifies a well-fitting model Browne and Cudeck (1992). In addition, the results of the model included a Tucker-Lewis Index of 0.96 and a Confirmatory Fit Index of 0.97, indicating a remarkable reliability since, in both instances, the indices recorded surpassed the recommended 0.95 level for the sound model fit. Moreover, the outcomes of Cronbach's alpha assessment targeting to determine the reliability of the scale after revision were very high. In retrospect, the high values encompassing 0.90 and 0.91 readings offered a robust index of internal consistency and the scale's reliability (Taber, 2018).

Phase two: real-world transfer assessment

In both near and far tasks, participants rated their 4Cs skills transfer after completing near and far activities. The ratings were conducted using the 5-point Likert Scale from 'Not at all' to 'Very much.' Internal consistency of the measure items was assessed. The Cronbach's alpha values in both near and far task were 0.97, indicating excellent reliability (Nunnally, 1978). In addition, participants' performance in each task was videotaped. This evidence-based approach empowers researchers and observers to comprehend how the transfer of skills occurs among learners (Knoblauch et al., 2012; Sparrman, 2005).

In the qualitative part of the study, we used computer-assisted self-interviewing (CASSI) for efficiency and to allow participants to self-guide through pre-set questions with the option to provide additional input (Fairweather et al., 2012; Galletta, 2013). The method also saves time on transcription. To delve into participants' experiences and challenges of skills transfer in both near and far contexts following skills training through competitive sandbox gaming, we formulated some key questions: how do you

feel about skills transfer in near/far contexts? Can you share an example of a skill you have successfully transferred to a near/far context? Did you encounter any challenges or difficulties when attempting to transfer skills in a near/far context? If so, please describe the situation. Each interview lasted 5–10 min.

Data analysis

Data analysis began with descriptive statistics (i.e. mean or median, standard deviation or interquartile range, and distribution of the pretest scores) to assess the participants' initial skill levels. Kolmogorov–Smirnov test was applied to check data normality, guiding the choice between parametric or non-parametric tests for further analysis. Levene's test assessed the equality of variances across groups, accommodating for non-normal distributions. For pre-test scores, the Mann–Whitney U test and Independent Samples t-tests were employed. After establishing baseline comparability between the two groups, the study proceeded with data analysis of self-report measures and performance-based assessments to determine if a gaming learning environment better facilitates the transfer of the 4Cs skills to near tasks than a nongame environment.

To investigate RQ1, we checked data normality with Kolmogorov–Smirnov tests and variance homogeneity with Levene's tests, followed by independent samples t-tests for testing hypotheses1b &1c and Welch's *t*-tests for hypotheses 1a &1d between-group comparisons (Howell, 2012). For Hypotheses 2a–2d, a panel including a course instructor and two research assistants evaluated participants' application of the 4C skills in near transfer settings, using a rubric for proficiency levels (AAC&U, 2024; Ramachandiran et al., 2016; Yujobo, 2015). Assessors underwent training to standardize their use of the rubric. The analysis involved iterative discussions among experts to ensure reliability and validity (Suen & Ary, 2014). Inter-rater reliability measures were calculated to assess the agreement among the experts' ratings using Cohen's kappa coefficient. There was excellent agreement among raters across four skills: creativity (Cohen's kappa = 0.91, z = 25.03, $p < 0.001$), critical thinking (kappa = 0.85, z = 21.93, $p < 0.001$), collaboration (kappa = 0.86, z = 22.05, $p < 0.001$), and communication (kappa = 0.89, z = 22.13, $p < 0.001$). Following the normality check, the analysis proceeded with the use of Mann–Whitney U tests for verifying hypotheses 2a, 2b, & 2c and Welch's tests for testing hypothesis 2c. Meanwhile, we calculated the effect size to measure the extent of any differences observed.

To test RQ 2, we predicted that the 4Cs skills acquired in a gaming environment were more effectively transferred to far tasks using self-reported measures and performance-based measures. After checking normality and quality of variance, the Mann–Whitney U tests were utilized to test hypotheses 3b and 3d respectively and Welch's tests were utilized to examine hypotheses 3a and 3c. As to Hypotheses 4a–4d which involved evaluation of students' performance, three raters assessed each participant's performance adhering to established rubrics as previously described. Inter-rater reliability for the assessments was measured using Fleiss' Kappa statistic (Fleiss et al., 2013; Nichols et al., 2010). The agreement among assessors was strong for the skills being assessed: creativity (kappa = 0.80, z-score = 22.08, $p < 0.001$), critical thinking (kappa = 0.85, z-score = 22.22, $p < 0.001$), collaboration (kappa = 0.82, z-score = 18.66, $p < 0.001$), and communication (kappa = 0.89, z-score = 19.39, $p < 0.001$). After verifying normal distribution and homogeneity of variance,

we proceeded to apply the Mann–Whitney U tests to investigate hypotheses 4c & 4d and use Welch's tests for hypotheses 4a and 4b. Additionally, we conducted an effect size analysis to measure the magnitude of the observed differences. While examining RQ1 and RQ2, the Bonferroni-adjusted alpha level was calculated to control the overall Type I error. We divided the original alpha level (0.05) by 4 tests conducted, resulting in an adjusted alpha level of 0.013 to account for the multiple comparisons.

To examine RQ3 which involved comparing the differences of the 4Cs skills between settings of near and far transferring following competitive sandbox gaming learning, we applied paired samples *t*-tests to test hypotheses 5a–5d after ensuring normality assumptions were met. Paired samples *t*-test analysis was utilized for hypothesis 6a, whereas Wilcoxon signed rank tests were implemented for hypotheses 6b, 6c and 6d.

To address RQ4, the process of determining the opinions held by the participants concerning the levels of support and skill transfer was undertaken using the natural language processing technique. The mechanism adopted in the natural language processing intervention encompassed the Latent Dirichlet allocation (LDA) (Blei et al., 2003; Joynes et al., 2019). Thematic analyses were also incorporated into the process of determining the experiences that participants have with skill transfer issues. The LDA framework was adopted for the determination of the factors impeding or facilitating skill transfer in both near and far tasks. Thematic analysis was harnessed for the determination of critical factors like the themes, and data narratives. An integration of both approaches would increase the feasibility of the exercise and facilitate significant improvements in skill transfer thus fostering validity and ease of skill mobility to new settings (Clarke & Braun, 2017).

Before running LDA, some pre-processing steps were conducted for the attainment of reliable results. LDA is a data mining approach hence the need for the operationalization of the pre-processing steps. The major pre-processing steps incorporated into the procedure included the translation of original texts into English and lowercasing the character in the string variable text. Other pre-processing interventions incorporated into the procedure involved erasing common stop words, punctuation deletion, and the lemmatization of the words to their root forms (Kang & Tian, 2018). After that, we performed the topic modelling part to process the data into the unsupervised topics and to evaluate the quality of the topics. We created a list of 10 top words with the highest probability scores to describe the theme of each topic. Next, we contrasted the changes in coherence and exclusivity topics to establish the number of the most appropriate topics to use in the LDA model. We also used coherence scores to check if the top words in a topic make sense together and referred to exclusivity scores to examine if the top words are specific to each topic (Roberts et al., 2014). We manually tested each topic to ensure it was contextually relevant to the study. Two research assistants helped review the thematic labels and interpretations. Finally, the themes were categorized to provide insights into the scaffolds and constraints of skills transfer in both near and far contexts.

Results

Quantitative results

RQ1: Differences of the 4Cs skills in near transfer setting between two groups

To accurately respond to research questions, we first compared the baseline of self-reported 4Cs skills between the NG group (N = 55) and the CSG group (N = 55). We

utilized the Kolmogorov- Smirnov test to assess the normality of self-reported 4Cs skill scores. Results suggested that Critical thinking and Communication ($p < 0.05$) significantly deviate from normality, while Creativity and Collaboration ($p > 0.05$) were normally distributed. The homogeneity of variances between the groups was assessed using Levene's test, showing no significant difference ($p > 0.05$). Accordingly, the Mann–Whitney U test was conducted to test the pre-test scores for Creativity and Communication and Independent Samples t-tests used for Critical thinking and Collaboration. The results showed that there was no statistically significant difference between the two groups in any measurement ($p > 0.05$), indicating that skills assessed for both groups were comparable at baseline.

To test Hypotheses 1a–1d that the 4Cs (critical thinking, creativity, collaboration, and communication) skills acquired in a competitive gaming environment could be more effectively transferred to near tasks compared to the traditional instruction, we first evaluated the assumption of normality for self-reported scores of the 4Cs skills transfer in the near task using the Kolmogorov- Smirnov test. The results showed that the scores for Critical thinking and Communication ($p < 0.05$) significantly departed from normality, while Creativity and Collaboration ($p > 0.05$) were not significantly different from a normal distribution. Levene's test for equality of variances suggested that the assumption of homogeneity of variances was met for Creativity ($F = 0.50$, $p = 0.483$) and Collaboration ($F = 3.27$, $p = 0.073$) but was violated for Communication ($F = 4.74$, $p = 0.032$) and Critical thinking ($F = 12.93$, $p < 0.001$). Given the results of normality and equality of variances, the independent sample t-tests were employed to compare the means of Creativity and Collaboration while Welch's t-tests for comparing the means of Communication and Critical thinking between two groups.

As shown in Table 2, no significant differences were found in four skillsets in the near tasks between the two groups after Bonferroni correction. Specifically, in terms of critical thinking, an independent samples *t*-test indicated no significant difference in the scores for the CSG group ($M = 13.98$, $SD = 3.23$, $N = 50$) compared to the NG group ($M = 13.63$, $SD = 2.01$, $N = 54$); $t(80.90) = -1.14$, $p = 0.256$, Cohen's $d = 0.13$). This suggests a small effect size with no statistically significant difference in critical thinking skills between the groups. In terms of creativity, results of Welch's t-test indicated that the scores for the CSG group ($M = 14.50$, $SD = 3.19$, $N = 50$) were not significantly

Table 2 Self-reported 4Cs skills transfer in near task between two groups

4Cs near transfer	Groups	*N*	Mean	Median	SD	Statistics	*p*-value	Effect size (Cohen's d)
Critical thinking	CSG group	50	13.98	12.50	3.23	80.90	0.256	0.13
	NG group	54	13.63	14.00	2.01			
Creativity	CSG group	50	14.50	14.00	3.19	102	0.411	0.04
	NG group	54	14.37	15.00	2.68			
Collaboration	CSG group	50	14.74	14.00	2.82	102	0.018*	0.42
	NG group	54	13.67	13.00	2.31			
Communication	CSG group	50	13.90	13.00	3.20	87.37	0.438	0.03
	NG group	54	13.81	14.00	2.26			

**$p < 0.013$ (significant after Bonferroni correction); *$p < 0.05$ (not significant after Bonferroni correction)

different from the NG group (M = 14.37, SD = 2.68, N = 54); $t(102) = 0.32$, $p = 0.411$, Cohen's d = 0.04, suggesting a negligible effect size. For collaboration skills, Welch's t-test indicated that the CSG group (M = 14.74, SD = 2.82, N = 50) had higher scores than the NG group (M = 13.67, SD = 2.31, N = 54); $t(102) = 2.63$, $p = 0.018$, Cohen's d = 0.42. Although this p-value indicates a significant difference at the conventional 0.05 level, it does not meet the stricter Bonferroni-adjusted criterion of $p < 0.013$ within the context of multiple comparisons. Lastly, an independent samples t-test comparing communication skills between groups found no significant difference. The CSG group (M = 13.90, SD = 3.20, N = 50) had similar scores to the NG group (M = 13.81, SD = 2.26, N = 54); $t(87.37) = -0.25$, $p = 0.438$, Cohen's d = 0.03. To summarize, none of the initial hypotheses were confirmed. It is worth mentioning, however, that the Collaboration scores, while not statistically significant, showed a moderate effect size of 0.42, indicating a meaningful difference between the groups.

To test Hypotheses 2a–2d, students' performance data was collected to provide an objective understanding of students' skills transfer in near tasks in respective groups. The results of Kolmogorov–Smirnov tests indicated that all measures were deviated from normality ($p < 0.05$). Homogeneity of variances was tested using Levene's test across four skills, suggesting no significant issues with homogeneity except for Collaboration, which was marginally significant ($F(1, 103) = 4.08$, $p = 0.046$). Therefore, we performed Welch's test to compare the performance of collaboration while applying Mann–Whitney U tests for the performance of the other three skill sets between the two groups.

As shown in Table 3, the Mann–Whitney U test was applied to compare critical thinking skills, showing that the CSG group (N = 51) had a median score of 9.00, and the NG group (N = 54) had a median of 8.00. The test yielded a p-value of 0.217, with a negligible effect size (Cohen's d = 0.08), indicating no statistically significant difference in critical thinking skills between the two groups. Creativity scores were analyzed using the Mann–Whitney U test as well. The CSG group (N = 51) had a median creativity score of 6.00, identical to the median score of the NG group (N = 54). The resulting p-value was 0.275 with a Cohen's d of 0.06, demonstrating no significant difference in creativity between the groups. The Mann–Whitney U test was also used to assess differences in communication skills. The CSG group (N = 51) had a median score of 9.00, closely matched by the NG group (N = 54) with a median of 9.00. The p-value was 0.256 and the

Table 3 4Cs skills transfer in near task evaluated by external assessment

4Cs near transfer	Groups	*N*	Mean	Median	SD	*p*-value	Effect size (Cohen's d)
Critical thinking	CSG group	51	7.98	9.00	2.16	0.217	0.08
	NG group	54	7.74	8.00	2.28		
Creativity	CSG group	51	7.16	6.00	2.43	0.275	0.06
	NG group	54	7.04	6.00	2.53		
Collaboration	CSG group	51	9.29	9.00	2.00	0.002**	0.59
	NG group	54	8.07	9.00	2.25		
Communication	CSG group	51	8.94	9.00	2.20	0.256	0.07
	NG group	54	8.78	9.00	1.84		

**$p < 0.013$ (significant after Bonferroni correction); *$p < 0.05$ (not significant after Bonferroni correction)

effect size was 0.07, showing no significant difference in communication skills between the two groups. For collaboration, results of Welch's t-test showed that the CSG group (N = 51) had a mean score of 9.29 (SD = 2.00) compared to the NG group (N = 54) with a mean of 8.07 (SD = 2.25). A significant difference was found in the collaboration scores after Bonferroni correction, as indicated by Welch's t-test ($t(102.98) = 3.01$, $p = 0.002$), 95% CI: [0.18, 0.98]). This result suggests that the CSG group had significantly higher collaboration scores compared to the NG group. The Cohen's d value was 0.59, indicating a medium effect size. Overall, he hypotheses 2a, 2b, and 2d were rejected; only the hypothesis 2c was supported by the data.

RQ2: Differences of the 4Cs skills in far transfer setting between two groups

Hypotheses 3a-3d predicted that participants following competitive sandbox gaming learning performed better than nongame learning in transferring their 4Cs skills to far tasks. We evaluated the assumption of normality and equality of variances for the 4Cs skills transfer scores in far tasks between two groups. The Kolmogorov- Smirnov test showed that the scores for four skill sets ($p < 0.05$) deviated from a normal distribution. Levene's test for equality of variances suggested that Creativity ($F = 0.25$, $p = 0.619$) and Communication ($F = 0.91$, $p = 0.343$) met the assumption while Critical thinking ($F = 3.97$, $p = 0.049$) and Collaboration ($F = 6.47$, $p = 0.012$) violated the assumption of homogeneity of variances. Accordingly, the Mann–Whitney U tests were employed to compare Creativity and Communication while Welch's t-test was conducted to compare the means of Critical thinking and Collaboration.

As shown in Table 4, analysis using Welch's t-test revealed no significant difference in the means of critical thinking between the CSG (M = 14.20, SD = 2.72) and the NG (M = 14.14, SD = 2.10), with a *p*-value of 0.449 and a negligible effect size (Cohen's d = 0.03). The Mann–Whitney U test for creativity showed no statistically significant difference between the CSG (Median = 15.00) and the NG (Median = 14.00), with a *p*-value of 0.357 and a small effect size ($r = 0.04$). In terms of collaboration, Welch's t-test indicated a small to moderate effect size (Cohen's d = 0.42) in collaboration skills ($t(df) = 88.04$, $p = 0.018$, 95% CI [0.02 to 0.82], with the CSG (M = 15.02, SD = 2.46) scoring higher on average than the NG (M = 14.12, SD = 1.74). However, the difference did not reach statistical significance under the adjusted criterion ($p = 0.018$). The

Table 4 Self-reported 4Cs skills transfer in far task between two groups

4Cs far transfer	Groups	*N*	Mean	Median	SD	*p*-value	Effect size (Cohen's *d*/*r*)
Critical thinking	CSG group	50	14.20	14.00	2.72	0.449	0.03
	NG group	51	14.14	14.00	2.10		
Creativity	CSG group	50	14.86	15.00	2.86	0.357	0.04
	NG group	51	14.71	14.00	3.00		
Collaboration	CSG group	50	15.02	14.00	2.46	0.018*	0.42
	NG group	51	14.12	14.00	1.74		
Communication	CSG group	50	14.58	14.00	2.76	0.543	0.01
	NG group	51	14.51	15.00	2.59		

**$p < 0.013$ (significant after Bonferroni correction);* $p < 0.05$ (not significant after Bonferroni correction)

Mann–Whitney U test for communication also failed to show significant differences between CSG (Median = 14.00) and NG (Median = 15.00), with a p-value of 0.543 and an effect size close to zero ($r = 0.01$). In short, the results suggested that there was no significant difference in the perceived transfer of the 4Cs skills in the far tasks between the two groups. Therefore, the hypotheses 3a-3d were rejected.

To test Hypotheses 4a–4d, we conducted Kolmogorov–Smirnov tests and Levene's tests to evaluate the assumptions of normality and Homogeneity of variances. Results showed that none of the measures conformed to a normal distribution ($p < 0.05$). Variances for Collaboration and Communication were homogeneous ($p > 0.05$) while Critical thinking and Creativity violated homogeneity ($p < 0.05$). Accordingly, we utilized Mann–Whitney U tests to determine the differences in the performance of Collaboration and Communication and employed Welch's tests to evaluate Critical thinking and Creativity between the two conditions (Table 5).

As presented in Table 5, the Welch's test showed no significant difference in critical thinking scores between the CSG group (M = 8.82, SD = 3.15, N = 50) and the NG group (M = 9.71, SD = 2.23, N = 51), with a p-value of 0.944 and the effect size, Cohen's d = -0.32. Similarly, for Creativity, the Welch's test results indicated no significant differences between the groups. The CSG group had a mean score of 8.42 (SD = 2.88) and the NG group a mean of 8.98 (SD = 2.31), with a p-value of 0.858 and Cohen's d value of -0.21. For Collaboration, the CSG group had a mean score of 10.06 (SD = 1.73) compared to the NG group's mean of 9.63 (SD = 2.24). The Mann–Whitney U test showed a borderline significant difference (U = 965, $p = 0.013$, 95% CI [0.08 and 0.88]), meeting the threshold set after Bonferroni correction. The effect size, Cohen's d, was 0.24, suggesting a small effect size favoring the CSG group. Additionally, no significant difference was found in Communication scores between the groups using the Mann–Whitney U test. Both groups recorded identical mean scores of 10.08, and the p-value was 0.498, with effect size at 0.00, indicating no difference between the groups. In summary, the only significant difference observed was in Collaboration, where the CSG group outperformed the NG group slightly. Critical thinking, Creativity, and Communication did not show significant differences between the two groups under the conditions tested. Therefore, the findings rejected hypotheses 4a, 4b, and 4d while marginally supported 3c.

Table 5 4Cs skills transfer in far task evaluated by external assessment

4Cs far transfer	Groups	*N*	Mean	Median	SD	*p*-value	Effect size (Cohen's d)
Critical thinking	CSG group	50	8.82	9.00	3.15	0.944	−0.32
	NG group	51	9.71	10.00	2.23		
Creativity	CSG group	50	8.42	9.00	2.88	0.858	−0.21
	NG group	51	8.98	12.00	2.31		
Collaboration	CSG group	50	10.06	9.00	1.73	0.013*	0.24
	NG group	51	9.63	9.00	2.24		
Communication	CSG group	50	10.08	9.00	2.14	0.498	0.00
	NG group	51	10.08	9.00	1.86		

**$p < 0.013$ (significant after Bonferroni correction);* $p < 0.05$ (not significant after Bonferroni correction)

RQ3: Differences of the 4Cs skills in far and transfer settings following the gaming instruction

Hypotheses 5a–5d expected that respective self-reported 4Cs skills in the near task were higher than that in the far task following gaming intervention. 50 participants were involved in both near and far tasks. The Kolmogorov–Smirnov tests indicated no significant departure from normality for all the measures ($p > 0.05$). Results of paired samples t-tests showed no significant differences were found in the self-reported 4Cs scores between near and far tasks: Critical thinking (t(49) = −0.49, $p = 0.627$, MD = −0.22, Cohen's d = −0.07); Creativity, (t(49) = −0.70, $p = 0.489$, MD = −0.36, Cohen's d = −0.10); Collaboration, (t(49) = −0.64, $p = 0.522$, MD = −0.28, Cohen's d = −0.09); and Communication, ($t(49) = -1.41$, $p = 0.165$, MD = −0.30, Cohen's d = −0.10). These findings rejected Hypotheses 5a–5d, suggesting no statistically significant differences in the 4Cs scores between near and far transfer tasks following the competitive sandbox gaming learning, although the scores in far transfer task were higher.

Hypotheses 6a–6d predicted that the 4Cs performance respectively in the near task was higher than that in the far task within gaming intervention. The Kolmogorov–Smirnov tests suggested that the critical thinking scores were normally distributed ($p = 0.126$) while the creativity, collaboration, and communication scores deviated from normality ($p < 0.001$). Correspondently, paired samples t-test was applied to compare the performance of critical thinking between near and far tasks while Wilcoxon signed-rank tests were used for the rest skillsets. The results showed significant changes in the measured skills between the near-transfer and far-transfer scenarios, with p-values less than 0.001 for all measures. However, contrary to hypotheses 6a–6d, scores in the far condition were significantly higher than those in the near condition across all measures. The paired samples t-test showed critical thinking scores in near task performance (M = 7.94, SD = 2.19) was lower than that in far tasks (M = 9.27, SD = 2.79), t (100) = −3.54, Cohen's d = -0.35. The Wilcoxon signed-rank tests also indicated creativity (Z = −4.92, Cohen's $r = -0.58$), collaboration (Z = −7.46, Cohen's $r = -0.91$), and communication scores (Z = −5.98, Cohen's $r = -0.81$) scores were significantly lower in the near task compared to far task. Given the results, the hypotheses 6a–6d were rejected by the data.

Qualitative results

The qualitative data gathered from 41 participants through interviews provided valuable insights into the personal experiences related to the transfer of the 4Cs skills. Through the metrics of coherence and exclusivity (Fig. 3), we balanced the interpretability and distinctiveness of topics to select the most appropriate model for further thematic analysis. A variety of themes were identified to understand the scaffolding mechanisms that facilitated skills transfer and constraints that impeded transferability in both near and far transfer settings.

Scaffolds in the 4Cs skills transfer

As detailed in Table 6, two important scaffolds were identified by participants that contributed to the transfer of their skills in near-transfer settings. One critical factor was mentorship that facilitated skill transfer. The participants generally acknowledged the positive role of the teacher in facilitating their application of skills. They perceived the

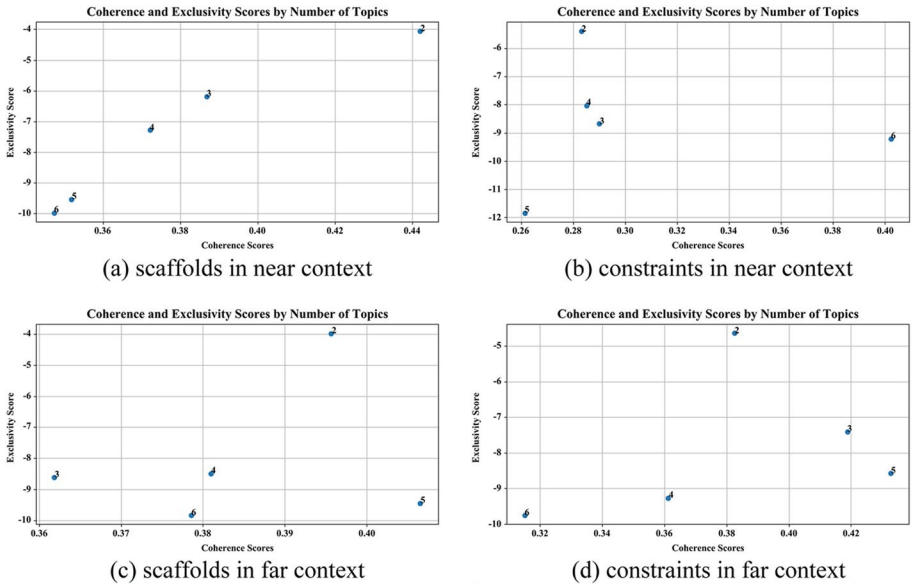

Fig. 3 Coherence and exclusivity scores for four main questions

Table 6 Scaffolds in the 4Cs skills transfer from interviews

Contexts	Scaffolds	Representative quotes
Near transfer	Mentorship	"The teacher was very responsible and patient. She taught me the importance of teamwork, which was the most valuable lesson" (Student 31, Personal Communication, November 5, 2023)
	Collaborative problem-solving environment	"The teamwork involved in communication and task completion was not only fun but also highly efficient in promoting our teamwork abilities" (Student 11, Personal Communication, November 3, 2023) "The game's sense of exploration and the brainstorming it required sparked my interest and enhanced team cohesion and cognitive functioning during discussions" (Student 35, Personal Communication, November 5, 2023)
Far transfer	Autonomy	"We were given the chance to reflect on our own thought processes, followed by a team discussion. This discussion time leveraged our team cohesion and our personal communication skills" (Student 31, Personal Communication, November 5, 2023)
	Guided checklist and questions	"The questions and list of points provided were helpful. We learned to analyze advantages and disadvantages, to think creatively, and to communicate effectively. In business, as in the scenarios we discussed—considering a company, refugees, and oneself—it's important to balance and distribute roles and responsibilities thoughtfully" (Student 25, Personal Communication, November 4, 2023)

teacher as responsible and patient, which made them feel secure enough to attempt applying skills in challenging situations. Knowing that their teacher would consistently support them greatly boosted their confidence. Another factor that facilitated skill transfer was the open environment for trial and error which encouraged creative and cooperative teamwork. A collaborative and interactive learning environment helps mitigate the fear of making mistakes, encouraging students to experiment and learn from them, which is critical for skill development and transfer.

In the far-transfer settings, participants appreciated autonomy for exercising their skills. Students were given much freedom to apply their skills. They leveraged the time for reflection, discussion, and problem-solving within the team. Autonomy can empower

students to take charge of their learning process, which fosters active engagement in the tasks presented (Yang et al., 2022). Additionally, students indicated that the checklist (i.e., a list of important points that students must consider during their group project) and guided questions (i.e., open-ended questions that encourage discussion and multiple perspectives or solutions) provided by teachers were useful for them to think and communicate more effectively in the tasks which were required to identify as many solutions as possible to settle the issue presented.

Constraints in the 4Cs skills transfer

Three primary constraints were identified that might impact students' ability to transfer skills upon completing the near-transfer task. First, the similarity in genre between the training and the application task did not equate to ease of transfer. This led to initial challenges when the game introduced a new set of rules that were unfamiliar to the participants. Another obstacle was the complexity of modifying established cognitive patterns in a short period. Participants struggled to adapt their problem-solving strategies to the new context, suggesting that a longer acclimatization period might be required for the effective application of these cognitive processes. Lastly, the aspect of working with new teammates introduced additional complexity. The participants experienced some difficulties in adjusting to unfamiliar group dynamics, which in turn hindered the smooth transfer of collaborative and communication skills developed from the previous training.

In the far transferring context, one major challenge highlighted by the students was the time required to attain proficiency in these skills. When time is limited, it might lead to increased stress and cognitive overload. Under time stress, students may revert to familiar patterns rather than applying new skills to new situations. Another challenge was the struggle to shift away from established cognitive patterns. Students generally felt challenged to adapting old thinking patterns to new situations effectively. Moreover, students expressed difficulty in team communication when divergent ideas within team members emerged. The transfer of communication skills was far more complex in the real-world settings than expected. Lastly, there was not sufficient opportunities for practice. Participants indicated that more practices would be helpful for them to apply the skills acquired in the training. The constraints for near and far transfer along with representative quotes from students are presented in Table 7.

Discussion

The central investigation of this study was to assess the effectiveness of the CSG in the transferability of the 4Cs skills to both near and far task contexts compared to traditional instructional methods. In the study, Hypothesis 2c was validated, showing that sandbox gaming environment had a more pronounced effect on the transfer of collaboration skills to near task evidenced by performance-based measures. Additionally, it was worth noting that Hypotheses 1c (self-reported collaboration in near task), 3c (self-reported collaboration in far task), and 4c (performance-based collaboration in far task) did not meet the strict threshold, $p < 0.013$, as adjusted by the Bonferroni correction. Nonetheless, the small ($r = 0.24$) to medium effect sizes ($r = 0.42$) suggest that there was a meaningful difference in collaboration skills between the two groups (Cohen, 2013). The results

Table 7 Constraints in the 4Cs skills transfer from interviews

Contexts	Constraints	Representative quotes
Near transfer	Unfamiliarity with rules	"Some of the skills and knowledge were new to us, and we faced difficulties and challenges at the beginning" (Student 3, Personal Communication, November 5, 2023)
	Established cognitive patterns	"I found it hard to break free from my previous thought patterns, making it difficult to adeptly apply the new skills and knowledge" (Student 16, Personal Communication, November 3, 2023)
	New team dynamics	"We had trouble communicating effectively with new team members. Sometimes we couldn't progress because we weren't on the same page, which led to ineffective communication" (Student 33, Personal Communication, November 5, 2023)
Far transfer	Insufficient time	"I feel difficulty in utilizing skills that had only recently been learned in a new environment (Student 5, Personal Communication, November 2, 2023)
	Established cognitive patterns	"The biggest challenge in using these skills was overcoming our previous mindsets to effectively apply this new knowledge and skills" (Student 16, Personal Communication, November 3, 2023)
	Communicative issues	"Communication is not easy in the group work. The discussions became unwieldy due to the number of group members and their varying perspectives. Sometimes, it was challenging to reach a consensus (Student 20, Personal Communication, November 3, 2023) "The suboptimal team communication affected skill application (Student 9, Personal Communication, November 2, 2023)
	Lack of practices	"During the short time, there were not many opportunities for me to fully apply the skills. I feel that I need more real-world practice." (Student 9, Personal Communication, November 2, 2023)

suggest that the interactive and cooperative nature of gaming environments is conducive to developing and transferring collaboration skills in both near and far situations. This supports the broader narrative suggested by Billing (2007): Transfer is promoted when learning takes place in a social context and when learning is through co-operative methods. In contrast to educational games, sandbox esports have a cooperative and competitive nature, strongly incentivizing participants to fully engage in group work during the intervention. Consistent engagement in team dynamics may contribute to the effective transfer of collaboration skills to both near and far settings. A similar phenomenon was observed in the study of Parong et al. (2017), which examined the effectiveness of a specially designed video game to identify conditions under which gameplay would translate into cognitive improvements in task-shifting abilities in the dimensional change card sort task and letter-number task in nongame context. Parong et al. (2017) indicated that successful transfer of skills relied on a focus on a specific skill for sufficient time of interaction at an appropriate level of challenge. Other possible explanations for the effective transfer of collaboration skills in this study can be found from qualitative data, where participants indicated that mentorship, collaborative problem-solving environment, and autonomy were effective for their skills transfer.

Surprisingly, however, the rest of the hypotheses were rejected. No significant differences were detected in the transfer of critical thinking, creativity, and communication following the two learning methods using either measure. Similarly, no significant difference was found between near and far tasks following the CSG instruction. These findings revealed the complex and multifaceted nature of skills transfer. In our study, the qualitative data can further explain the failure to detect a positive effect of the gaming

environment on the transfer of communication, creativity, and critical thinking skills compared to the traditional teaching method.

In the near-transfer setting, participants reported a range of constraints, including the challenge of navigating rules of games they were not used to, resistance to changing established cognitive habits, and the need to adjust to new team interactions. For instance, students indicated that when they engaged in the gaming environment which resembled the previous sandbox games, the near task presented new game rules that they were not familiar with. Another challenge was the difficulty of shifting long-standing ways of thinking within the short timeframe of the training. Although the training allowed participants to be exposed to new creative and critical thinking concepts and strategies, it takes time to internalize these skills. This observation echoes past research, affirming that internalizing a certain skill requires constant effort and extensive practice (Mehta & Al-Mahrooqi, 2015; Pierce et al., 2018). On the other hand, participants engaging in the far transfer scenarios identified insufficient time, a tendency to stick to their existing cognitive patterns, issues in communication, and a lack of opportunities for practices as the main reasons for their struggles in skills application. Particularly, the issues of time constraints and a scarcity of practices were accentuated. Some students reported that the training improved their skills, but that they did not have enough time to reflect on the learning process. They also indicated that insufficient practice in the session prevented them from mastering and transferring the skills. These constraints resonate with the study of Parong et al. (2017), which also highlighted the importance of allocating sufficient time for students to reflect on their learning experiences and engage in practice to make the necessary connections for skills transfer. This further points to a critical insight, namely that without repeated and deliberate practice of skills in different contexts, the transfer is less likely to occur.

The challenges reported by participants are supported by earlier research on transfer of learning. Some available studies have identified the underlying reasons that may lead to unsatisfactory skills transfer. Factors that may affect the skills transfer in the gaming environment include self-efficacy and interest (Nietfeld, 2020), duration (Parong et al., 2017), lack of practice (Parong et al., 2020), difficult levels of game tasks (Yang & Li, 2023), cognitive loads (Liu & Jeong, 2022; Yang & Li, 2023), and individual experiences in micro-time activity (e.g., Chen et al., 2010; Chiu, 2008; King et al., 2015). Aside from the factors and challenges mentioned above, the insignificant differences identified in the transfer of creativity, critical thinking, and communication skills in near and far settings might be attributed to the choice of measurements. In this study, an existing validated questionnaire survey on the 4Cs was adopted for several reasons: (1) validity and reliability, (2) time and cost efficiency, (3) collecting data in a standardized manner, and (4) ease of use (Artino et al., 2014; Rattray & Jones, 2007). Despite the benefits of using existing instruments, there are some potential drawbacks. Existing surveys may not align perfectly with specific cultural context, resulting in data that might not be entirely relevant and comprehensive for the research in the Chinese educational context. This calls for a necessity to design authentic formative tests to comprehensively evaluate the transfer of the skills. Moreover, the structure and difficulty of tasks in transfer activities could affect their success. According to Haji et al. (2016), decreasing the complexity of tasks improves performance and reduces cognitive load during the acquisition and

retention of skills. In the current study, asking students to finish tasks within one hour without sufficient understanding of new game rules could have raised their cognitive load. There is potential to optimize the design of these performance tasks for better skills transfer. Above all, by understanding the multifaceted reasons that might account for the effectiveness of transfer, this study supports a better understanding of the skills development that caters to the diverse needs of learners, the dynamics of their interactions, and the characteristics of learning environments.

Furthermore, the findings enrich our theoretical understanding of game-based learning and skills transfer. The significant impact of CSG instruction in facilitating the transfer of collaboration skills as validated by performance data further substantiates the effectiveness of game-based learning in skill development and transfer. Games have been seen as beneficial tools for facilitating and supporting situated learning of students (All et al., 2016). Competitive video gaming inherently requires players to work together, which directly enhances skills that are expressly collaborative in nature. The finding of our study aligned with socio-cultural learning theories which suggest that interactive environments, like those found in competitive video gaming, provide social contexts that naturally enhance collaborative skills (Steinkuehler & Tsaasan, 2020;Vygotsky, 1978). This finding was also consistent with existing literature which suggests that a game-based learning approach can be effective in facilitating the development and transfer of twenty-first century skill such as collaboration among students (e.g., Duncan, 2020; Qian & Clark, 2016; Sung & Hwang, 2013).

On the other hand, the nonsignificant effects of CSG on the transfer of critical thinking, creativity, and communication skills found in this study challenge and prompt a reevaluation of existing theories about game-based learning and skills transfer. The ineffectiveness in transferring the skills might reflect the specific design and nature of the competitive games used in the instruction. As detailed in qualitative findings, constraints such as time pressure, lack of practice, and established cognitive patterns might affect the effectiveness of transfer of these skills. These insights reflect the complexity of game-based learning environments. Some existing literature has documented various factors that may impact the integration of games into instruction. All et al. (2016) provides an overview of variables, including prior knowledge, social economic status, motivation, gender, computer skills, and game experience. In a different context, Nietfeld (2020) studied a transfer task derived from a serious game and identified interest as a consistent predictor of performance, but did not find similar predictive value in the motivational variables that were measured. This contradiction highlights the need for careful research design, clear consideration of game and implementation, and attention to contextual factors. Additionally, Admiraal et al. (2011) observed from the perspective of instructional design that distractions and team-based competition had an influence on the learning outcome. The combination of findings from this study and prior literature could lead to improved game-based learning strategies that promote skill transfer. Generally, the results suggest that although competitive video games are beneficial for enhancing collaborative skills, their capacity to develop and transfer other essential abilities such as critical thinking, creativity, and communication might be restricted without careful attention to game design and additional considerations. This highlights the importance for educators and researchers to extensively analyze these factors when

embedding competitive video gaming into instructional strategies for skills development and transfer.

Implications

Theoretical implications

In this study, CSG was found to be more effective than NG in fostering collaboration in near settings as evidenced by student performance data evaluated by external assessors. This reinforces the transfer of learning theory, which posits that knowledge is retained within the mind in terms of representations that are continually reconstructed based on new experiences (Goldstone & Day, 2012). This finding contributes to the understanding of situated learning theory, which emphasizes the role of environments in skill development and transfer. It further supports the notion that the context in which learning activities occurs plays an essential role in transfer of learning (Griffin, 1995; Kirshner & Whitson, 2021; Lemke, 2021; Wu et al., 2020).

However, the differential transferability of skills, with collaboration transferring effectively—but not communication, creativity, or critical thinking—indicates the need for a re-examination of the binary categorization of transfer contexts into just 'near' and 'far' may be overly simplistic. The students in the study indicated that their skills transfer was constrained by a lack of time for reflection and internalization of what they learned. Insufficient practice and rapid changes of team dynamics further hindered this process. These findings suggest that the process of transfer is complex and that additional factors, beyond the similarity of contexts, can influence the success of skills transfer.

Apart from the quantitative results, qualitative data also suggests the need to expand the theory on transfer of learning. This would explain why some skills transfer in situations where others do not, as well as under what conditions they transfer. There is also a need for a more refined framework for categorizing transfer contexts. This framework should be based on the spectrum of context similarities and differences, rather than a simple dichotomy (Heilman et al., 1990; Laker, 1990; Pierce et al., 2017). Such theoretical implications can guide future research and the development of new, evidence-based approaches to teaching and learning. These approaches can be incorporated to enhance skills transfer across contexts.

Practical implications

This study's findings support the argument that collaborative skills learned in one context can generalize to others. It implies that a competitive game learning environment not only prepares learners for immediate, context-specific challenges (near tasks) but also equips them with skills that are generalizable and applicable to broader contexts (far tasks). The transfer of skills from competitive gaming makes a strong case for its integration into multiple settings. These results are especially relevant for educational practices, curriculum design, and serious game development.

First, educators may consider employing competitive sandbox gaming for instruction—not merely as an entertaining 'alternative pedagogy', but also as a strategically powerful means to fostering collaboration among learners. As collaboration has been shown to be a crucial skill for success in various professional and interpersonal domains (Castañer & Oliveira, 2020; Riveros, 2012; Weiss & Hughes, 2005), such integration may

be particularly beneficial in subject areas that traditionally lack group-based learning opportunities. During game-based instruction, the teacher's role transitions to a facilitator, guiding students, helping troubleshoot, and keeping discussions focused on learning objectives. Students are transformed into active learners rather than passive recipients of knowledge in the gameplay that allows them to interact and enhance their skills. Besides this, competitive video gaming can extend beyond the classroom as an extracurricular activity, fostering peer collaboration and helping to build a learning environment that is both inclusive and collaborative.

Curriculum developers can strategically integrate competitive gaming modules into lesson plans to enhance collaborative learning. For instance, video games could be strategically included in curriculum areas that benefit from enhanced teamwork, such as science labs, group projects, or team sports to boost collaborative skills in scenarios where teamwork and group dynamics are focal. Specifically, curriculum designers could consider designing game-based activities or assignments with specific roles and tasks for students that compel them to interact and collaborate. For example, curriculum developers could structure assignments in a way that mimics the competitive, yet cooperative aspects of video games, thereby cultivating an environment that promotes group cohesion and collaborative problem-solving.

Additionally, these findings inform developers of serious games (Girard et al., 2013; Lamb et al., 2018) to design games that more effectively target and develop a wider range of skills. This might involve creating games that combine competitive elements with those that require critical thinking, creativity, and communication, ensuring a more holistic skill development. It is also advisable for game developers to integrate adaptive learning technologies into their games, allowing players to evaluate their abilities and tailor the game's difficulty and challenges accordingly. Such customization can personalize the learning experience and may improve the acquisition of specific skills.

Limitations and future directions

The current research illuminates the transfer of the 4Cs skills. However, interpreting the results requires consideration of several limitations. First, this study was conducted in a higher educational context in mainland China; the findings should be interpreted cautiously considering variations in cultural values and behaviors that can influence how interventions are received and their efficacy. Recent research indicates that skills development differs across cultures. In studies by Blau et al. (2020) and Park et al. (2021), it was found that students display varying skills depending on whether they are part of a more individualistic learning culture, which focuses on personal achievement and independence, or a more collectivistic setting that values group harmony and collective success. Therefore, to fully understand the impact of competitive video gaming on essential skills such as collaboration, cross-cultural research involving students from various backgrounds is necessary. There is a need for more studies that explore the role of cultural perceptions in the development of skills within the competitive game-based experiential instruction. Moreover, given that the participants in this study were university students, the findings might not be completely generalized to other populations. Future studies can expand the research population to different age groups (children,

adolescents, or adults) and compare how they develop and transfer skills through game-based methods, with assessments at multiple points post-intervention over a longer period.

Second, this study adopted randomization an experimental design by controlling prior skill levels to ensure that each group was comparable for the intervention being tested; however, it did not account for variables such as self-efficacy (Fryer et al., 2022a, 2022b; Meluso et al., 2012) or motivational and affectional levels (e.g., Chen & Law, 2016; Fryer, Shum, et al., 2022; Fryer & Bovee, 2018; King & Gaerlan, 2014). Given that games have been viewed as motivational tools that make learning motivating and enjoyable (Cutting & Deterding, 2024), further research should examine how these variables impact skills transfer. For instance, future research can examine how intrinsic motivation—motivation driven by interest and enjoyment in the task itself (Ainley & Hidi, 2014; Rheinberg & Engeser, 2018)—impacts the long-term retention and transfer of skills acquired through game-based learning. To investigate this issue, several methodological approaches can be employed. Researchers can combine quantitative methods (such as pre-tests and post-tests on skill proficiency) with qualitative methods (such as interviews) to probe into how intrinsic motivation may affect long-term retention and transfer of skills. Qualitative data can provide insights into learners' perceptions and experiences of the game-based learning process. It is also recommended that research consider using use digital tools and analytics within the game-based learning environment to track user engagement, choices, and progress and correlate specific in-game behaviors and choices with levels of intrinsic motivation and subsequent skill transfer.

Third, the intervention for this study involved 12 sessions spanning over 3 weeks. There might be 'novelty effects' due to the relatively short duration of the gaming intervention. It was not clear whether the positive impact could be attributed to the temporary increase in performance when novel technologies were introduced into instruction (e.g., Fryer et al., 2017). Addressing the novelty effect in game-based instruction requires offering preparatory workshops, training sessions, and peer coaching to help learners become familiar with game dynamics. Future research can implement repeated measures to see if improvements decline as the novelty wears off. This involves assessing participants' performance several times throughout the intervention. It is advisable to schedule assessments at the beginning, middle, and end of the intervention period, and possibly follow-up tests after the intervention concludes. Another approach to address novelty is to compare the effectiveness of various games to observe if the novelty effect is consistent across different types of games with different styles and complexities in similar settings. Apart from novelty effects, the short-term intervention also raises concerns regarding the sustainability and long-term retention of the transferred skills. Accordingly, we need longitudinal research designs to measure the long-term effects of GBL on the 4Cs transfer and retention of skills. For example, the 4Cs skills training through a competitive sandbox game could be incorporated into the regular curriculum in university, where students would be tested at fixed intervals (e.g., half a year) with the same set of instruments. This would allow the researchers to observe the micro-process of skill transfer.

Additionally, this study adopted sandbox game for intervention. This game genre has unique features for open world and flexible regulations, allowing players to freely

navigate in the game. In line with the learning goals, *Shadow of Doubt*, a detective sandbox game was selected for CSG instruction. Interpretations of our findings should be confined to the context of this particular game. Considering that each game possesses distinct storylines, narratives, and a variety of game elements and mechanisms, future research should include interventions using other game genres to broaden the comparative analysis. It is also beneficial to assess how different game genres contribute to skill development and transfer when integrated into the instruction effectively.

Moreover, the study contributed significantly to the enhancement of the validity and richness of the 4Cs skills transfer by including self-reports, performance, and interview data. However, the process has its limitations, and the ultimate mechanisms that would foster effective skills transfer were not identified through it. As a result, there is a need for the development of mechanisms involving new observations and measurements of skill transfer to boost efficacy. Given that its nature of transferring as a neurocognitive mechanism (Haskell, 2000), biometric technologies such as eye-tracking (Lai et al., 2013) and electroencephalogram (EEG) (Wan et al., 2021) can provide a more holistic and accurate reflection of cognitive processes of skills transfer. Other technologies such as artificial intelligence (Wang et al., 2021; Zheng et al., 2023), sensors (Jraidi & Frasson, 2013; Mohamadipanah et al., 2021), and virtual reality (Dobrowolski et al., 2021) can be harnessed for tracking mechanisms and easy object identification, offering real-time monitoring on the effectiveness of skills transfer.

Conclusion

This study compared the effectiveness of transfer of the 4Cs skills in near and far scenarios following both competitive gaming (CSG) and nongame learning (NG) environments. The findings did not point to any significant variations in the transfer of creativity, critical thinking, and communication skills in both near and far tasks between the two conditions. However, students with CSG demonstrated higher collaboration skills in near tasks, as evidenced by student performances assessed by external assessors. Additionally, although the hypotheses that CSG would be more effective in transferring collaboration skills to near and far task were not statistically supported by self-reported measures based on threshold of Bonferroni correction, the small to medium effect sizes suggested that CSG might have practical differences in self-reported collaboration skills in near and far tasks and is worth additional study. The quantitative outcomes were made clearer through the support of qualitative evidence. The combination of data mining techniques with thematic analysis of interview data identified an array of scaffolds (e.g., as mentorship, open environment, autonomy) that facilitated skills transfer. The analysis also pointed out constraints that included insufficient time, lack of practice, and communication conflicts, which impeded the effective transfer. These findings suggest that researchers should further investigate the longitudinal effect of skills transfer and retention across various populations and contexts. The findings also make a significant contribution to existing theories on the transfer of learning by recommending a more refined framework to categorize contexts for transfer.

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Author contributions
Yuchun Zhong (First and corresponding author) conceptualized the study, designed the methodology, completed the writing of the initial manuscript, and coordinated the integration of all co-authors' contributions to the paper. Luke Kutszik Fryer offered critical guidance in the study design, data collection, and data analysis, and played a pivotal role in interpreting the results. He contributed significantly to the manuscript. Shiyue Zheng managed the project logistics, engaged in the design and implementation of the intervention, and coordinated with the research team, ensuring compliance with ethical standards. Alex Shum assisted in the methodology, offered critical feedback, and helped refine the manuscript and address reviewers' comments for intellectual rigor. Samuel Kai Wah Chu provided feedback on the theoretical framework for the study and helped revise the original proposal for the research.

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Availability of data and materials
The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Competing interests
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