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More than just fun: Investigating students' perceptions towards the potential of leveraging esports for promoting the acquisition of 21st century skills

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Abstract

Esports (electronic sports) or competitive video gaming has taken its place as a leading form of entertainment for young people worldwide. However, esports were generally studied as a popular form of entertainment, and rarely have studies examined esports from an educational perspective. This study aimed to investigate the perceived impact of various types of esports on the acquisition of the 4Cs skills (critical thinking, creativity, collaboration, and communication) through the lenses of higher education students. A sequential mixed methods research design was adopted, with a questionnaire survey involving 628 participants followed by semi-structured interviews with 46 participants. The quantitative findings showed that the players generally perceived that esports can cultivate the 4Cs skills and their perception was significantly related to gaming experience, gaming frequency, and time spent on each gameplay. The higher level of engagement in games was associated with higher 4Cs skills. No significant difference was found in scores of the 4Cs skills across nine esports genres. Apart from statistical inferences, natural language process (NLP) techniques combined with thematic analysis were used to identify various mechanisms and elements of different games associated with the 4Cs skills development. The quantitative and qualitative findings collectively shed light on the potential of integrating esports elements into innovative pedagogies for promoting learning and developing the 4Cs skills for both life and career.

Keywords Esports · 21st century skills · Higher education · Game genres · Game mechanisms and elements · Natural language processing

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1 Introduction

Esports captivate young people due to their thrilling blend of risk-taking, competition, engagement, and various other dynamic aspects (Pedraza-Ramirez et al., 2020). The popularity of competitive video gaming has captured scholarly attention(e.g., Başaran & Şimşek, 2023; Ye et al., 2018), with most research directed at commercial, social, and cultural dimensions of esports (Bányai et al., 2019; Rogstad, 2022; Sanz-Matesanz et al., 2023). Beyond recreational appeal, however, the educational potential of esports in facilitating skills acquisition has been largely overlooked. Some existing research has shed light on how esports is associated with the acquisition of skills required for the 21st century (e.g., Melián Díaz et al., 2020). For instance, evidence suggests that engagement in Multiplayer Online Battle Arena (MOBA), First Person Shooter (FPS), Role Playing Games (RPG) can lead to improved communication and collaboration (Putra, 2023; Xia et al., 2019). Additionally, players engaged in sandbox games, such as Minecraft, were reported to enhance their collaboration and creativity (Andersen & Rustad, 2022; Melián Díaz et al., 2020). Despite these, much of the existing research has treated esports as a monolithic activity, failing to differentiate the diverse skills fostered by each game genre. To date, no studies have specifically examined the distinction of categories of esports and how they are related to a wide breadth of skills development. The absence of refined categorization due to the divergent conceptualization of esports among scholars leads to a divide in understanding how to fully utilize the opportunities and impacts associated with the rise of the esports industry (Cranmer et al., 2021). Additionally, perceptions among the academic community vary widely (e.g., Chan et al., 2022; Funk et al., 2018). Despite the growing recognition of esports (Harvey & Marlatt, 2021; Rothwell & Shaffer, 2019), concerns about esports being associated with the potential for addiction, sedentary behaviors, and exposure to online toxic environments (Macey & Hamari, 2018; Wattanapisit et al., 2020) have led to reservations regarding its value.

Esports are linked to skills acquisition due to a variety of mechanisms and elements that are inherent to gaming and the culture surrounding competitive play. However, there is a limited understanding of how skills acquisition is linked to the mechanisms and elements of each game genre. Added to that, the lack of understanding of esports hinders educators and researchers from effectively integrating esports or elements of the esports gameplay into learning environments in a way that maximizes educational benefits. The current research seeks to bridge the identified gaps by examining the connections between different esports categories and essential skills needed for the 21st century and by identifying the mechanisms and elements of each game genre within which these skills are developed.

2 Background

2.1 Definition and categorization of esports

Esports, or electronic sports, is a form of competitive sports using video games (Chan et al., 2022). The definition of esports has been a subject of controversy

within the academic and gaming community. Key points of contention mainly revolve around the recognition of esports as a legitimate form of sport, the criteria for what constitutes an esport, and the identity of esports itself (Funk et al., 2018; Hamari & Sjöblom, 2017; Jenny et al., 2017; Wagner, 2006; Witkowski, 2012). Regardless of whether esports is a sport, competitive video gaming has established a presence around the world (Holden et al., 2017). The rapid expansion of digital territory has broadened the conceptual scope of esports. Witkowski (2012) conceptualizes esports as an organized and competitive approach to playing computer games. Hamari and Sjöblom (2017) extended the idea of 'organization' by identifying key attributes that qualify a gaming activity as esports: 1) the existence of professional players, 2) tournaments with significant spectatorship, and 3) the presence of economic investments. Jenny et al. (2017) propose a more inclusive definition, which considers any form of video gaming that is played competitively under certain rules as esports. This definition has been increasingly embraced by academics with a general recognition that video games with formal rulesets, organized gameplay, and competitive elements can classified as esports (Funk et al., 2018; Savas et al., 2020). As an illustration, Candy Crush Saga, originally a non-competitive mobile game, has been included in the world of esports with the launch of its first U.S. Candy Crush All-Stars tournament (Nieva, 2021). With the advancement of information and technologies, the family of esports will expand with a rising variety of video games emerging, the 'loose' definition of esports allows for a broader categorization that can evolve with technological development.

In accordance with the inclusive definition of esports, a broad spectrum of video games were identified. These esports games can be categorized into nine types based on key distinct characteristics: (1) First/Third-Person Shooters Games (e.g., Counter-Strike and Call of Duty), (2) Real-time Strategy Games (e.g., StarCraft and Warcraft), (3) Multiplayer Online Battle Arena Games (e.g., Defence of the Ancients and League of Legends), (4) Sports Simulation Games (e.g., the FIFA series), (5) Sandbox Games (e.g., Minecraft), (6) Massively Multiplayer Online Role-playing Games (e.g., World of Warcraft), (7) Fighting Games (e.g., Super Smash Bro), (8) Racing Games (e.g., iRacing), and (9) Card and Board Games (e.g., Hearthstone) (Alexander, 2020; 'Different types of sports', 2022; Lin & Sun, 2015; Steel, 2022). Table 1 lists descriptive definitions of esports game types.

2.2 The 21st century skills

The changes and characteristics of the new century require individuals to be equipped with a collection of prominent skills that enable them to cope with challenges in the modern world (Bağcı et al., 2019). The concept of 21st-century skills was envisioned as a collection of skills essential for individuals to effectively engage with and thrive in modern society (Chu et al., 2017). Multiple different perspectives emerge on what constitutes 21st-century skills. There are six major theoretical frameworks that represent different perspectives on the 21st century skills recognized by various societies. These frameworks included

Table 1 Characteristics of esports by types

Type of esports	Characteristics
First-Person Shooter (FPS) and Third-Person Shooters (TPS) Games	Players use a first-person or third-person point-of-view camera to navigate their avatar around a shared game area. A controller is used by players to control character movement (Hitchens, 2011)
Real-Time Strategy (RTS) Games	Players compete concurrently, making quick, accurate decisions with limited information while using structures, technology, resources, and units (Gutierrez, 2022)
Multiplayer Online Battle Arena (MOBA) Games	Two teams compete in a predetermined region, with each character possessing a unique set of talents and roles (Gutierrez, 2022)
Sports Simulation Games	Emulates traditional sports follow the rules of the sports they emulate (Gutierrez, 2022; Marie, 2023)
Sandbox Games	The game is interacted with by the players without any predetermined aims. They are frequently allowed to choose their path in the game, which activities they participate in, which characters and items they utilize, and where they wish to focus their attention (Steel, 2022)
Massively Multiplayer Online Role-Playing Games (MMORPGs)	Participants play fictitious characters, traveling and interacting inside multidimensional gaming maps based on novels, films, and comic books (Lin & Sun, 2015)
Racing Games	Players compete in driving games, often against multiple opponents (Gutierrez, 2022)
Card and Board Games	Digital card games are played in a turn-based structure, with cards used for activities such as attacking and casting spells. Players take turns moving their pieces around the board, generally to capture opponents' pieces, reach a specified position on the board, or accumulate points or resources (Hearthstone, n.d.; The History of Card Game Esports, 2023)
Fighting Games	Two players engage in combat employing a variety of attacks, sophisticated button combinations, and a predefined stage or territory (Alexander, 2020)

OECD's Definition and Selection of Competencies Project (Ananiadou & Claro, 2009), P21's Framework for 21st Century Learning (Partnership for 21st Century Skills, 2009), En Gauge (Lemke, 2003), The International Society for Technology in Education Framework (ISTE, n.d.), The European Reference Framework Competences (The European Parliament and of the Council, 2006), and the ATCS21 framework (Binkley et al., 2012).

While each of the various frameworks for 21st-century skills highlights particular competencies deemed crucial for the success and adaptability of individuals within their respective societies, there are notable commonalities that transcend cultural and

geographic boundaries. Skills such as critical thinking, creativity, communication, and collaboration (the 4Cs) reflect a global consensus on the types of skills (Kivunja, 2015; Mazzola, 2020) that are universally applicable and valuable in an interconnected world (National Education Association, 2012). First, almost every framework emphasizes the importance of critical thinking skills. This focus stems from the need for individuals to analyze information, assess complex problems, and devise solutions in an era of information overload and rapid change (Dwyer et al., 2014). Another key skill across various sections is creativity. Binkley et al. (2012) defined creativity as the act of coming up with new ideas, working creatively with others, and implementing innovations. It is these essential attributes that drive our society to progress and succeed (Henriksen et al., 2016; Piirto, 2011). Moreover, to adapt to the world characterized by rapid information exchange, the ability to communicate in various forms to articulate and express clearly, listen actively, and deliver the message effectively through various modalities (i.e., verbal, audio, written, and visual) is highlighted as an essential skill across various frameworks (Battelle for Kids, 2019; Binkley et al., 2012). Additionally, collaboration is a recurring theme in 21st-century skills frameworks. With the increase of team-based work towards globalization, it is essential to possess the competence to collaborate with others from diverse cultural and geographical backgrounds (Binkley et al., 2012; Graesser et al., 2020). Collaboration is defined as "interacting effectively with others, working effectively in diverse teams, and guiding and leading others towards a shared goal" (Binkley et al., 2012, p. 46). These skills form an important baseline from which to advance workforce development initiatives across the world. The current research drew upon the 4Cs framework (National Education Association, 2012) to examine how students acquire these skills in various esports types (see Fig. 1).

In the present study, we focused on the students' perceptions of the acquisition of the 4Cs skills within esports gaming contexts. The study explored students' perceptions of how effectively their creativity, critical thinking, communication, and collaboration skills are being fostered and enhanced in the context of gaming environments. Specifically, we investigated how the 4Cs skills link to gaming by assessing how much esports gameplay promotes: 1) creativity through students' ability to create, adapt, and enhance ideas within their team or league; 2) critical thinking by students' capability of question formulation, evaluation of reasoning and evidence, idea generation specific to gaming, solution innovation, decision justification, and information synthesis; communication, through effective time management, efficient discussions, organized information sharing, and clear goal articulation during gameplay; and 4) collaboration, observed as respect for teammates, adherence to rules, valuing others' ideas, offering help, and self-improvement from feedback (Binkley et al., 2012; Graesser et al., 2020; National Education Association, 2012). These aspects provide insights into how the 4Cs skills develop in different esports gaming contexts.

2.3 Research questions

The overarching aim of this study is to explore the role of esports on the 4Cs skills acquisition among students from higher education. To achieve the goal, a mixed methods

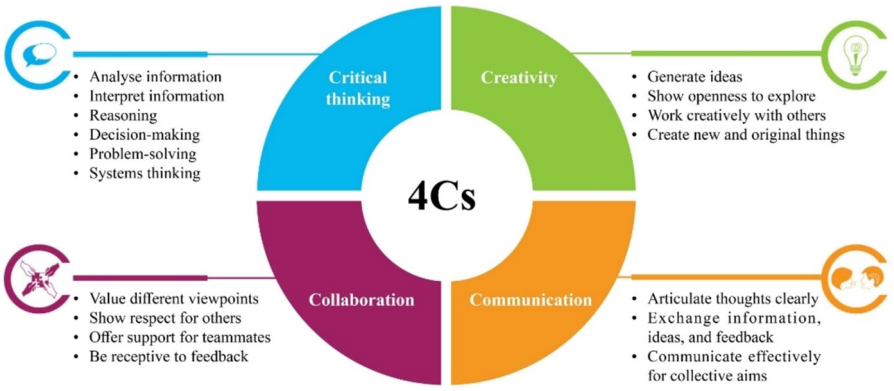

Fig. 1 The 4Cs framework

research design was used. First, a quantitative inquiry was implemented to examine (1) players' perception of the impact of esports on their acquisition of various skills, (2) factors that impact their perception of skills development in esports, and (3) the relationships between 21st century skills components in esports participation (see RQ1-RQ3). Meanwhile, a qualitative inquiry was conducted to gain deeper insights into the mechanisms and elements related to skills acquisition within each esports game genre (see RQ4). The research questions are presented as follows:

RQ1: To what extent do players perceive they acquire the 4Cs skills through playing esports?
RQ2: In what ways do players' behavioral characteristics (i.e., gaming experience, gaming frequency, and duration of each gameplay) affect their perceptions of the 4Cs skills acquisition through esports?
RQ3: What are the relationships between different 4Cs skillsets in players' skills acquisition through esports?
RQ4: How do students perceive the mechanisms and elements associated with skills acquisition within each esports genre?

3 Methodology

3.1 Research design

A sequential mixed methods research design was adopted in this study (Creswell & Clark, 2017). The quantitative data were first collected through an online questionnaire survey to structured responses that can easily be quantified to identify relationships among variables. Qualitative data was then collected from semi-structured

interviews for helping further explain the quantitative results. Specifically, in this study, the quantitative data was gathered to investigate the relationships between esports and various 21st century skillsets. Qualitative data served to complement primary quantitative findings, providing deeper insights into underlying mechanisms and elements related to the 4Cs skills within various esports games.

The employment of both quantitative and qualitative methods allows for a panoramic and in-depth perspective on the development of 21st century skills across different esports genres.

3.2 Research context

This study was situated in China, specifically targeting university students, for several reasons. In the geography of esports, Asia Pacific accounted for a significant number of global gamers, among which China has not only taken on South Korea as the mecca of esports but also taken over North America and Europe becoming the largest single-country market in the world with $403.1 million in esports revenue in 2021 (Kharpal, 2022; Yu, 2018). While esports are widely enjoyed by young people in China, the negative image of esports associated with physical and mental issues has caused researchers and educators to be hesitant to incorporate esports into educational considerations. Against this backdrop, the Chinese national policy tightened the restriction for young video gamers under the age of 18 and announced permission for young people above 18 as mature age to play esports (Ye, 2021). The Chinese government has recognized esports as an official profession and supports the industry, which has also influenced the esports culture among university students (Barattin, 2022).

Despite the massive growth of esports in China and government support at the collegiate level, research into esports in higher education settings is still in its preliminary stages. Most of the existing research has concentrated on the recreational and commercial aspects of esports (e.g., Szablewicz, 2016; Zhao et al., 2023), with a dearth of studies investigating esports from educational perspectives. Among the available studies, there is a strong focus on how the demographic factors, such as gender and genre preferences and psychological factors (e.g., motivation and addiction), are associated with participation of esports (e.g., Feng, 2024; Luo et al., 2022). For instance, Feng (2024) conducted semi-structured interviews with 23 Chinese undergraduate students spread across four grades participating in the study. The thematic analysis showed that university students engaged in a variety of esports, with female students favoring role-playing, fantasy, and simulation games, whereas male students tended to prefer games that involve tower-defense, shooting, sports, and tactical competitions. In Cheng et al.'s (2023) cross-sectional survey on 1441 collegiate e-sports players in China, the analysis revealed that there was a relationship between how students participate in esports and their lifestyle and psychological health, noting that the time spent and the extent of engagement in esports varied with different lifestyle behaviors and mental well-being.

Other investigations into collegiate esports cover topics including the drivers of student participation in esports, their possible positive impacts, and the barriers to

their incorporation into educational settings (Feng, 2024; Zhong et al., 2024). As indicated in Feng's (2024) study, Chinese college students involved in esports for several reasons, including 1) entertainment and relaxation, 2) identity recognition and group inclusion, 3) experiencing different life, and 4) escaping reality and seeking fulfilment in the virtual world. With respect to the potential benefits of esports, findings from Zhong et al.'s (2024) interviews with 8 teachers and 32 college students in China suggested that esports participation could promote the development of skills like collaboration, communication, creativity, and critical thinking, boost learners' motivation, and support an inclusive learning atmosphere. Similarly, Feng (2024) identified various benefits associated with esports engagement, including an enhancement of team spirit and cooperation, an opportunity for experiencing different life, cultivation of a holistic mindset and promotion of economic and technological development. In addition to advantages associated with esports, these studies recognized several potential constraints of introducing esports in educational settings. Challenges that may arise during the integration of esports into the Chinese educational settings include individual differences, parental and teachers' concerns on academic achievement and wellbeing, and inadequate support from universities (Zhong et al., 2024). Feng (2024) adds that there are risks involved, such as addiction to games, negative health consequences, and illegal or unethical behaviors including gambling and cheating.

The current literature provides a foundational understanding of esports being integrated into higher education and its potential affordances and constraints. However, there is a significant gap in directly linking esports with its affordances particularly for facilitating skills development. While many studies on esports have provided insights into its potential to promote the cultivation of various skills required by 21st century societies (e.g., Zhong et al., 2022, 2024), there is a need for empirical research that measures how participation in various types of esports influences the development of specific 21st-century skills among students. Accordingly, the present study aims to fill this research gap by conducting an empirical study to fully understand the impact and implications of integrating esports for skills development into the Chinese higher education context.

3.3 Participants

In this research, we employed a convenience sampling strategy (Sousa et al., 2004) to gather data from a population of university students. This non-probability sampling method provided a pragmatic approach for data collection in this study. We initially contacted the student association of 12 universities to assist in the recruitment of participants. Out of the 12 student associations contacted, eleven of them were willing to offer support for our research. Through distributing the questionnaires to their respective student communities. Informed consent was obtained before proceeding to the survey. Participation in the study was entirely voluntary. As a result, we successfully gathered a total of 628 questionnaires. Upon careful review of the submissions, a subset of the questionnaires (18 in total) was found to have inconsistencies within critical consistency check

questions. Ten questionnaires contained missing values for key items that were essential to the research questions. The absence of this information rendered these questionnaires incomplete, and as such, they could not be confidently used in the analysis. Ultimately, we determined that 600 of these questionnaires met our criteria for validity and completeness and were suitable for further analysis. The entire research adhered to the ethical guidelines set by the Human Research Ethics Committee of the affiliated university.

The profile of the sample included demographic information (i.e., age and gender), favorite game genre, and behavioral characteristics (i.e., game experience, game frequency, and duration of gameplay each time). We observed that age data were missing for 2 participants, which constitutes approximately 0.33% of the overall sample. The absence of age information for these participants is noted; however, as age was not a variable of interest in our analyses, its missingness does not affect the core outcomes of the study. With 598 out of 600 participants providing age information, their ages ranged from 18 to 35 years, with an average age of 21.63 years ($SD = 2.93$). Of these participants, 298 were male and 302 were female, comprising 52% and 48% respectively of the total sample.

Following the questionnaire survey, semi-structured interviews were conducted, which sought to understand students' opinions on the game elements that contribute to skill advancement in distinct genres. The individuals who took part in this study were those who had earlier participated in the questionnaire survey. A total number of 46 participants (21 males and 25 females) were involved in the interviews. The age ranged from 18 to 34, with an average age of 22.75 ($SD = 2.99$). Among those interviewed, 25 respondents (54% of the total) had been playing games for 5 years or more, followed by 11 respondents (24% of the total) who had been playing games for 2–3 years, and 10 respondents (22% of total) who had been playing games for 3–4 years. In terms of gaming frequency, 18 students (39%) engaged in gameplay more than five times per week. Ten students (22%) indicated that they play games two to three times per week, followed by 8 students (17%) who played three to five times per month. Six participants reported that they played games four to five times per week while only four students indicated they once to twice per month. Additionally, 25 participants (54%) played video games for 1–2 hours at a stretch, followed by 11 gamers (24%) who played for 3–4 hours at a time and 6 of those (13%) who played games for 1–2 hours each time. Fewer participants (8%) reported playing for 5–6 hours or longer than 6 hours. Their detailed information can be found in Appendix 1.

3.4 Data collection

In the quantitative phase, participants self-reported their perception of 21st century skills in nine esports types. The questionnaire consisted of two sections, with the first section collecting participants' information regarding age, gender, favorite esports type, gaming experience, frequency of gameplay, and time spent on each gameplay. The second section inquired about the participants' self-perceived acquisition of the 4Cs skills as they partake in their chosen esports type. This section was made up of 30 items,

categorized under four essential skills: creativity (five items), critical thinking (eleven items), communication (five items), and collaboration (nine items). These items were adopted from previously tested and valid measurements developed by Kelley et al. (2019) and were tailored to align with the cultural and contextual relevance in China. The participants rated their skill acquisition on a Likert scale from 1 (strongly disagree) to 5 (strongly agree).

We employed a confirmatory factor analysis (CFA) to validate the instrument, by which items factors loading (< .6) were removed. (Brown, 2015; Tabachnick et al., 2013). The finalized scale consisted of 23 items, distributed among Critical thinking (ten items), Collaboration (five items), Communication (three items), and Creativity (five items). We then evaluated the model fit based on several fit indices. The comparative Fit Index (CFI) was .92, and the Tucker-Lewis Index (TLI) was 0.91. Both values were above the threshold of .90, indicating a sufficient model fit (Marsh et al., 2005). The Root Mean Square Error of Approximation (RMSEA) was .06, 90% CI [.05, .07], suggesting a close fit (Browne & Cudeck, 1992). We further performed Cronbach's alpha statistic to test the reliability of revised items and obtained a coefficient of .93 for both the overall scale and its subscale items, which demonstrated that our revised items have high internal consistency and reliability (Creswell et al., 2003).

Following that, we formulated several principal questions for the semi-structured interviews (Aldemir et al., 2018) aimed at eliciting participants' insights into particular aspects of game features or elements within their chosen esports game type and their relationship with the 4Cs skills acquisition. As an illustration, when probing the relationship between gameplay features and critical thinking, participants were invited to answer with "What specific characteristics or game mechanics in the genre you enjoy most do you feel foster critical thinking skills, and could you provide some details? Would you be able to present a case to demonstrate this?" Before answering these inquiries, we introduced the concept of the 4Cs skills to the participants by giving them a brief with a descriptive overview of each skill. This can help participants to better familiarize the concepts so that they can provide more thoughtful responses that reflect the skills they are expected to develop. Each interview lasted for around 10 mins. The main questions regarding the 4Cs skills and esports are enclosed in Appendix 2.

3.5 Data analysis

The quantitative data were analyzed using descriptive analysis through Jamovi statistical software (Version 2.3.28.0). In addressing Research Question 1, the statistical values of responses to the 23 items on the perceived 4Cs skills development across various game genres were calculated. This included computing descriptive statistics, including mean, median, and standard deviation, to understand the general trend of participants regarding skills development in esports.

In response to Research Question 2, the researchers examined the differences in behavioral characteristics on students' perceptions. The differences in perception of skills development in various esports were analyzed by the comparison of means of Kruskal–Wallis H test according to the behavioural variables. This procedure allowed us to determine to the extent to which the variables might impact the perceived skills

development in various esports. After a significant Kruskal–Wallis test, the Dwass-Steel-Critchlow-Fligner (DSCF) method was applied to compare the medians of each possible pair of groups to find out which specific groups differ from each other.

To address Research Question 3, Partial Least Squares Structural Equation Modeling (PLS-SEM) was employed using the SmartPLS software (Version 2.3.28.0). The use of PLS-SEM was to identify the complex relationships of the 4Cs skills between four constructs (i.e., critical thinking, creativity, communication, and collaboration). This method was also utilized to validate the formative measurement model regarding the relationships of the 4Cs skills between four constructs. In this study, we conceptualized and operated the 4Cs skills as a latent construct where four skillsets are the observed variables that serve as indicators for the latent construct. The development of the 4Cs skills is attributed to the influence of four skillsets, not the other way around. Following the guidelines by Hair et al. (2023), we conducted the assessment through a sequential two-step process, affirming the reliability and validity measurement model in the first stage and then evaluating the formative measurement model. In the first stage, we examined the indicator loadings, indicator reliability, internal consistency, and both convergent and discriminant validity. In the second stage, we confirmed convergent validity, and multicollinearity with the Variance Inflation Factor (VIF) and examined the significance and weights of the outer model. Following that, conventional metrics including the coefficient of determination (r^2), effect size (f^2), the significance of path coefficient, as well as the practical predictive value of the model (Q^2) were reviewed for the interpretation of results (Hair et al., 2023).

To address Research Question 4, we used natural language processing (NLP) techniques combined with thematic coding analysis to identify game mechanisms and elements related to the development of skills in line with the 4Cs skillsets. NLP comprises various computational methods for the automated analysis and representation of human languages. Many new computational models are aiming to bridge the cognitive gap by emulating brain processes recognized as integral to human language processing (Chowdhary, 2020). This method has been adopted extensively across several domains, such as machine translation, information retrieval, information extraction, question answering, text summarization, topic modeling, and has recently expanded into opinion mining (e.g., Chowdhary, 2020; Khurana et al., 2023; Manke & Shivale, 2015). Considering that the qualitative study encompassed interview datasets from 46 respondents, NLP technologies proved effective when handling large volumes of data (Chowdhary, 2020). In line with that, we implemented inductive thematic coding to deepen the knowledge of situational meanings, particularly within the gaming environments (Gonzalez et al., 2022). The reliability and validity of the achieved results were enhanced by using a combination of two strategies (Clarke & Braun, 2017).

Among various NLP techniques, one of the most powerful data mining techniques that can be used to identify interrelations and patterns in information is the Latent Dirichlet allocation (LDA) (Blei et al., 2003; Jelodar et al., 2019). The LDA was employed to determine whether the respondents linked game mechanisms and features as per 4Cs skill development. The data analysis was performed in a spyder environment (Python 3.9.12). Several key procedures were involved in using LDA for extracting data, which included preprocessing

(i.e., tokenization, stopword removal, lemmatization, and vectorization), model configuration (i.e., defining the number of topics and distributing parameters), application of the pre-trained model to the data to generate topic distributions, and analysis of topic distributions to understand the themes (Blei et al., 2003). Specifically, data mining preparation began with the transformation of interviews into text format in English, eliminating punctuation signs and common stop words such as "the" at, "or," "and," and others. We then lemmatized the text, which involves converting words into their base also known as root form (Wang et al., 2017). After that, we progressed to the advanced stages of topic modeling which included data preparation in order to process them into unsupervised topics and assess their quality. For every topic, we pinpointed the top 10 words with the highest probability scores, recorded their corresponding probability distributions, and computed the ratio of the selected word's probability within a topic to its aggregate probability across all topics. Coherence and exclusivity were utilized to assess the quality of themes identified through the analysis. Coherence measures the semantical interconnectedness of top-scoring words in a topic while exclusivity represents the distinctiveness of the topic words within each topic (Bischof & Airoldi, 2012). These two metrics directed our interpretation and guided the generation of insights.

For the most informative representation, we considered topics that ideally exhibit high coherence and exclusivity. To achieve the most effective representation, we focused on topics with the highest possible coherence and exclusivity. Shown in Fig. 2, the top coherence and exclusivity scores for critical thinking were .46 and -5.72 respectively. For creativity, these scores were .49 and -4.22; for communication, .40 and -4.90; and for collaboration, .38 and -3.7. We used these scores to identify the number of topics for each skillset. After identifying distinct topics within the data, thematic analysis, which was both inductive and iterative (Fereday & Muir-Cochrane, 2006), was subsequently employed to discern overarching themes within the data. Topics were manually labeled by examining the words most closely associated with each one. After multiple reviews by two members of the research team, the data were categorized into distinct units or codes, each supported by relevant text excerpts. By integrating scores from coherence and exclusivity and thematic analyses, we concluded that the optimal number of topics included three topics for Critical thinking, four for Creativity, two for Communication, and three for Collaboration.

4 Results

4.1 Quantitative results

4.1.1 To what extent do players perceive they acquire the 4Cs skills through playing esports? (RQ1)

As shown in Table 2, the results suggested that there was a generally positive perception among participants that playing games could cultivate critical 4Cs skills. The mean scores for all four skills were above the midpoint of the scale, indicating a general agreement that

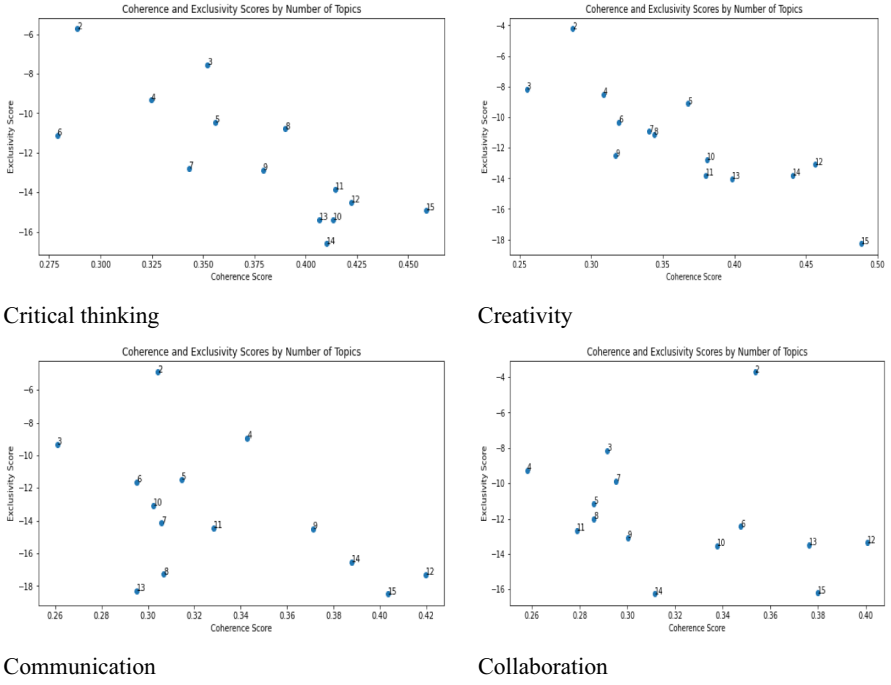

Fig. 2 Coherence and exclusivity scores by number of topics under the 4Cs skills

games could cultivate the 4Cs skills. All medians were at or above 3.70, which was higher than the midpoint. This suggested that more than half of the respondents believed games could contribute positively to these skills, particularly for collaboration and communication, where the median was 4.00. The relatively low standard deviation across all skills indicated a consensus among the participants. This could be indicative of an overall positive belief in social skills like collaboration (Mean = 3.96) and communication (Mean = 3.82).

Following this, the Shapiro–Wilk test was utilized to assess the distribution of self-reported 4Cs skills scores. Results indicated deviations from a normal distribution for all assessed skills ($p < .001$). A nonparametric method, the Kruskal–Wallis test, was conducted to determine the differences in participants' perceived 4Cs skills acquisition among the nine types of esports. The results showed that there no strong evidence to suggest differences between the groups in any of the four skill sets: critical thinking ($p = .29$), creativity ($p = .07$), collaboration ($p = .89$), and communication ($p = .51$).

4.1.2 In what ways do players' behavioral characteristics (i.e., gaming experience, gaming frequency, and duration of each gameplay) affect their perceptions of the 4Cs skills acquisition through esports? (RQ2)

The influence of players' behavioral variables on their perception of the impact of esports on 21st century skills acquisition was investigated. To determine if there

Table 2 Descriptive results on self-reported 4Cs skills in esports

4Cs skills	Mean	Median	SD	Min	Max
Critical thinking	3.67	3.70	.72	1	5
Creativity	3.77	3.80	.68	1	5
Communication	3.82	4.00	.81	1	5
Collaboration	3.96	4.00	.70	1	5

were statistically significant differences in perceived 4Cs skills among various groups with gaming experiences, a non-parametric Kruskal–Wallis H test was conducted. In terms of Critical thinking, the results revealed a significant difference among the groups ($\chi^2(3) = 29.49$, $p < .001$, with an effect size of $\varepsilon^2 = .05$). For Communication, the test statistic was $\chi^2(3) = 9.13$, with a p-value of .028, and an effect size $\varepsilon^2 = .02$. The results showed a significant difference in Collaboration among the groups, $\chi^2(3) = 10.47$, $p = .015$, and an effect size $\varepsilon^2 = .02$. In regard to Creativity, the results indicated significant group differences, $\chi^2(3) = 12.01$, $p = .007$, with an effect size $\varepsilon^2 = .02$. Following the significant Kruskal–Wallis test results, post hoc pairwise comparisons were conducted using the Dwass-Steel-Critchlow-Fligner (DSCF) test to identify specific group differences. Significant differences were found between groups 1 and 3, and groups 1 and 4. Significant differences were noted between groups 1 and 4 in Collaboration and between groups 1 and 4 in Creativity. These results are shown in Table 3. No significant differences were found in other groups and in the skill of Communication.

In respect to gaming frequency, the Kruskal–Wallis tests results showed statistically significant differences in critical thinking ($\chi^2 = 48.84$, df = 4, $p < .001$, $\varepsilon^2 = .08$), communication ($\chi^2 = 19.72$, df = 4, $p < .001$, $\varepsilon^2 = .03$), and creativity ($\chi^2 = 18.88$, df = 4, $p < .001$, $\varepsilon^2 = .03$) among the groups, with critical thinking showing the largest effect size. Collaboration ($\chi^2 = 9.86$, df = 4, $p = .043$, $\varepsilon^2 = .02$) also differed among groups but with a smaller effect size, indicating subtler differences. The DSCF test was used after a Kruskal–Wallis test when there were significant differences. These results suggested that there were statistically significant differences in the median scores of the 4Cs skills when comparing groups with different levels of gaming experience. Group 5 consistently had higher medians across the skills, suggesting that the gaming experience of this group might be associated with higher 4Cs skills (Table 4).

In terms of the duration of each gameplay, the Kruskal–Wallis test showed significant differences in players' perceptions of the 4Cs skills development in esports: critical thinking ($\chi^2 = 34.55$, df = 4, $p < .001$, $\varepsilon^2 = .06$), creativity ($\chi^2 = 16.92$, df = 4, $p = .002$, $\varepsilon^2 = .03$), communication ($\chi^2 = 13.73$, df = 4, $p = .008$, $\varepsilon^2 = .02$), and collaboration ($\chi^2 = 5.93$, df = 4, $p = .205$, $\varepsilon^2 = .01$) among the groups. The post hoc results are presented in Table 6. Based on the findings, it appeared that for critical thinking, as well as the assessed aspects of creativity and communication, Group 1 consistently scored lower in median values compared to other groups. This indicated that Group 1 who engaged less in the gaming assumed that the gaming does not foster the 4Cs skills effectively (Table 5).

Table 3 Significant results from post hoc pairwise comparisons by gaming experience

4Cs skills	Gaming experience	Median difference	W value	*P* value
Critical thinking	Group 1 vs. Group 3	3.40/3.70	4.71	.005
	Group 1 vs. Group 4	3.40/3.90	7.30	< .001
Creativity	Group 1 vs. Group 3	3.60/3.80	3.90	.030
	Group 1 vs. Group 4	3.60/3.80	3.64	.050
Collaboration	Group 1 vs. Group 4	3.80/4.00	4.75	.004

Group 1: less than 1 year; Group 2: 1–2 years; Group 3: 3–4 years; Group 4: 5 years and more

4.1.3 What are the relationships between different 21st century skillsets in players' skills acquisition through esports? (RQ3)

The results for the reflective measurement model assessment involved constructs critical thinking (ten items), Creativity (five items), Communication (three items), and Collaboration (five items). The indicator loadings within each construct surpassed the threshold value of .70. The internal consistency reliability was evidenced by examining Cronbach's alpha values which were above .80. The discriminant validity was also established with the scores of Average Variance Extracted above 0.5 and HTMT between the values of .57 and .80, which was below the threshold of .85, indicating that the model was distinctive. The first stage assessment demonstrated that the measurement model has achieved established reliability and validity (Table 6).

Based on the results of the first stage, the structural model was assessed in the second stage. Results for formative measurement models are presented in Table 7. The variance inflation factor (VIF) values for all items ranged from 1.53 to 2.12, which met the criteria that all variance inflation factor values for the constructs should be less than 3. Therefore, no collinearity issue was detected. All items in the

Table 4 Significant results from post hoc pairwise comparisons by gaming frequency

4Cs skills	Gaming experience	Median difference	W value	*P* value
Critical thinking	Group 2 vs. Group 5	3.75/4.00	5.42	.005
	Group 3 vs. Group 5	3.80/4.00	5.96	< .001
	Group 4 vs. Group 5	3.80/4.00	4.81	.006
	Group 1 vs. Group 5	3.40/4.00	9.39	< .001
Creativity	Group 1 vs. Group 2	3.60/3.90	4.27	.022
	Group 1 vs. Group 3	3.60/3.80	3.90	.046
	Group 1 vs. Group 5	3.60/4.00	5.38	.001
Communication	Group 1 vs. Group 2	3.67/4.00	4.66	.009
	Group 1 vs. Group 3	3.67/4.00	3.95	.042
	Group 1 vs. Group 5	3.67/4.00	5.27	.002
Collaboration	Group 1 vs. Group 5	3.80/4.00	3.94	.043

Group 1: 1–2 times monthly; Group 2: 3–5 times monthly; Group 3: 2–3 times weekly; Group 4: 4–5 times weekly; Group 5: More than 5 times weekly

Table 5 Significant results from post hoc pairwise comparisons

4Cs Skills	Gaming experience	Median difference	W value	*P* value
Critical thinking	Group 1 vs. Group 2	3.50/3.80	5.92	< .001
	Group 1 vs. Group 3	3.50/3.70	4.25	.022
	Group 1 vs. Group 4	3.50/4.10	5.17	.002
	Group 1 vs. Group 5	3.50/4.00	6.19	< .001
Creativity	Group 1 vs. Group 2	3.60/3.80	4.49	.013
	Group 1 vs. Group 3	3.60/3.80	3.99	.038
Communication	Group 1 vs. Group 5	3.67/4.00	4.50	.013

Group 1: less than 1 h; Group 2: 1–2 hours; Group 3: 3–4 hours; Group 4: 5–6 hours; Group 5: more than 6 hours

Table 6 Reflective measurement model results

Construct	Outer loadings (range)	Cronbach's Alpha	Composite Reliability	Average Variance Extracted (AVE)
Critical thinking	.70—.79	.83	.91	.60
Creativity	.76—.83	.80	.85	.71
Communication	.80—.87	.85	.80	.62
Collaboration	.76—.80	.90	.83	.54

formative measurement model were significant, with outer weights ranging from .13 to .41 and outer loadings above .50.

The bootstrapping was subsequently performed to assess the relative contribution of the formative items. The Coefficient of Determination (r^2) was 0.702, which indicated that 70.2 percent of the variance in the latent variable was explained by the four skill sets (Fig. 3). Cohen's f^2 effect size for each skill was calculated to understand their relative contribution to the explained variance in the 4Cs skills. The f^2 value of 0.165 for Collaboration suggests a medium effect on the 4Cs skills. This indicated that Collaboration contributes significantly to the variance explained in the model, implying that changes in collaborative practices are likely to produce noticeable changes in the 4Cs skills. The f^2 value for Communication was found to be .075, indicating a small to moderate effect. Similarly, Creativity yielded a f^2 value of .092, which is indicative of a small but meaningful impact on the 4Cs skills. It suggests that creative skills have a tangible, although not dominant, influence on the variance in the outcome. Critical thinking yielded an f^2 value of .114, implying a small to medium effect on the 4Cs skills. Additionally, the out-of-sample predictive relevance was assessed using a blindfolding procedure. Results showed that Q^2 values were .680, indicating good predictive relevance of the model.

Table 7 Formative measurement model results

Construct	Outer weight (range in items)	Sig	Outer loadings (range in items)	Sig
Critical thinking	.13—.15	.000	.70—.79	.000
Creativity	.25—.26	.000	.76—.83	.000
Communication	.36—.41	.000	.80—.87	.000
Collaboration	.25—.29	.000	.76—.80	.000

4.2 Qualitative results

The evaluation focused on four sets of interview questions regarding mechanisms and game elements in the esports genre that are related to the 4Cs skills. Data derived from each set of questions were examined through the lens of topic coherence, exclusivity, and topic dominance. The analysis was performed across a range of topics, considering models with 2 to 15 topics to identify the optimal number of topics for our corpus (see Fig. 2). The optimal number of topics was chosen based on where these metrics show the most appropriate balance, indicating meaningful and distinct topics. Combined with qualitative analysis, we obtained a rich breadth of themes regarding game mechanisms and elements, which were sorted based on 4Cs skills: Critical thinking ($N=3$), Creativity ($N=4$), Communication ($N=2$), and Collaboration ($N=3$).

Three major themes were identified to illustrate how game mechanics can influence the development of critical thinking, as included in Appendix 3. One significant theme was the necessity of strategic and tactical planning within games. Players reported the need to constantly analyze the game environment. The complexity and dynamic nature of games requires players to manage resources and the economy effectively and

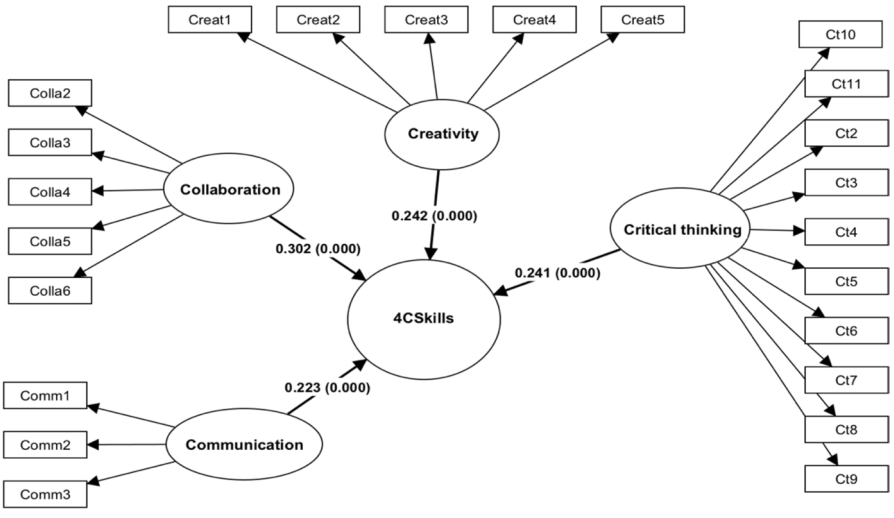

Fig. 3 The 4Cs reflective-formative measurement model

optimize their routes, locations, and benefits. Another theme that emerged was adaptability. Players discussed how games often present changing scenarios and rules that require them to adjust strategies in real-time in response to new challenges. Furthermore, the analysis revealed that the elements within games, such as puzzles, competitions, and risks which adjust based on player strategies, added a layer of complexity that required players to engage in analytical thinking continuously.

The analysis revealed four central themes that shed light on the relationships between video game mechanics and the cultivation of creativity. A prominent topic was dynamic systems within games. This idea reflects the players' experiences with evolving game strategies, storylines, characters, and competitive environments, which necessitate the continual formulation of innovative tactics. The constant evolution in gameplay stimulates players to think creatively. Additionally, the architectural design of the games themselves was found to be influential. The players noted that the way a game is structured—its rules, storyline, and challenges—encourages them to engage in creative thinking to navigate through the games successfully. Another key theme was personalization and customization options available in games. Players particularly appreciated the ability to tailor their gaming experience through these features, which in turn motivated them to harness their creativity to invent and design unique elements within the game world. This freedom to modify and personalize their gameplay leads to a deeper level of engagement and a sense of ownership (Kim et al., 2015). Lastly, the study highlighted that games infused with elements of discovery and simulation were particularly effective in promoting creative thinking. These elements encouraged players to explore and experiment within virtual environments, which resembled the trial-and-error process often seen in creative endeavors.

Regarding collaboration, two themes were extracted from the participants' responses (Appendix 4). Firstly, the participants emphasized the value of collaboration in gameplay, which is often necessitated by the variety of roles and character specializations available. Different characters possess unique abilities and functions, which can lead to a natural division of labor and a need for cooperative strategies among players. Secondly, the study uncovered a spectrum of gaming mechanics and features that serve as catalysts for cultivating teamwork abilities among players. The fabrics of game design include: 1) Games often set goals that cannot be achieved by a single player alone, requiring collective effort and strategic planning, thus promoting a sense of unity and shared purpose among participants; 2) Games often incorporate systems that necessitate or enhance player communication, such as chat functions, emotes, or even in-game gestures and signals, emphasizing the importance of clear and concise interaction; 3) Games constantly requests players to support each other in critical moments—whether in combat, puzzle-solving, or navigating challenges—in achieving success; and 4) games frequently strive for a balance that ensures no single player can dominate the play space, compelling participants to rely on each other's strengths to overcome obstacles and progress (Appendix 5).

There were three distinct themes regarding how game mechanisms and elements foster communication skills (Appendix 6). Firstly, participants pointed out an array of in-game tools and systems specifically designed to enable and streamline player-to-player interaction. These included integrated voice chats, text messaging systems, and other in-game communication that allow players to connect and strategize in

real-time. Beyond direct player interaction, the second theme emerged around the concepts of information exchange and rules and guidelines that govern polite and effective communication within gaming communities. Participants recognized the critical importance of sharing knowledge and insights effectively, which is often key to advancing in a game. They also touched upon the necessity of adhering to certain standards of behavior and communication, which can include respecting turn-taking, using appropriate language, understanding the context of group dynamics, and practicing active listening. These norms and practices within games parallel real-life communication etiquette and underscore the social aspects of gaming, where being able to convey messages politely and effectively is as important as the strategic content of the communication itself. The third theme highlighted the role of the game's interface and architecture in enhancing communication abilities. The way players engage with the game's structural components, such as feedback, community platform, or voting system, can contribute to the development of communication skills. These themes pointed to the multifaceted ways in which gaming can serve as a medium for practicing and refining communication skills.

5 Discussion

Conducted in the Chinese higher education context, this study investigated students' perceptions of how esports can enhance the 4Cs skills and identified the specific game mechanisms and elements that facilitated this development.

The agreement among students on esports' role in enhancing the 4Cs skills forms an essential basis for educators interested in embedding esports into the higher education in China. The Chinese educational system has placed an excessive emphasis on academic excellence (Mangue, & Gonondo, 2021). Traditional learning methods have been predominantly lecture-centric, focused on rote memorization, mechanical training, and high-stakes testing (Tan, 2017). The traditional exam-centric education system has been subjected to criticism for its inadequate focus on essential skills, including creativity, critical thinking, communication, and collaboration (e.g., Grey & Morris, 2024; Jiang, 2013; Tian & Low, 2011). These skills are increasingly sought after by employer and graduates lacking them are finding themselves less competitive in a job market that values soft skills as key differentiators between top and average candidates (Yan & Kongjit, 2020). In response to the critique, the government has launched a series of initiatives on curriculum and pedagogical innovation to facilitate the development of various skills required for the 21st century societies (Chu et al., 2017; Newton & Newton, 2014). Added to that, the Chinese government has offered a range of support for esports industry and encouraging the establishment of esports majors in higher education over the years (Zhao & Lin, 2021; Zhao et al., 2022). The support from the government, combined with student consensus on the effectiveness of esports in enhancing the 4Cs skills as identified in this study, lays a promising educational groundwork for incorporating esports into the curricula of higher education institutions in China.

While the quantitative findings revealed that participants generally agree on the beneficial impact of gaming on developing the 4Cs skills, the impact of esports in

cultivating skills was significantly correlated with gaming experience, gaming frequency, and duration of each gameplay. The results indicated that greater levels of engagement in gameplay (i.e., gaming frequency and the duration of each game play) were typically associated with higher scores in the 4Cs skills. This aligns with previous findings suggesting that gaming experience and presence contribute to gaming performance (Lachlan & Krcmar, 2011).

There are unexpected findings regarding the non-significant variance in the acquisition of the 4Cs skills among the nine esports genres. Earlier research have often focused on specific types of esports to develop skills. For instance, sandbox games such as Minecraft have been used for developing creativity and innovation (e.g., Checa-Romero & Pascual Gómez, 2018; Fan et al., 2022), board games for critical thinking (Barnabè et al., 2023) and Multiplayer Online Battle Arena (MOBA) for teamwork (Thavamuni et al., 2023). While the research has pointed to genre-specific skill developments, the unexpected findings in the study suggest that the relationship between game genre and skill acquisition might be more complex than previously understood. This complexity could arise from the multifaceted nature of games where multiple skills are often developed simultaneously, or from the possibility that certain foundational skills are central to all esports genres. The choices for specific games in previous research may suggest that the inherent design and gameplay mechanics of these genres are thought to foster specific skills. Another explanation for this might be that esports inherently require a baseline level of the 4Cs skills. In other words, although the specific context in which these skills are applied may vary among various games, the fundamental skills developed may remain consistent across genres.

Our analysis of the qualitative data provides additional insights into skills development in esports. Our findings showed that a wide array of game mechanics and elements across various genres are thought to foster the 4Cs skills. While a wealth of research has been conducted on the mechanisms and elements of games (Aldemir et al., 2018; Amory et al., 1999), the concept of gamification was often discussed in terms of its potential to motivate and engage (Huber et al., 2023; Leitão et al., 2022). Rarely have studies touched upon the linkages of mechanisms or game elements to concrete skills development, particularly in the context of esports. The identification of game mechanisms and elements in esports not only enriches the existing gamification research but also increases insights into the use of game-design elements in fostering skills development.

6 Implications

The findings of this study shed light on crucial design and mechanics that could enhance the effectiveness of gamified educational technologies and their strategic implementation. The quantitative findings indicate that the effectiveness of esports in skill development is related to behavioral characteristics, with more frequent and longer gaming sessions resulting in higher scores in the 4Cs skills. The findings suggest that educators adjust difficulty levels dynamically in esports-based learning, aligning them with the individual's gaming experience and frequency to maintain an optimal challenge without causing excessive stress. The findings also suggest that instructors should strategically

determine the duration of gameplay sessions to maximize both engagement and educational outcomes, while ensuring it does not lead to student fatigue. In observing the connections between the frequency and length of gaming sessions and the enhancement of the 4Cs skills, instructors can employ learning analytics tools, utilizing (both behavioral and perceptual) log data to customize the educational process.

The thematic analysis of interview data generated insights into the mechanisms of esports in facilitating the cultivation of each of the 4Cs skillsets. These findings inform educational approaches and support the integration of game elements and gameplay to promote learning. Instructors are encouraged to formulate learning objectives that merge gamified components with targeted curriculum outcomes, especially focusing on distinct skill sets. Students reported that various aspects of gaming, including strategies, narrative structures, character development, competitive settings, and customization features, are instrumental in their ongoing development of creative solutions. These observations suggest that educators incorporate these elements strategically into gamified learning settings to enhance creativity. Different from gamification that uses game features to stimulate learning in non-game contexts (Dahalan et al., 2024), educators can use esports to establish immersive game-based learning environments that facilitate holistic skills enhancement among learners. Moreover, given that gamification and game-based learning are underpinned by the psychological theoretical frameworks such as self-determination theory and flow theory and learning theories, such as experiential learning and constructivist learning (Krath et al., 2021), educators are encouraged to incorporate these theories into the formulation of learning strategies, contributing to enhancing the efficacy of using esports in instructional practices.

7 Limitations and future research directions

While this study significantly contributed to the understanding of the development of the 4Cs skills within various esports genres, the findings should be interpreted in light of several limitations. One of the limitations of this study was the primary reliance on self-reported data to interpret how participants perceived the impact of esports on skills development. Due to the subjective data, we were not able to make causal inferences about the impact of esports on skills development, which might have certain bias. In light of this, future studies are advisable to utilize Stealth assessment, an approach that is both formative and grounded in evidence, to measure the outcomes of skill development within the game environment (Shute, 2008, 2011; Shute et al., 2009). Objective data sources, including system logs and in-game analytics, are highly endorsed to capture behavioral data that can provide insights into the cognitive processes and decision-making skills employed during gameplay (Almond et al., 2020; Shute et al., 2019). Added to that, longitudinal research designs are recommended for future studies to explore the causality and long-term effects of esports participation on the 4Cs skills.

Another limitation relates to the generalizability of findings to populations in other cultures. Previous studies have indicated that skills development through video gaming should consider cultural differences (Irava et al., 2019; Yılmaz et al.,

2022). Since this study was set in Asian context, cross-cultural studies on esports are needed to provide a more in-depth understanding of factors associated with students' skills acquisition in esports and detect important associations and trends that would otherwise be neglected in a single context. Future research could benefit from a larger and more diverse sample that encompasses different age groups, cultural backgrounds, and educational settings. Additionally, most investigations into esports in the context of Chinese higher education, such as preliminary studies conducted by Cheng et al. (2023) and Zhong et al. (2024), have primarily focused on gathering perceptions and attitudes from educational stakeholders regarding esports. While these studies offer insights into the educational potential of esports and support its practical integration, there is a need for more rigorous research methods. Future studies could use experimental designs to test whether instruction that integrates esports is more effective than traditional teaching methods for skills development.

Despite these, the findings of this study illuminate several research directions for scholars. First, while students broadly showed positive attitudes towards esports, much remains to be done to convert motivational involvement for entertainment to educational environments. A longitudinal study may be required to track students' learning attitudes in esports and changes in motivation with the intervention of an esports academic program. Second, as the education systems in many countries remain high-stakes exam-based, the obstacles to integrating esports into the deeply ingrained education stigmas as well as the level of parental and school support for integrating esports into current education need to be thoroughly investigated. Finally, the study identified a rich array of mechanisms and elements associated with the 4Cs skills development. However, the effectiveness of gamification in developing concrete skills needs further investigation. This includes questions about which specific game elements are most effective for promoting certain skills, how these elements can be adapted to different learning styles and environments, and what the long-term impacts of gamified learning experiences might be on an individual's skills.

8 Conclusion

The present study significantly contributes to esports research by investigating the students' perceptions on the impact of various esports on the 4Cs skills. While the 4Cs skills were not found to be statistically different among various esports genres, there was a consensus that esports can contribute to skills development. The findings found that students' perceptions of skills development were significantly related to their behavorial charactersitics (i.e., gaming experience, gaming frequency, and duration of each gameplay). The study further identified a wide array of game mechanisms and elements associated with the 4Cs skills development, which provided comprehensive insights into the underlying reasons for the acquisition of the 4Cs skills within the context of esports. These findings suggest that esports are more than just a prevalent form of digital entertainment; they can be leveraged for various skills development in both educational and professional settings.

Appendix 1

"Table 8" Profile of participants in qualitative survey

Participant	Age	Gender	Education level	Favorite esports
Student 1	21	Female	Undergraduate	Card & board games
Student 2	22	Male	Postgraduate master level	FPS
Student 3	19	Male	Undergraduate	RTS
Student 4	25	Female	Postgraduate master level	MOBA
Student 5	18	Female	Post-secondary	FPS
Student 6	20	Male	Undergraduate	Card & board games
Student 7	22	Female	Postgraduate master level	MOBA
Student 8	22	Female	Postgraduate master level	FPS
Student 9	22	Female	Postgraduate master level	FPS
Student 10	22	Male	Postgraduate master level	FPS
Student 11	27	Male	Postgraduate master level	Card & board games
Student 12	18	Male	Undergraduate	FPS
Student 13	23	Female	Postgraduate master level	MMORPG
Student 14	21	Male	Undergraduate	MOBA
Student 15	23	Male	Postgraduate master level	Sandbox games
Student 16	26	Male	Postgraduate master level	MOBA
Student 17	23	Male	Postgraduate master level	MOBA
Student 18	19	Male	Undergraduate	MOBA
Student 19	26	Female	Postgraduate doctoral level	FPS
Student 20	24	Female	Postgraduate master level	FPS
Student 21	23	Female	Postgraduate master level	RTS
Student 22	22	Female	Postgraduate master level	MOBA
Student 23	34	Female	Postgraduate master level	MOBA
Student 24	26	Male	Postgraduate master level	MMORPG
Student 25	23	Female	Postgraduate master level	MOBA
Student 26	22	Male	Postgraduate master level	MOBA
Student 27	30	Female	Postgraduate doctoral level	MOBA
Student 28	27	Male	Postgraduate master level	MOBA
Student 29	23	Male	Postgraduate master level	Sandbox games
Student 30	22	Male	Postgraduate master level	Sports simulation games
Student 31	22	Male	Postgraduate master level	MOBA
Student 32	23	Female	Postgraduate master level	MOBA
Student 33	25	Female	Postgraduate master level	RTS
Student 34	21	Female	Undergraduate	MOBA
Student 35	19	Male	Undergraduate	MOBA
Student 36	24	Female	Postgraduate master level	MOBA
Student 37	23	Male	Postgraduate master level	MOBA
Student 38	19	Male	Undergraduate	FPS

"Table 8" (continued)

Participant	Age	Gender	Education level	Favorite esports
Student 39	19	Female	Undergraduate	Sandbox games
Student 40	21	Female	Undergraduate	FPS
Student 41	20	Male	Undergraduate	FPS
Student 42	22	Female	Postgraduate master level	Card and board games
Student 43	24	Female	Postgraduate master level	FPS
Student 44	25	Female	Postgraduate master level	MMORPG
Student 45	24	Female	Postgraduate master level	Racing games
Student 46	23	Female	Postgraduate master level	MMORPG

Appendix 2

Table 9 Semi-structured interview questions

Aims of inquiry	Questions
Basic information	What is your age/ game experience/gaming frequency/duration of gameplay? What are reasons for playing the chosen game type?
Chosen esport and critical thinking	What specific characteristics or game mechanics in the genre you enjoy most do you feel foster critical thinking skills, and could you provide some details? Would you be able to present a case to demonstrate this?
Chosen esport and creativity	Based on your chosen type of games, how do you think the design or gameplay of these games stimulates creativity? Are there specific aspects within the game that allow for creativity? Are there particular moments during gameplay that encourage you to come up with innovative methods or solutions? Can you provide an example to illustrate this?
Chosen esport and collaboration	Based on your chosen type of games, are there gaming experiences within this genre that support or enhance communication? What mechanisms or elements within the game do you think effectively help players improve their communication skills? Can you provide an example to illustrate this?
Chosen esport and communication	How do the types of game promote or encourage collaboration? Can you share a moment when you collaborate with other players? Can you explain which mechanisms or elements in the game require you to collaborate with other players and how this has helped you develop your collaborative skills?

Appendix 3

Table 10 Themes of games mechanisms and elements associated with critical thinking

Themes ($N=3$)	Subthemes	Example quotes/responses
Strategic and tactical decision-making	• Resource management • Economy management • Optimization (e.g., routes, locations & benefits)	"Players need to customize and optimize their routes and locations according to the map scenario and the distribution of the enemies, as well as their own weapons and other circumstances, which makes a lot of use of critical thinking." (Student 10, Personal communication, Jan 10, 2024)
Adaptability	• Dynamic systems • Game balance	"The dynamic system, which makes the game extremely rich and not static… and I need to adjust my strategy and develop new strategy development." (Student 3, Personal communication, Jan 10, 2024)
Analytical and problem-solving	• Puzzles • Competitions • Maps • Attack & defence • Risks	"Firstly, players need to analyze the map structure, formulate strategies to fight against the enemy, and familiarise themselves with the layout of the map to make critical judgments on the enemy's position. Secondly, players need to evaluate which tactic is the most suitable according to the current situation, which can also exercise critical thinking. Finally, in this game, players often have to make decisions about whether to take risks, such as whether to defuse bombs, whether to save equipment, etc." (Student 43, Personal communication, Jan 10, 2024)

Appendix 4

Table 11 Thematic analysis of games mechanisms associated with creativity ($N=4$)

Themes ($N=4$)	Subthemes	Example quotes/responses
Dynamic systems	• Storylines • Characters • Competition modes • Strategies	After each version update, players need to find strong heroes or equipment that game designers and planners have overlooked in their updates and develop supermodels or interesting routines. (Student 1, Personal communication, Jan 10, 2024) "Dynamic systems make it so that you can't respond to changes in the enemy in one way, but rather make new strategies based on the status quo… such a dynamic system can be more stimulating to the creativity of the player, reflecting a personalized different analysis and understanding of the situation." (Student 1, Personal communication, Jan 10, 2024)
Artistic game design (Visual elements)	• Colour scheme • Terrain of maps • Drawing cards • Outfits and accessories	"The art and visual elements of this game, Lost Ark, are well done! The costumes and accessories of the characters are beautifully done, and the overall colors fit the worldview and current scenario of the game, such as the image of the mage when he puts his skills into play. When I create PPTs for presentations or look for posters or PPT templates, I always subconsciously look for posters or PPT templates with a similar style of painting, and then adjust them to fit my presentation needs and content." (Student 26, Personal communication, Jan 10, 2024)
Customization and personalization	• Maps (hidden paths) • Resources management • Economy management • Flexible use/match of skills, weapons & teams • Customize characters	"Players can form a team of different characters and can also be free to adjust the order of the use of different skills." (Student 44, Personal communication, Jan 10, 2024) "Developing new hero combinations or tactics to deal with specific opponents or game situations requires players to be creative." (Student 14, Personal communication, Jan 10, 2024)
Open-world exploration and environmental interaction	• Discovery (e.g. loopholes) • Simulation • Survival challenges • Community & Sharing	"Sandbox games develop players' creativity. For example, in Minecraft, building your own structures develops the player's imagination and brings your blueprints to life. In addition to basic buildings, the Redstone system allows players to design their own mechanisms or machines to enhance the gameplay." (Student 15, Personal communication, Jan 10, 2024) "I think simulation games can inspire the most creativity. For example, the main simulation games I have played are. Simulated life, simulated city. There are also games like My World. Creativity-rich games have such a characteristic, that is to give the player the full freedom, the player is free to explore in this virtual world."(Student 24, Personal communication, Jan 10, 2024)

Appendix 5

Table 12 Thematic analysis results of game mechanisms associated with collaboration

Themes ($N=2$)	Subthemes	Example quotes/responses
Role designation	• Roles (e.g., healers, tanks & dealers) • Character classes • Matchmaking	"Characters in a game may have different skills and responsibilities, requiring players to collaborate based on their respective character traits." (Student 41, Personal communication, Jan 10, 2024)
Collaboration strategies	• Shared goals (awards, resources, golds) • Effective communication • Timely support • Balanced gameplay	"Give warnings to your teammates when you find enemy actions and movements. This allows us to react in time or adjust our strategy quickly. " (Student 18, Personal communication, Jan 10, 2024) "When you see your teammates need help, support them in time." (Student 18, Personal communication, Jan 10, 2024)

Appendix 6

Table 13 Thematic analysis results of game mechanisms associated with communication

Themes ($N=3$)	Subthemes	Example quotes/responses
Direct player Interaction	• Chat systems (e.g., text, voice & emotes) • Non-verbal cues (e.g., gestures)	"Through voice communication, teammates can more directly express their intentions, share information, and formulate tactics." (Student 2, Personal communication, Jan 10, 2024)
Communication strategies	• Information Sharing • Communication etiquette	"For those players who are unwilling or unable to use voice chat, text chat offers another way to communicate." (Student 43, Personal communication, Jan 10, 2024)
Game interaction	• Environmental signals • Feedback • Dialogues with NPCs • In-game gifting • Voting system • Strategy board • Social features (e.g., guilds and community platforms)	"For example, the Overwatch and Call of Duty series allow players to exchange strategies and feedback with teammates via voice and text chat before, during and after matches." (Student 41, Personal communication, Jan 10, 2024) "Some games, such as the Battlefield series and Apex Legends, offer strategy boards and voting systems that allow players to vote and discuss important decisions during a match, which can help improve teamwork and communication." (Student 41, Personal communication, Jan 10, 2024)

Authors Contribution Yuchun Zhong: conceptualization, project management, data collection, data analysis, and initial draft completion.
Kai Guo: editing, reviewing and revising the manuscript, providing feedback, and data validation.
Luke Kutszik Fryer*:* supervision, reviewing the manuscript, methodology, and providing feedback.
Samuel Kai Wah Chu: conceptualization and reviewing the manuscript.
Hao Deng: data validation and visualization.

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