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Gamifying science education: How board games enhances engagement, motivate and develop social interaction, and learning

Mohd Kamal Othman[1] · **Sim Kah Ching**[1]

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Abstract

This study investigates the impact of gamified learning, specifically through computerised and paper-based board games, compared to conventional teaching methods on science education for 10-year-old students. We conducted an experimental design with 574 Malaysian Type Chinese Primary School participants, using pre- and post-tests, questionnaires, classroom observations, and interviews over three weeks. Students who engaged in gamified learning with computerised board games saw a significant improvement in academic performance (mean increase of 55.41%) and learning motivation compared to the conventional teaching group. Notably, the computerised board game group displayed the highest academic performance gains. Social interaction improved in all groups, with the mean score ranks (conventional teaching: 83.50, paper-based board games: 400.71, computerised board games: 340.29), suggesting gamification's potential to foster collaborative learning environments. Learning motivation also improved, with the mean score ranks (conventional teaching: 83.50, paper-based board games: 409.82, computerised board games: 331.18). The theoretical framework integrates Activity Theory and Social Constructivism, providing a robust foundation for analysing behavioural, cognitive, and motivational aspects. This study extends beyond current research by offering empirical evidence of the pedagogical impact of computerised and paper-based board games on science education for 10-year-olds, highlighting the positive influence of innovative teaching methods. The findings suggest a potential transformation in traditional pedagogical approaches, aligning with the global pursuit of high-quality learning experiences.

Keywords Collaborative learning · Teaching/learning strategies · Pedagogical, Elementary education

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✉ Mohd Kamal Othman
omkamal@unimas.my

[1] Universiti Malaysia Sarawak, Fakulti Sains Kognitif dan Pembangunan Manusia, Kota Samarahan, Malaysia, Sarawak

1 Introduction

1.1 Enhancing science education through gamified learning: national context and challenges

Declining student engagement and motivation pose significant challenges to contemporary education systems. This is reflected in Malaysia, where national policies like the National Education Policy and the Malaysia Education Blueprint 2013–2025 demonstrate a strong commitment to improving science and technology education (Rashid et al., 2021). Despite these efforts, challenges persist, as evidenced by declining international rankings in science subjects (Aliyu, 2020; Suhaili et al., 2020). One key concern is the emphasis on test scores over a deeper understanding of science (Phang et al., 2020; Mat & Yusoff, 2019), coupled with traditional approaches that often fail to engage and motivate students, particularly at the primary level (Ateş, 2024; Melo et al., 2020). This lack of engagement can hinder the development of critical skills like collaborative learning and social interaction, negatively impacting student well-being and learning outcomes (Melo et al., 2020). Furthermore, the teachers' inability to use digital content effectively from the pedagogical aspect can negatively impact the students' learning and motivation (Bozkurt & Sharma, 2020; Ferdig et al., 2020).

To address these challenges and enhance student learning experiences, educators are increasingly exploring innovative approaches like gamification and integrating game elements into non-game contexts (Christopoulos & Mystakidis, 2023; Kalogiannakis et al., 2021). While research suggests positive impacts on academic performance (Candan & Başaran, 2023), a comprehensive understanding of its effects on students' holistic well-being, including social interaction, remains an ongoing area of inquiry (Aura et al., 2023).

1.2 Gamification

Gamification, the integration of game elements into non-game contexts, is gaining momentum as a potential solution to these challenges. From the learner's perspective, gamification offers a more immersive and interactive learning experience, fostering a sense of playfulness, healthy competition, and achievement. This translates to increased knowledge acquisition, positive attitudes towards learning, and improved learning behaviours (Chiang et al., 2022). Research suggests that gamification can promote active learning, enhance student engagement, and foster intrinsic motivation (Lin & Cheng, 2022; Díaz et al., 2024), lead to improved knowledge retention, deeper understanding of concepts, and better academic performance (Tsai & Tsai, 2020; Chen et al., 2023a, b; Sun et al., 2023; Alfaro-Ponce et al., 2023). However, for effective implementation, gamification must be grounded in sound pedagogical principles (Alt, 2023).

Tsai and Tsai (2020) suggest that research on game-based science learning should focus on cognitive skills, instructional design, and affective (emotional) influences rather than solely on scientific knowledge achievement. However, Komalawardhana and Panjaburee (2023) highlight that many previous studies focused on cognitive aspects, with limited exploration of learning behaviour in technology-enhanced personalised learning experiences.

From the learner's perspective, gamification offers a more engaging and interactive learning experience, particularly reaching those disengaged in traditional classrooms (Arztmann, 2023). By incorporating game elements and mechanics, gamified learning fosters a sense of playfulness, competition, and achievement, increasing knowledge, attitudes, and behaviours (Chiang et al., 2022). Research suggests gamification can promote active learning, engagement, and motivation (Lin & Cheng, 2022; Díaz et al., 2024), improved knowledge retention, deeper understanding of concepts, and better academic performance (Tsai & Tsai, 2020; Chen et al., 2023a, b; Sun et al., 2023; Alfaro-Ponce et al., 2023) and impacting learner motivation, engagement, and academic achievement (Zeybek & Saygı, 2024). However, effective gamification requires a sound pedagogical rationale rather than mere adoption (Alt, 2023). Fernando and Premadasa (2024) further emphasise that aligning gamification aids with students' characteristics (generational traits).

School environments should be organised to support instruction, fostering social, emotional, academic, and other traits for a child's development (Darling-Hammond et al., 2020). As educational paradigms evolve, technology integration with gamification elements emerges, raising concerns about the potential effects on students' holistic well-being (Melo et al., 2020; Díaz et al., 2024). Understanding this complex relationship between gamification in learning environments and students' physical, cognitive, emotional, and social well-being is crucial, aligning with recent calls for comprehensive studies beyond academic outcomes (Díaz et al., 2024).

While research suggests positive impacts on academic performance and motivation (Dehghanzadeh et al., 2023; Lin & Cheng, 2022; Lin et al., 2021; Hayati et al., 2022; Janakiraman et al., 2021), many studies have not comprehensively assessed social interactions. Our research aims to address this gap, providing evidence beyond current research and aligning with insights from Melo et al. (2020), Tsai and Tsai (2020), and Komalawardhana and Panjaburee (2023).

Gamification has become increasingly popular for enhancing the learning experience, particularly in the science curriculum. Several aspects make it an effective tool, (1) Deeper engagement: Gamification makes learning more interactive and fun, leading to increased understanding and retention (Wang & Zheng, 2021); (2) Safe environment for problem-solving: Students encounter challenging scenarios and receive immediate feedback, allowing them to learn from mistakes and develop a deeper understanding (Wang & Zheng, 2021) and (3) Motivation through competition: Gamification fosters a sense of competition, motivating students to learn and engage more (Fonseca et al., 2023).

1.3 Board games

Paper-based board games (PBBGs) and computerised board games (CBGs) can complement conventional teaching (CT) methods and address the prevalent issue of motivation in science learning. Studies show that gamified learning, regardless of format (plugged-in or unplugged), outperforms traditional methods in terms of student performance (Wang & Zheng, 2021). Furthermore, gamification fosters intrinsic motivation by fulfilling the three fundamental psychological needs: autonomy, relatedness, and competence (Qiao et al., 2023), and enhances student achievement through content interaction in online learning environments (Taşkın & Kılıç Çakmak, 2023).

While using digital board games as educational tools represents an innovative approach, its potential remains underutilised within the educational landscape (Khoushaini et al., 2022). Existing research on board games primarily focuses on their practical implications and learning outcomes (Sousa et al., 2023).

This study investigates the pedagogical impact of gamified learning, specifically through Computerised Board Games (CBGs) and Paper-Based Board Games (PBBGs), on the academic performance, learning motivation, and social interaction of 10-year-old students in science education. By examining these factors, we aim to contribute to the ongoing discussion on gamification in educational settings whilst exploring its nuanced effects on student well-being. This research positions itself at the forefront of understanding how gamified approaches contribute to cognitive development and student well-being beyond solely academic performance.

The rationale behind introducing PBBGs and CBGs lies in examining the multifaceted aspects of pedagogy and the diverse pedagogical approaches in science education. This study seeks to contribute to pedagogical innovation by evaluating the potential benefits of both plugged-in (CBGs) and unplugged (PBBGs) board games in enhancing academic performance, motivation, and social interaction. This aligns with the ongoing discussion on transforming educational practices for improved learning outcomes.

The following research questions drive our inquiry:

1. Is there a statistically significant difference in academic performance among 10-year-old students learning science using CBG, PBBG and CT (with multimedia aids such as PowerPoint)?
2. How do CBG and PBBG influence social interaction among 10-year-old students in science education?
3. How does the learning motivation among 10-year-old students differ when exposed to CBG, PBBG, and CT (with multimedia aids such as PowerPoint)?

The remainder of this paper will thoroughly explore our research findings and their implications. The literature review in the next section synthesises existing knowledge on collaborative learning, board games, social interaction, and learning motivation in education (Sect. 2.0). The theoretical framework establishes the theoretical underpinnings of our research (Sect. 2.6). The methodology section outlines our research design, participants, data collection procedures, and instruments (Sect. 3.0). We present our results and findings on academic performance, learning motivation, and social interaction (Sect. 4.0), followed by a detailed discussion of these findings' implications (Sect. 5.0, 6.0 and 7.0). The paper concludes with recommendations for future research and practical implementations and a reflection on the study's limitations (Sect. 8.0).

2 Literature review and theoretical framework

This section explores the theoretical and empirical landscape of gamified learning, focusing on its potential impact on science education for 10-year-old students. The review is structured around key themes that contribute to understanding the effectiveness of gamified learning: collaborative learning, social interaction, learning motivation, and the use of board games (both paper-based and digital).

2.1 Collaborative learning and social interaction

Collaborative learning (CL), where students work together towards shared goals, has been recognised as an effective teaching strategy (Zhu & Zhang, 2023; Agonafir, 2023). This flexible and adaptable approach can be applied to various disciplines, including science subjects in contemporary schools. CL encompasses a range of educational approaches that promote the intellectual engagement of pupils, either individually or in collaboration with teachers.

CL shows great potential for improving pupils' learning performance by fostering interaction among them in the classroom (Khan et al., 2021). This approach fosters critical thinking, communication skills, and collaboration, benefiting lower-achieving students (Li et al., 2023) and contributing to their learning and development (Agonafir, 2023; Novak et al., 2022). Furthermore, CL integrates well with various methods, including gamified learning, further enhancing learning outcomes (Qureshi et al., 2023). Technology-integrated (Plugged-in) CL using electronic devices and game-based learning strategies can facilitate content sharing and collaboration (Zhang & Zou, 2022; Adipat et al., 2021). This approach potentially leads to increased student engagement and teamwork, potentially improving cognitive abilities (Alfaro-Ponce et al., 2023). By engaging in collaborative problem-solving and discussions, pupils can deepen their understanding and develop critical thinking skills, leading to improved learning outcomes.

CL represents a significant departure from the traditional teacher-centred approach in schools. While teachers may still be present, they are complemented by pupils' active discussions and diligent engagement with the learning materials (Ariffin, 2021). CL in the classroom offers several advantages. First, CL approaches, such as social collaboration theme-based project collaboration (Urrea et al., 2022) and peer activities like peer helping and peer tutoring (Novak et al., 2022), can be effectively applied among pupils in the science classroom. Furthermore, teachers act as expert facilitators who guide students in constructing their understanding of learning through scaffolding (Rahma et al., 2020) and create a conducive environment where pupils can effectively collaborate and learn from one another (de Hei et al., 2020). This approach empowers pupils to actively participate in their learning, encouraging critical thinking and fostering a deeper grasp of scientific concepts through meaningful interactions and problem-solving activities.

Social interaction holds a significant role in the learning process for pupils in the classroom. Interacting with their peers enables pupils to organise their thoughts, reflect on their understanding of scientific concepts, and identify gaps in their reasoning (Tocaimaza-Hatch & Santo, 2020).

Science teachers play a crucial role in the classroom, requiring them to possess social skills and facilitate meaningful interactions with their pupils during science lessons (Hymel & Katz, 2019). However, many teachers do not frequently explore or employ effective strategies to address the issue of social interaction with pupils within their educational practices (Azmat & Ahmad, 2022).

Positive social interaction within the classroom influences student preferences, behaviours, and learning performance (Qureshi et al., 2023). Understanding social dynamics surrounding CL is crucial for designing effective learning environments (Li et al., 2023). Positive social interaction, characterised by mutual respect and meaningful exchange of ideas, fosters understanding and feedback, relying on supportive relationships that enhance communication and collaboration (Eriksson et al., 2021; Fiş Erümit, 2021; Nordin et al., 2022). This positively impacts class dynamics, emotional well-being, and cognitive development, aiding students in organising thoughts, encouraging reflection on complex concepts, and nurturing essential social skills (Perez-Aranda et al., 2023; Li et al., 2023; Alfaro-Ponce et al., 2023; Valiente et al., 2020).

Overall, CL offers a valuable approach to education. It promotes student engagement, critical thinking, and positive social interaction, ultimately improving learning outcomes and fostering well-rounded individuals.

2.2 Learning motivation

Learning motivation influences students' attitudes towards science and ultimately contributes to their success (Ateş, 2024). Dessie et al. (2024) and Sellami et al. (2023) conducted a study investigating the impact of motivation on students learning science subjects. Highly motivated students exhibit positive attitudes towards science, facilitating knowledge absorption and critical thinking (Stark, 2019). Recognising its multifaceted nature, science educators should create a stimulating learning environment that enhances students' interest and understanding (Virata & Castro, 2019; Teppo et al., 2021). Integrating technology into science learning has positively impacted students' motivation and acceptance of technology (Lin & Cheng, 2022; Lin et al., 2021).

2.3 Gamification

Gamification has emerged as a promising approach to enhance motivation and engagement in science education, driven by the transformative power of digital games (Navarro-Espinosa et al., 2022; Zourmpakis et al., 2023). It leverages devices like smartphones, tablets, and laptops to extend the pedagogical approach of teaching into the digital domain, potentially democratising education (Montiel et al., 2020), enhancing learning effectiveness (Chen et al., 2023) and increasing students' motivation (Hou et al., 2023a, b). While research suggests promise, further investigation is needed to understand its long-term impacts on various learning outcomes across diverse subject areas.

PBBGs with cards, dice, or boards have evolved from parent-child interactions in Europe and the US (Musick et al., 2021; Gennari et al., 2019) to recognised teaching tools in Taiwan (Kuo & Hsu, 2020). Studies highlight their effectiveness in increasing motivation (Madariaga et al., 2023), active participation (Díaz et al., 2024), and fostering collaborative learning environments that reduce anxiety (Hou et al., 2023a, b). Additionally, research suggests positive impacts on computational thinking skills when used as an unplugged activity (Zhang et al., 2022; Chen et al., 2023a, b). However, limitations exist, including a lack of research on academic performance beyond motivation (Parks, 2023) and a focus on specific skills without examining broader learning outcomes (Assapun & Thummaphan, 2023). Furthermore, studies highlight the need for qualitative data (Alejandria et al., 2023) and diverse research instruments to understand PBBGs' effects comprehensively (Miculob et al., 2022).

On the other hand, CBGs blending technology with gaming mechanics effectively enhance learning performance (Chen et al., 2023a, b; Cook-Chennault et al., 2022). They improve learning interest, motivation, and behaviour (Janakiraman et al., 2021), creating a stimulating environment that surpasses traditional technology-enhanced learning methods (Gök & İnan, 2021). While CBGs offer advantages in engagement and interactivity, they may come at the cost of reduced opportunities for social interaction compared to PBBGs (Yang & Chen, 2023). This highlights the need for a nuanced understanding of the specific benefits and potential drawbacks of each type of gamified learning approach.

2.4 Theoretical framework

This research employs a theoretical framework (Fig. 1) that combines Activity Theory (AT) and Social Constructivism Theory (SCT) to understand the potential impact of gamified learning, specifically PBBGs and CBGs, on science education for 10-year-old students.

2.4.1 Activity Theory (AT)

AT highlights how contradictions within activity systems can initially pose challenges but ultimately become driving forces for learning and development (Engeström, 2001). In this context, introducing novel gamified learning approaches like PBBGs and CBGs may initially create challenges for unfamiliar participants. However, through guided exploration and engagement with these tools, students can overcome these challenges and experience "expansive transformations" in their understanding and approach to science learning (Engeström, 2001). This framework, particularly Leontiev's model with its interconnected levels of activity, action, and operation (Leontiev, 1981), allows us to analyse the individual cognitive processes

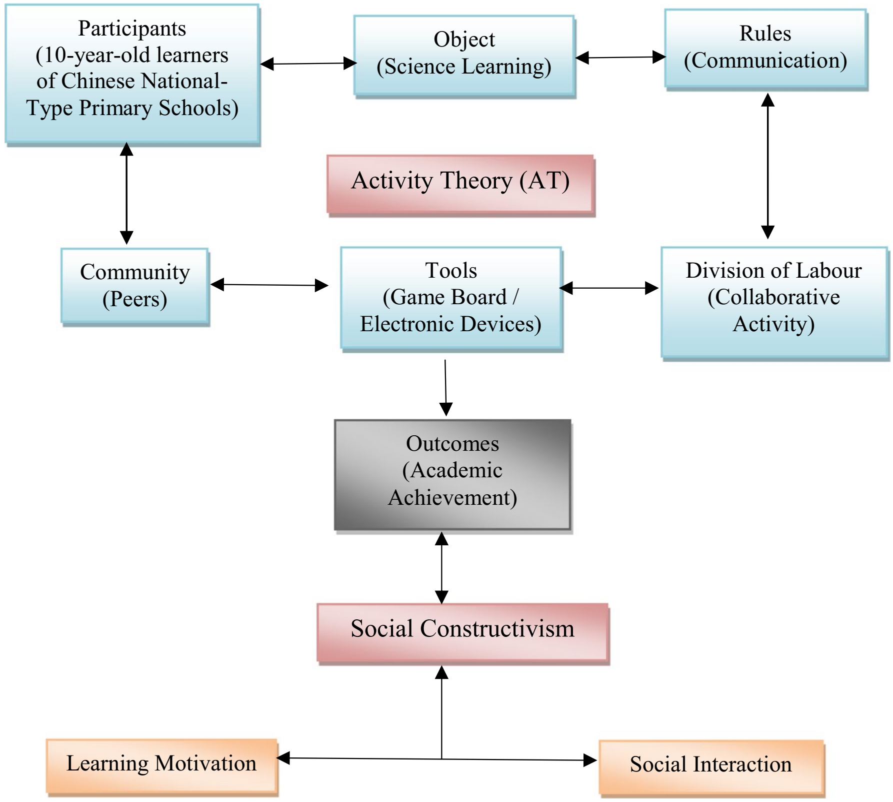


Fig. 1 Proposed Theoretical Framework of General Concepts

and motivations involved in engaging with gamified learning activities. Our framework focuses on 10-year-old participants engaged in face-to-face discussions using mobile devices or board games, with the researcher as the teacher, guiding activities according to cultural norms.

2.4.2 Social Constructivism Theory (SCT)

SCT emphasises the role of social interactions and cultural context in shaping learning (Vygotsky, 1978; Lameras & Arnab, 2021). Vygotsky's Zone of Proximal Development (ZPD) highlights the importance of collaborative learning, suggesting that interactions with peers or educators trigger internal developmental processes (Silalahi, 2019). SCT emphasises the role of social context and culture in cognitive development and learning (Picciano, 2021). Gamified learning, particularly through collaborative PBBGs and CBGs, can create opportunities for students to interact, share ideas, and work together within the ZPD, fostering their individual learning and cognitive development (Rogti, 2024).

2.4.3 Integrated framework

By merging AT and SCT, this research framework offers a comprehensive lens for examining the impact of gamified learning on 10-year-olds. While AT focuses on individual cognitive processes within activity systems, SCT emphasises the social and cultural aspects of learning. Integrating these perspectives allows us to explore the individual and collective dimensions of learning within gamified science education for 10-year-olds. Figure 1 visually represents this integrated framework, depicting the interplay between individual learners, the gamified learning environment (including PBBGs and CBGs), and the broader social and cultural context.

2.4.4 Hypothesis

> Ho1: There is no significant difference in the change scores (pre-test to post-test) between the control group (CT) and the two experimental groups (PBBG and CBG).
> Ha1: There is a significant difference in the change scores (pre-test to post-test) between at least one pair of groups (e.g. CT vs. PBBG, CT vs. CBG, or PBBG vs. CBG).
> Ho2: There is no significant difference in the mean scores (social interaction) between the control group (CT) and the two experimental groups (PBBG and CBG).
> Ha2: There is a significant difference in the mean scores (social interaction) between at least one pair of groups (e.g. CT vs. PBBG, CT vs. CBG, or PBBG vs. CBG).
> Ho3: There is no significant difference in the mean scores (learning motivation) between the control group (CT) and the two experimental groups (PBBG and CBG).
> Ha3: There is a significant difference in the mean scores (learning motivation) between at least one pair of groups (e.g. CT vs. PBBG, CT vs. CBG, or PBBG vs. CBG).

3 Methodology

3.1 Research design

This study employed a true experimental design (between-group pretest-posttest design). Three methods were employed: CT with multimedia aids (PowerPoint), PBBG, and CBG. Each method was implemented over three weeks after regular school hours, involving 574 participants who underwent a pre-test to establish a baseline performance.

3.2 Participants

Five hundred seventy-four participants in this study were 10-year-old students from national-type Chinese primary schools, selected through purposive sampling. These students were proficient with electronic devices and screened for positive technology and academic attitudes through interviews. Participants represented diverse backgrounds and received science instruction in Mandarin. Table 1 summarises the demographic distribution of participants according to gender and teaching methods.

3.3 Research procedure and data collection

The two-month data collection period during the school holidays followed a systematic process:

(1) Ethical Clearance: Researchers obtained ethical clearance from Universiti Malaysia Sarawak to ensure adherence to ethical standards.

(2) Permission from Tuition Centre: Formal approval was obtained from the Principal of Damai Tuition Centre, Sibu Tuition Centre.

(3) Participant Recruitment: 10-year-old participants from various National-Type Chinese Primary Schools were recruited.

(4) Participant Consent: Consent letters were provided to participants and parents, assuring confidentiality.

(5) Teaching Approaches: Three teaching methods were employed for different groups- CT ($n=166$), PBBG ($n=205$), and CBG ($n=204$).

(6) Pre-test: A pre-test was administered to establish a baseline performance for each group.

(7) Science Lessons: Participants underwent three weeks of instruction based on their groups for three science topics.

(8) Observation: Participants were observed using a hidden camera, with another teacher as a non-participant observer.

(9) Post-Test: Participants completed a post-test evaluation within 2 h after lessons each week, and results were compared to pre-test scores.

(10) Questionnaire and Interviews: All participants completed learning motivations and social interactions questionnaires. Semi-structured interviews were conducted after PBBG and CBG sessions.

(11) Data Analysis: Data from interviews, post-task walkthroughs, and video recordings were analysed.

Table 1 Participants Distribution according to Gender and Teaching Methods

Teaching methods (Groups)	Gender		Total
	Male	Female	
CT	57	109	166
PBBG with CL	66	138	204
CBG with CL	63	141	204
Total	186	388	574

3.4 Instrument and research materials

3.4.1 Pre-test and post-test

The pre-test and post-test questions were meticulously designed to align with Year 4 Science subject requirements following the curriculum and standard guidelines. A Table of Specifications (TOS) was the foundation for constructing these tests, ensuring alignment of objectives, instructions, and assessments. The TOS facilitated item distribution across cognitive domains and syllabus components, with weightage allocated as follows: Knowledge (50%), Understanding (30%), and Thinking (20%).

To validate and enhance the reliability of the tests, two experienced Science teachers conducted a thorough review and evaluation of all items. Using a 5-point Likert Scale, Teachers A and B assessed multiple-choice and open-ended questions. Their 107 pre-test and post-test questions assessment exhibited an impressive agreement of 92.2% or a Kappa value of 0.922. This Kappa value signifies a robust agreement, falling within the range of 0.81 to 0.92, signifying robust agreement and affirming the high reliability and validity of the assessments based on the substantial consensus reached by the two educators.

3.5 Questionnaire

A questionnaire was employed to gather perceptions on social interactions and learning motivation. The Learning Motivation section was adapted from Pintrich et al. (1991) and Sousa et al. (2017), while the Social Interaction section was adapted from Högberg et al. (2019). Revisions based on feedback from two experienced science teachers were made to enhance the questionnaires's validity. Teacher feedback resulted in modifying two items related to social interaction, while the remaining twenty-nine items remained unchanged. The questionnaire items were translated into Mandarin because the instructions for learning were conducted in Mandarin. To assess the questionnaire's reliability, an inter-rater reliability (IRR) test was conducted using Cohen Kappa's IRR, yielding a score of 0.968, indicating excellent agreement.

Furthermore, we conducted a reliability test of the adapted questionnaire, which resulted in a Cronbach's alpha coefficient of 0.936 for Learning Motivation, signifying excellent agreement between the two experienced science teachers, and 1.000 for Social Interaction, indicating perfect agreement. These Cronbach's alpha coefficients affirm the instrument's reliability and consistency in assessing social interaction and learning motivation. Additionally, the p-value for both Learning Motivation and Social Interaction was less than 0.05, signifying that the agreement levels observed in the reliability test differed significantly from what would be expected by chance.

3.6 Board games

Two versions of board games, PBBG and CBG, were developed using the AGILE life cycle instructional design by Unger and Novak (2011). These board games were tailored to align with the learning objectives of the Year 4 science syllabus in National-Type Chinese Primary Schools. The innovative design integrates CL, shifting from traditional teaching to student-centered and material-centered learning. The AGILE life cycle process involves several critical steps that demand careful attention during the design and development of PBBG and CBG within the science classroom. Maintaining a reasonable balance of speed and flexibility is crucial to achieving optimal outcomes. The articulation of the product's vision, specifically for PBBG and CBG, was guided by research questions focused on academic performance, social interaction, and learning motivation in the science classroom.

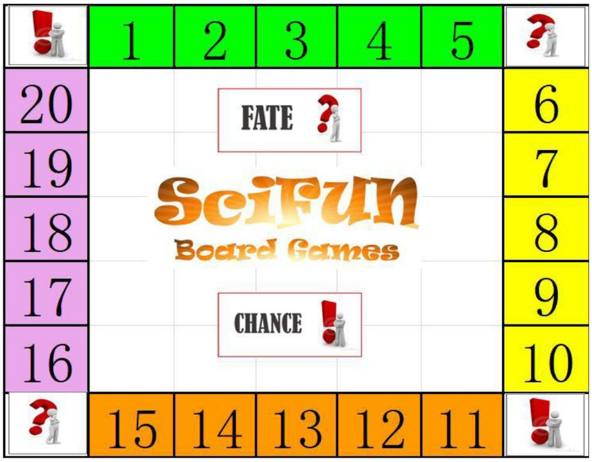
To create an innovative educational board game for 10-year-old participants in this research, the concept of the commercial board game "Millionaire Monopoly Game" was analysed. The rules and regulations of the "Millionaire Monopoly Game" were adapted into the "SciFun board game." After several iterations, the PBBG prototype (Fig. 2) and the Score Board (Fig. 3) are finalised. Additionally, the CBG is depicted in Figs. 4 and 5. The development process aimed to align with educational goals and create engaging and effective tools for collaborative learning in the science classroom.

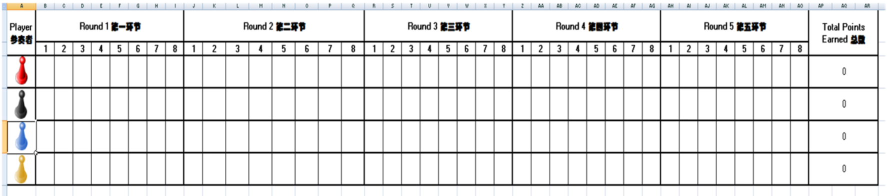
To ensure the effectiveness of PBBG and CBG, rigorous playtesting and validation involving educators/experts (4 science teachers) and students were conducted. Both games underwent iterative evaluation, focusing on mechanics, player experience, and component functionality. Science teachers provided valuable insights on learning motivation, social interaction, and game strengths/weaknesses. Observations and feedback from experts and students informed design decisions for both games. An iterative validation process ensured the games aligned with student preferences and learning objectives. This student-centred and expert validation process ensured the effectiveness and engagement of both PBBG and CBG as learning tools.

Fig. 2 The final version of the PBBG "SciFun board game"

Fig. 3 The Scoreboard of the PBBG "SciFun board game"

Fig. 4 The final version of the CBG "SciFun board game"





Player 参赛者	Round 1 第一环节								Round 2 第二环节								Round 3 第三环节								Round 4 第四环节								Round 5 第五环节								Total Points Earned 总数
	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8	
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Fig. 5 The Scoreboard of the CBG "SciFun board game"

3.6.1 Understanding the differences between Paper-based Board Games (PBBG) and Computerized Board Games (CBG)

- Both board games aimed to assess their effectiveness in influencing 10-year-old participants' academic performance, social interaction, and learning motivation within a science learning context. However, they differed significantly in their approach and design. PBBG represent the classic board game format, relying on physical components to facilitate gameplay. These components typically include (1) a Game board, A physical surface displaying the playing area, often marked with squares, grids, or other visual elements guiding player movement; (2) Pieces: Movable objects representing players or game elements made from plastic. These pieces physically traverse the game board according to the game's rules; (3) Markers: Additional elements used to track progress or information within the game, such as tokens, dice, or cards; (4) Data columns: PBBG utilise designated areas on the board or separate sheets to record game data, such as points or scores; and (4) Rulebook: A set of written instructions outlining the game's objective, gameplay mechanics, and specific rules governing player actions, movement, and victory conditions. During PBBG gameplay, players physically interact with the components, manipulating them on the board according to the established rules. This traditional format fosters face-to-face and participant communication, potentially impacting social interaction dynamics.
- CBG, in contrast, represent a digital adaptation of the traditional board game experience. They leverage electronic devices, such as computers, tablets, or smartphones, to deliver the game digitally. This transformation necessitates translating physical components into their digital counterparts: (1) Game board: Instead of a physical board, CBG utilise a digital representation displayed on the electronic device's screen. This digital board retains the core functionality of the physical board, guiding player movement and interactions within the game's virtual space; (2) Components: Physical pieces, markers, and cards are replaced with digital representations within the CBG interface. Players interact with these digital elements on the screen, manipulating them according to the game's mechanics; and (3) User Interface (UI) elements: CBG incorporate various UI elements to facilitate gameplay. These elements might include buttons for actions, virtual dice rolling mechanisms, and digital scoreboards, all displayed on the screen and allowing players to interact with the game's functionalities.
- While CBG shares some similarities with PBBG regarding core gameplay mechanics and objectives, the digital format eliminates the need for physical components and face-to-face interaction. This distinction presents a unique opportunity to explore the potential influence of digital elements on learning motivation, social interaction patterns, and academic performance within the research context.
- In essence, PBBG and CBG offer distinct learning environments. PBBG prioritises a hands-on, traditional approach that fosters physical manipulation and face-to-face interaction. CBG, on the other hand, provides a digital experience, potentially influencing engagement and motivation through interactive UI elements and the novelty of the digital format.

3.7 Classroom observation protocol and analysis

This research utilised a classroom observation protocol adapted from Singh et al. (2017) to gather data on learning motivation and social interaction features among 10-year-old participants from National-Type Chinese Primary Schools. The focus was on observing these features during the implementation of PBBG and CBG in Science classrooms.

3.7.1 Developing the observation protocol

Before commencing the research, the researcher collaborated with a non-participant observer, an experienced teacher with over seven years of experience in different schools. This collaboration leveraged the concept of “Shared Personal Practice” within Professional Learning Communities (PLCs) (Hassan et al., 2022), which facilitates knowledge sharing and professional development. The teacher provided valuable insights and feedback on the observation technique while observing the implementation of PBBG and CBG in the Science classroom.

The observation protocol was selected based on its relevance to the research objectives, specifically its ability to capture learning motivation and social interaction features. The inter-rater reliability between the observer and researcher was perfect, with a 100% agreement or a Kappa value of 1.00. This high level of agreement strengthens the reliability and validity of the observation data, ultimately reinforcing the study’s findings regarding learning motivation and social interaction.

3.7.2 Enhancing data collection

A well-established observation protocol was employed to capture detailed data and gain deeper insights into classroom occurrences. This protocol focused on learning motivation and social interactions, including learner-learner and researcher-participant interactions. While the protocol provided examples, it lacked specific details for robust data analysis. Therefore, video recordings of classroom sessions and feedback from the non-participant observer were utilised alongside the protocol. These additional resources allowed for comprehensive observation summaries and facilitated connections to predetermined standards or indicators.

3.7.3 Data analysis

Following implementing PBBG, CBG, and CL at different times within the science classroom, the researchers analysed the observed data, considering its potential impact on participants’ learning motivation and social interaction. This comprehensive analysis allowed for a well-rounded understanding of the research outcomes.

Several strategies were implemented to guarantee the reliability of classroom observations:

(1) Standardised protocol: A well-established protocol provided structure and consistency in recording data across observation sessions.

(2) Dual coding: Two researchers independently documented observations, meticulously recording specific behaviours, interactions, and contextual details. This enhanced the accuracy and replicability of data collection. Any discrepancies were resolved through consensus discussions.

3.8 Interview protocol and analysis

This research employed individual, semi-structured interviews with ten 10-year-old participants following the classroom observation phase. These interviews aimed to gather participant feedback regarding their experiences with the learning environment. Audio recordings were made for comprehensive data analysis. The researcher ensured close alignment between the interview questions and the questionnaire statements, focusing on research objectives related to learning motivation and social interaction features. Additionally, post-task walkthroughs were conducted.

3.8.1 Developing the interview protocol

The interview protocol comprised 20 questions translated into both English and Mandarin. Recognising the participants' age, the researcher simplified the language to facilitate comprehension. Two Science teachers reviewed and assessed the translated versions specific to PBBG and CBG implementations, ensuring suitability for the target audience. Involving experienced Mandarin teachers further enhanced the interview protocol's validity and reliability. Their expertise ensured age-appropriate language, facilitating meaningful responses within the study context. Inter-rater agreement between the science teachers regarding interview questions was assessed using Cohen's Kappa test with a 90 % level or Kappa value of 0.90. This outcome suggests that a very good agreement enhances the reliability and validity of the interview data and strengthens the credibility of the findings related to learning motivations and social interaction.

3.8.2 Data analysis

The researcher meticulously recorded participant feedback during interviews. A suitable transcription method and manual thematic analysis were employed to ensure accurate and effective analysis. This involved verbatim transcription and systematic coding of participants' thoughts directly related to the research questions (Rahmawati, 2022). Thematic analysis and coding procedures (Lochmiller, 2021) adhered to Braun & Clark (2006) protocol.

Immediate post-interview transcription served as a preliminary analysis, allowing the researcher to reflect on emerging themes (Syamsuddin, 2022). Braun and Clark's (2006) six-step thematic analysis was followed: (1) familiarisation with the data, (2) generating initial codes, (3) generating themes, (4) reviewing potential themes, (5) defining and naming themes, and (6) producing the report.

Several measures were implemented to enhance the reliability of interview analysis: (1) Rigorous transcription: All interviews were transcribed verbatim by the first researcher, followed by verification by a second researcher to minimise discrepancies; (2) Multiple coders: Two researchers independently coded the data using a predetermined coding scheme. Consistency was assessed to identify discrepancies and reach consensus interpretations. By implementing these comprehensive strategies, this study aimed to ensure the reliability of interview data, strengthening the validity and trustworthiness of the research findings.

Our research employed a true experimental design with pre-and post-tests, questionnaires, classroom observations, and interviews over three weeks to investigate the impact of different teaching methods on academic performance, learning motivations and social interactions. We meticulously developed and validated research instruments aligned with our objectives. The study adhered to ethical principles and received prior approval. Participants completed a pre-test, participated in lessons under each condition, and completed post-tests, questionnaires, and interviews/video recordings. Data was analysed using appropriate statistical and qualitative methods to ensure validity and reliability. Finally, we synthesised and presented the findings clearly and concisely to offer valuable insights into the research objectives.

4 Results

The results section presents the findings following the research questions' structure. Each question is addressed in its subsection: (1) Academic Performance: This section analyses pre-test and post-test scores to answer RQ1, which explores potential differences in academic performance between students in the CBG, PBBG, and CT (multimedia aids) groups, (2) Social Interaction: RQ2 focuses on how CBG and PBBG influence students' social interaction and is divided into three subsections: (i) Social Interaction Questionnaire, which analyses data from a questionnaire designed to assess social interaction; (ii) Classroom Observation, which presents findings from direct classroom observations focusing on social interaction patterns; and (iii) Interview which analyses data collected through interviews conducted with participants to gain deeper insights into their social experiences. The final section is (3) Learning Motivation, which addresses RQ3 to investigate differences in learning motivation among students exposed to the three learning methods. It is further divided into three subsections: (i) Learning Motivation Questionnaire, which analyses data from a specific questionnaire designed to measure learning motivation; (ii) Classroom Observation, which presents findings from observations focusing on aspects related to learning motivation; and (iii) Interview which analyses interview data to gain a deeper understanding of students' motivational experiences.

4.1 Academic performance: pre-test and post-test

> RQ1: Is there a statistically significant difference in academic performance among 10-year-old students learning science using CBG, PBBG and CT (with multimedia aids such as PowerPoint)?

A Shapiro-Wilk normality test showed non-normal distributions ($p = 0.000$) across all conditions (CT, PBBG, and CBG) for pre-test and post-test scores and learning topics. Subsequently, non-parametric tests were applied to compare change scores of learning performance (pre-test to post-test) among these conditions.

The Kruskal-Wallis H test indicated a significant difference among the groups ($\chi^2 = 220.075$, $p < 0.001$), with mean rank scores of 133.23 (CT), 384.81 (PBBG), and 315.73 (CBG). The p-value is extremely small ($p < 0.001$), indicating strong evidence against the null hypothesis that no difference exists. Therefore, we reject the null hypothesis. A post-hoc Dunn's test ($\alpha = 0.00033$) further indicated significant differences between CT vs. CBG and PBBG vs. CBG, as summarised in Table 2.

These results prove significant differences in academic performance change scores between the CT, PBBG, and CBG groups. Specifically, post hoc tests revealed significant differences between CT vs. CBG and PBBG vs. CBG. Furthermore, PBBG had the highest overall achievement rate compared to CT and CBG, with a mean score change of (CT: 36.64%, PBBG: 65.10%, and CBG: 65.41%). It indicates that PBBG consistently outperformed CT and CBG.

4.2 Social interaction

> RQ2: How do CBG and PBBG influence social interaction among 10-year-old students in science education?

4.2.1 Social interaction questionnaire

Data distribution for social interaction was assessed, revealing non-normality ($p = 0.000$) across all learning topics and conditions (CT, PBBG, and CBG) based on the Shapiro-Wilk test. Subsequently, non-parametric tests were conducted to compare social interaction among these conditions. The Kruskal-Wallis H test revealed a significant difference ($\chi^2 = 377.347$, $p < 0.001$) among the groups, with mean rank scores of 83.50 (CT), 400.71 (PBBG), and 340.29 (CBG).

Table 2 Kruskal-Wallis Dunn's Post Hoc Test results for change scores between CT, PBBG and CBG groups

Post Hoc Test	Chi-Square	Asymp. Sig. (2-tailed)
CT vs. PBBG	201.936	0.083
CT vs. CBG	135.414	0.000
PBBG vs. CBG	21.012	0.000

This p-value is less than the significance level of 0.001, signifying a statistically significant difference in the mean social interaction scores between at least two groups, indicating strong evidence against the null hypothesis that no difference exists. Therefore, we reject the null hypothesis. A post-hoc Dunn's test ($\alpha = 0.00033$) identified significant differences in mean ranks between CT vs. PBBG, CT vs. CBG, and PBBG vs. CBG, as summarised in Table 3.

These results prove significant differences in mean social interaction scores between the CT, PBBG, and CBG groups. Post hoc tests indicate significant differences between CT vs. PBBG, CT vs. CBG, and PBBG vs. CBG. Moreover, PBBG outperformed CBG and CT for learning motivation with mean score rank (PBBG: 400.71, CBG: 340.29, and CT: 83.50).

4.2.2 Classroom observation

Classroom observations revealed two key themes:

(1) Researcher-participant interactions with four subthemes.

i. *Nature of Researcher-Participant Interactions*: This subtheme focused on the characteristics and dynamics of interactions between researchers and participants.
ii. *Types of Questions*: Different questions posed by the researcher during interactions were examined.
iii. *Participant Questions*: This subtheme focused on the questions raised by the participants.
iv. *Researcher Responses*: Examining how the researcher responded to participant questions and engaged in discussions.

(2) Interactions Among Participants with four subthemes.

i. *Opportunities for Participant Interaction*: This subtheme explored instances in which participants had opportunities to interact with each other.
ii. *Interaction Styles*: Examining the participants' styles and modes of interaction.
iii. *Task Collaboration*: Focusing on collaborative efforts among participants while working on tasks.
iv. *Feedback Provision*: Analysing how participants provided feedback to each other.

Table 3 Kruskal-Wallis Dunn's Post Hoc Test results for mean social interaction scores between CT, PBBG and CBG groups

Post Hoc Test	Chi-Square	Asymp. Sig. (2-tailed)
CT vs. PBBG	297.462	0.000
CT vs. CBG	213.946	0.000
PBBG vs. CBG	13.331	0.000

These themes and subthemes offer a comprehensive understanding of the nature of interactions within the classroom setting, providing the researcher-participant dynamics and peer interactions. Figure 6 summarises these findings.

4.2.3 Interview

This study applied Braun & Clarke's (2006) Thematic Analysis (TA) process to explore social interactions among 10-year-old participants using PBBG and CBG in science classrooms. Due to space limitations, the transcript is not presented here but is available upon request from the researchers. Based on the TA, four themes emerged.

> *Theme 1 (*Collaborative Learning): The findings strongly favour collaborative learning when employing PBBG and CBG in the science classroom. Participants wanted to interact with other group members throughout the learning process.
> *Theme 2 (*Learning with Friends): Participants preferred using PBBG or CBG alongside friends for their science learning. This collaborative approach significantly enriched their educational experiences through social interaction.
> *Theme 3 (*Active Engagement): Participants, whether utilising PBBG or CBG, preferred group activities. They actively discussed science-related questions during gameplay, fostering a conducive environment where they could learn and master scientific knowledge collectively.
> *Theme 4* (Group Interaction): Group interaction was prominent in the analysis. Participants consistently and actively communicated with group members during PBBG and CBG, facilitating concurrent learning and fostering positive social interactions.

This TA provides valuable insights into the preferences and behaviours of 10-year-old students engaged in collaborative learning through board games. The identified themes highlight the significance of social interaction in the learning process, paving the way for understanding the dynamics at play in science classrooms utilising PBBG and CBG.

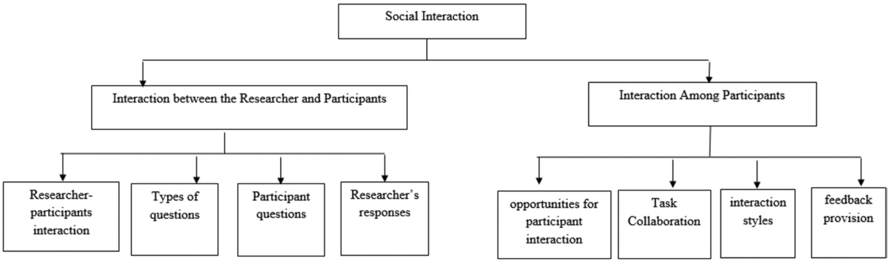

Fig. 6 Themes and Subthemes for Social Interaction analysed using Classroom Observation

4.3 Learning motivation

> RQ3: How does the learning motivation among 10-year-old students differ when exposed to CBG, PBBG, and CT (with multimedia aids such as PowerPoint)?

4.3.1 Learning motivation questionnaire

A Shapiro-Wilk test for normality was conducted for all learning topics and conditions (CT, PBBG, and CBG), revealing non-normality ($p = 0.000$). Non-parametric tests were subsequently employed to compare learning motivation among these conditions.

The Kruskal-Wallis H test revealed a significant difference ($\chi^2 = 378.20$, $p < 0.001$) among the groups, with mean rank scores of 83.50 (CT), 409.82 (PBBG), and 331.18(CBG). This p-value is less than the significance level of 0.001, signifying a statistically significant difference in the mean learning motivation scores between at least two groups, indicating strong evidence against the null hypothesis that no difference exists. Therefore, we reject the null hypothesis. A post-hoc Dunn's test ($\alpha = 0.00033$) identified significant differences in mean ranks between CT vs. PBBG, CT vs. CBG, and PBBG vs. CBG, as presented in Table 4.

These statistical findings highlight significant differences in learning motivation among students exposed to different teaching methods, emphasising the importance of considering pedagogical approaches in shaping students' motivation levels in the science classroom.

4.3.2 Classroom observation

Observation and reflective notes covered two primary themes:

(1) lesson structure and technology/resource utilisation, with two sub-themes:

(i) *Classroom situation at the beginning, middle, and end*: Investigating the evolving dynamics and engagement levels within the classroom at different points in the lesson, capturing the initial setup, the ongoing activities in the middle phase, and the conclusion towards the end.

(ii) *Researcher-participant activities*: Analysing the interactions and activities involving researcher and participants in integrating and utilising technology/resources, providing insights into their collaborative engagement and the impact on the learning atmosphere.

Table 4 Kruskal-Wallis Dunn's Post Hoc Test results for mean learning motivation scores between CT, PBBG and CBG groups

Post Hoc Test	Chi-Square	Asymp. Sig. (2-tailed)
CT vs. PBBG	297.462	0.000
CT vs. CBG	287.911	0.000
PBBG vs. CBG	27.578	0.000

(2) Use of technology/device resources, with five sub-themes:

(i) *Integration into the activity*: Exploring how technology/resources were seamlessly integrated into the learning activity.
(ii) *Usage method and purpose: Investigate* the methods employed and the specific educational purposes served by using technology/resources.
(iii) *Issues faced by the researcher or participants: Identify and address* challenges or difficulties encountered by the researcher and participants while using technology/resources.
(iv) *troubleshooting capability*: Evaluating the ability to troubleshoot and resolve issues promptly, ensuring smooth integration and use of technology/resources.
(v) *Additional resources/devices employed by the researcher*: Examining any supplementary resources or devices introduced to enhance the overall learning experience.

Figure 7. Themes and Subthemes for Learning Motivation analysed using Classroom Observation.

4.3.3 Interview

Braun and Clarke's (2006) TA was employed in this study, revealing seven significant themes based on participants' responses. These interview themes provide strong insights into the participants' perspectives and experiences with PBBG and CBG in the science classroom, emphasising the positive impact on learning, motivation, and engagement. Due to space constraints, the interview transcript is available upon request from the researchers.

*Theme 1 (*Enhanced Learning): Participants reported improved comprehension of Year 4 science topics using PBBG and CBG.
*Theme 2(*Positive Material Engagement): PBBG and CBG allowed participants to engage positively with science materials, facilitating peer interaction and understanding.

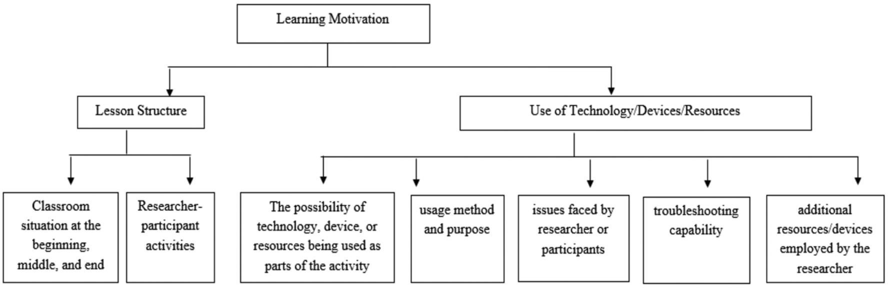

Fig. 7 Summarises these findings

Theme 3 (Enriching Learning Experience): Collaborative learning with PBBG and CBG resulted in a more profound understanding and enriched learning experience.
Theme 4 (Motivated Learning): The board games (PBBG and CBG) motivated participants through intrinsic and extrinsic incentives, combining fun gameplay with knowledge acquisition.
Theme 5 (Altered Perceptions): Participants perceived board games (PBBG and CBG) as effective tools for science learning, distinguishing them from the conventional teaching method.
Theme 6 (Application Proficiency): Participants in this study felt proficient in using board games (PBBG and CBG) to explain content, leading to a clear understanding and enjoyment of science education.
Theme 7 (Empowering Learning): The board games (PBBG and CBG) successfully empowered participants to learn collaboratively, reinforcing their understanding of science topics.

5 Discussion

Researchers have recognised the importance of technology for science education (Komalawardhana & Panjaburee, 2023; Kumar et al., 2023) and the impact of gamification on learner motivation, engagement, and academic achievement (Zeybek & Saygı, 2024). However, limited research has focused on the gamification of science education (Kalogiannakis et al., 2021) and the multifaceted aspects of science education using gamified educational approaches to contribute to cognitive development and student well-being (Melo et al., 2020), and this study acknowledges these limitations by focusing on the pedagogical impact of board games (plugged-in or unplugged) on academic performance, learning motivation, and social interaction in 10-year-old students. Sousa et al. (2023) also addressed the practical implication of the pedagogical approach in terms of learning, cognitive and psychological. Building upon the previous analysis, this section explores how the inherent characteristics of PBBG, CBG, and CT contribute to their effectiveness in academic performance, social interaction, and motivation. Our research's outcomes, relevance, and potential challenges are summarised below.

5.1 Impact on academic performance and social interaction

Our study revealed no statistically significant differences between PBBG and CT methods regarding academic performance. However, both PBBG and CBG significantly outperformed CT, emphasising the effectiveness of board game methods in enhancing students' academic performances. Additionally, both PBBG and CBG fostered significantly higher levels of social interaction than CT.

Although CBG and PBBG demonstrated significant improvements, there were no significant differences between PBBG and CT, implying that PBBG can be equally effective as conventional teaching methods, offering practical benefits for educators and students. The engaging and interactive nature of board games can improve motivation and engagement compared to traditional teaching methods, aligning with Alejandria et al. (2023), who emphasised the board games (PBBG or CBG) in enhancing exam results (Miculob et al., 2022), improving grades (Montejo Bernardo & Fernández González, 2021) and learning achievements (Hou et al., 2023b; Arufe Giráldez et al., 2022).

Our study emphasises the integral role of social interaction in the educational experience, revealing significant differences across all groups and highlighting the positive impact of CBG and PBBG in fostering heightened student social engagement. This is crucial in education, as social interactions can enrich the learning experience (Assapun & Thummaphan, 2023).

While CBG emerged as an effective tool for improving students' understanding of scientific concepts, PBBG demonstrated better educational outcomes than CT. Our results emphasise the pedagogical potential of CBG and PBBG in education, aligning with Dziob's (2020), highlighting CBG's advantage in improving knowledge retention. Additionally, our findings resonate with Tsai et al. (2021) and Meekaew and Yasri (2020), emphasising the significant impact of board games on various science topics. This study provides valuable insights into the pedagogical impact of CBG and PBBG in enhancing academic performance.

PBBG utilises familiar physical components like boards, pieces, and dice, creating a sense of comfort and ease of interaction for children. This finding aligns with the review conducted by Chen et al. (2023a, b) on the impact of unplugged activities on students' computational thinking skills. Furthermore, this tangibility of physical components can enhance engagement and facilitate learning (Cardinot & Fairfield, 2022). PBBG inherently requires players to interact and communicate face-to-face, potentially fostering social interaction and teamwork skills (Janakiraman et al., 2021). This collaborative aspect can encourage positive learning interactions and enrich the learning experience (Assapun & Thummaphan, 2023).

CBG leverages technology to create engaging and interactive learning experiences through animations, sounds, and dynamic visuals (Candan & Başaran, 2023; Taşkın & Çakmak, 2023). Furthermore, this dynamic feedback and adaptation allows them to adapt their learning strategies and improve their understanding. These features can capture and sustain student attention (Dziob, 2020), leading to deeper engagement and potentially improved learning outcomes (Lin & Hou, 2022; Hou et al., 2023b; Arufe Giráldez et al., 2022). CBG can provide immediate and personalised feedback to students, allowing them to adapt their learning strategies and improve their understanding.

CBG and PBBG integrate game mechanics like points, badges, and leaderboards, boosting motivation and engagement (Alsawaier, 2018). These elements can provide a sense of accomplishment and encourage students to continue learning and striving for improvement. However, CT can lead to passive learning experiences, failing to capture students' attention and engagement (Chan et al., 2023; Deng, 2023). This lack of engagement can hinder learning outcomes. Also, CT limited individualisation to cater to individual learning styles and paces, potentially demotivating some students (Renau, 2023). This one-size-fits-all approach might not be suitable for learning science.

There are limitations to implementing PBBG and CBG in the classroom. PBBG can be challenging to implement in large classrooms due to logistical constraints and the need for physical resources. At the same time, CBG relies on access to electronic devices and stable internet connections, which might not be readily available in all educational settings. While PBBG offers some level of interactive learning, they might not provide the same level of individualised feedback and adaptation as digital technologies (Kaimara et al., 2021), and the engaging features of CBG can become distractions if not carefully designed and managed (Arayapisit et al., 2023). Also, CBG may encourage social interaction through collaborative gameplay; they generally offer less face-to-face interaction than PBBG (Hwang et al., 2012; Hou et al., 2023a, b).

5.2 Fostering learning motivation

Building upon the previous analysis of performance and social interaction, this section explores how the inherent features of each method (PBBG, CBG, and CT) can influence learning motivation. Our study significantly emphasises the impact of learning motivation on the pedagogical outcomes of CBG and PBBG in science education, revealing significant differences across all groups. These findings are consistent with earlier studies that demonstrated the influence of PBBG on learning motivation and engagement (Parks, 2023; Díaz et al., 2024).

The novelty of Board games and inherent fun can spark student engagement and motivate learning (Díaz et al., 2024). This can lead to a more positive and active learning experience than traditional lectures (Dessie et al., 2024). Board games often involve achieving goals and competing with peers, which can motivate students to learn and perform well. This sense of accomplishment and healthy competition can foster a desire to participate and master the material. The collaborative aspects of PBBG can foster a sense of belonging and shared goals, further enhancing motivation (Lebron et al., 2024). Working together towards a common objective can create a supportive learning environment and encourage students to support and learn from each other.

Like PBBG, CBG's interactive, engaging features, such as animations, sounds, and dynamic visuals, can intrinsically motivate learners (Kaimara et al., 2022). These elements can capture and sustain student attention, creating a more immersive and enjoyable learning experience. CBG can provide immediate feedback and recognition for correct answers and achievements, motivating learners (Chen & Chi, 2022). This reinforcement loop can help students solidify their understanding and encourage them to remain engaged in learning.

The gamification elements in CBG and PBBG, like points, badges, and leaderboards, can further incentivise participation and motivate students to learn and progress (Fonseca et al., 2023). These elements can provide a sense of accomplishment and recognition, encouraging students to continue learning and strive for improvement. The results resonate with the primary theme of board games as catalysts for increased enthusiasm and commitment to learning.

Consequently, our research extends the existing literature, comprehensively exploring the pedagogical impact of the gamified learning environment in enhancing motivation, like the outcome of Chen et al. (2023). These outcomes signify the promise of these innovative pedagogical in various educational settings.

Like academic performance and social interaction, traditional teaching methods and presentations can be passive learning experiences, failing to capture students' attention and intrinsic motivation (Chou et al., 2021; Hung et al., 2023). This lack of engagement can lead to disengagement and hinder learning outcomes. The focus on teacher-centred instruction can lead to a passive learning experience and limit opportunities for students to engage with each other. Traditional teaching methods cannot often cater to individual learning styles and paces, potentially demotivating some students. This one-size-fits-all approach might not effectively address all learners' diverse needs and interests.

6 Conclusion

This study highlights the potential of both PBBG and CBG for enhancing learning compared to traditional teaching methods. While PBBG offers a familiar and engaging format with positive social interaction aspects, CBG stands out through its ability to provide dynamic feedback, gamified elements, and potential for personalised learning, potentially leading to improved academic performance. However, it is crucial to consider the affordances and limitations of each method when designing and implementing them in educational settings. Both PBBG and CBG increased motivation compared to CT. The engaging and interactive nature of both PBBG and CBG, coupled with the element of play and competition, likely contributed to increased learning motivation compared to the potentially passive nature of CT (Dessie et al., 2024). The inherent features of PBBG and CBG encourage active participation, provide opportunities for achievement and recognition, and create a more supportive and stimulating learning environment, ultimately leading to higher motivation levels (Díaz et al., 2024).

Also, this study recognises the significance of tailoring pedagogical approaches to different student generations and employing diverse gamification tools, as advocated by Fernando and Premadasa (2024). Consequently, it compares the effectiveness of computer-based board games (CBGs) and paper-based board games (PBBGs) against conventional teaching (CT) for 10-year-old students in science education. The study focuses on three key areas: academic performance, learning motivation, and social interaction, utilising a true experimental design to address these questions.

> RQ1: Is there a statistically significant difference in academic performance among 10-year-old students learning science using CBG, PBBG and CT (with multimedia aids such as PowerPoint)?

Social interaction has a positive implication on academic performance (Qureshi et al., 2023), and recent studies by Alejandria et al. (2023) and Hou et al. (2023a, 2023b) established the efficacy of board games in enhancing academic performance. Gamification also positively affects behavioural and cognitive engagement, enhancing students' achievement (Taşkın & Kılıç Çakmak, 2023). Our findings resonate with this, highlighting the substantial and positive impact of CBG and PBBG on academic performance, surpassing the traditional CT method. This aligns with existing research, such as Tsai and Tsai (2020), suggesting that games-based science learning improves students' science learning compared to other methods. However, this finding differs from Yang and Chen (2023), who emphasise that CBG increases engagement over learning.

Similar improvements in academic performance were observed in unplugged and plugged-in activities, aligning with Yang and Chen (2023) and Hou et al. (2023a, 2023b). These findings support Zhang et al. (2022) and a meta-analysis by Li et al. (2022) on unplugged activities, showcasing enhanced academic performance with PBBG and emphasising the pedagogical impact of teaching methods. However, no significant difference is recorded between game-based groups (plugged-in vs. unplugged) in science learning (Wang & Zheng, 2021).

RQ2: How do CBG and PBBG influence social interaction among 10-year-old students in science education?

Our study emphasises the enriching impact of gamification, specifically CBG and PBBG (plugged-in and unplugged), on social interaction in science education. Noteworthy differences across all groups highlight the pedagogical effectiveness of board games in creating interactive and engaging learning environments, fostering collaborative learning, active engagement, and positive group interaction. While consistent with prior studies showcasing PBBG's promotion of social interaction (Cardinot & Fairfield, 2022; Assapun & Thummaphan, 2023), it deviates from Yang and Chen's (2023) findings, suggesting reduced social interaction.

The divergence in findings emphasises the need for future investigation to determine the generalizability of Yang and Chen's (2023) observations.

RQ3: How does the learning motivation among 10-year-old students differ when exposed to CBG, PBBG, and CT (with multimedia aids such as PowerPoint)?

Safkolam et al. (2024) posited that inquiry-based learning in science education can enhance science understanding and motivation. Our study reveals a significant enhancement in learning motivation across all groups, highlighting the pedagogical impact of CBG and PBBG on students' motivation. These board games' intrinsic and extrinsic incentives fostered enthusiasm for learning and a positive attitude towards acquiring new knowledge. These findings align with previous studies by Díaz et al. (2024) and Madariaga et al. (2023), underlining the potential of CBG and PBBG to ignite students' intrinsic and extrinsic motivation.

Acknowledging the broader implications of gamification, our study explores how these pedagogical methods may influence academic outcomes and the students' holistic well-being. While primarily focusing on practical outcomes, such as academic performance, learning motivation, and social interaction, the study recognises the theoretical underpinnings of gamification in education, contributing to the ongoing discourse on its broader implications.

In conclusion, our research emphasises the potential of gamification as a transformative pedagogical approach in education to enhance 10-year-old students' science learning (Christopoulos & Mystakidis, 2023; Dehghanzadeh et al., 2023). This study explored the use of computer-based board games (CBGs) and paper-based board games (PBBGs) and their impact on academic performance, learning motivation, and social interaction. The findings suggest that CBGs hold promise for improving students' comprehension of scientific concepts. PBBGs and CBGs create a more engaging and motivating learning environment than traditional methods by incorporating novelty, enjoyment, achievement, recognition, collaboration, and communication. This fosters higher levels of social interaction and potentially leads to improved learning outcomes.

While both approaches share these benefits, CBGs' additional gamification elements might offer further incentivisation and engagement for some learners. Ultimately, the choice of method should be guided by specific learning objectives, student needs, and the educational context. Encouraging educators, curriculum designers, and educational technology developers to integrate CBGs, PBBGs, and collaborative learning (CL) can create engaging and impactful learning experiences, fostering collaborative skills and a deep understanding of science concepts. These findings advocate for integrating board games into the modern classroom, aligning with the Malaysian educational landscape's commitment to achieving high-quality international standards.

7 Research implications

Integrating AT and SCT in our theoretical framework represents a unique and innovative approach. This combination leverages the strengths of both theories, creating a framework that addresses the intricate interplay between human activities, social interactions, and cognitive development in the context of introducing PBBG and CBG for science learning.

This study's exploration of CBG, PBBG, and gamification's impact on learning outcomes benefits from the combined theoretical framework of SCT and AT. By analysing the research results through the lens of SCT and AT, we can gain a deeper understanding of:

1) Integrating SCT using Vygotsky's ZPD, emphasising the significance of social interactions and culture in cognitive development. This inclusive approach extends beyond AT's individualistic focus, providing a more comprehensive framework for analysing collaborative learning and cognitive processes among 10-year-old participants. By analysing how CBG and PBBG, through their collaborative elements and shared goals, encourage interaction and knowledge exchange among students, SCT helps us understand why gamified learning can lead to improved social interaction and collaborative learning compared to CT. This supports Agonafir's (2023) study on collaborative learning's impact on learning,

performance, and motivation. Also, Rogti (2024) posited that interactive media in learning can facilitate communication and collaborative learning.

2) This study examines the dynamic learning environments fostered by gamification. Drawing upon Activity Theory (AT), we view learning as a complex interplay between the learner, the tools (CBG/PBBG), the object (learning objective), the community (peers, teacher), and the rules (game mechanics). AT helps us analyse how CBG and PBBG mediate the learning environment, providing insights into the effectiveness of gamification. By examining how the game mechanics, rules, and social interactions within the game structure learning activities and facilitate collaboration, AT reveals how gamified learning differs from traditional classroom activities in fostering social interaction and collaborative learning. Furthermore, applying AT to introduce innovative technology to 10-year-old participants highlights potential contradictions and challenges in the learning process. The concept of "expansive transformation" illustrates how these initial challenges can lead to positive changes in approach, contributing to the evolving nature of AT.
3) Our integrated framework offers a comprehensive view for analysing and enhancing various aspects of human behaviour, cognition, and learning motivation. Drawing from AT and SCT, this holistic perspective contributes to a more thorough understanding of the dynamics of introducing PBBG and CBG in science education.

In summary, our theoretical framework combines established theories and extends and integrates them novelly. The advancements lie in its nuanced understanding, integration of multiple perspectives, and applicability to the specific context of introducing digital board games in science education. This integration can contribute significantly to the broader discourse in educational computing and pedagogy.

8 Limitations and future work

This study offers valuable insights into the effectiveness of CBG and PBBG in science education for 10-year-old students. However, acknowledging the study's limitations is essential for future research.

1. *Specific Educational Context*: We conducted this study using Mandarin in a specific educational context, potentially limiting the generalisation of findings. Future research should prioritise diverse educational environments, considering participants' cultural differences and socio-economic backgrounds, to offer a more comprehensive understanding of the applicability of gamification using board games.
2. *Short-term Impact Assessment*: Our study examined the short-term impacts of CBG and PBBG on academic performance, learning motivation, and social interaction. Future work should focus on conducting longitudinal studies to comprehensively understand the long-term benefits and sustainability, offering insights

into the persistence of positive effects over time, as Zourmpakis et al. (2023) suggested.

3. *Age Group Representation*: Our research centred on 10-year-old students, limiting the generalisability of CBG and PBBG for different age groups. Future investigations should investigate how these methods impact students of various ages, facilitating age-specific conclusions and insights into developmental considerations.
4. *Integration into Curriculum*: Our study highlighted the potential benefits of integrating CBG and PBBG into the curriculum. However, this integration has proven challenging. Future research should concentrate on establishing a seamless alignment with educational standards and providing resources to assist teachers in implementing these methods effectively, addressing practical challenges.
5. *Equitable Access and Inclusivity*: Ensuring equitable access to CBG and PBBG is crucial. Future works should address accessibility concerns and adapt these resources for students with varying needs, including those with disabilities. For instance, Rodríguez-Ferrer et al. (2023) conducted a longitudinal study on gamification and game-based learning for people with dyslexia, reporting improved academic performance.
6. *Self-Reported Data*: Our study relies on self-reported data to assess media use, introducing potential subjectivity and recall biases, which could lead to inaccuracies in reporting actual media engagement, as Parry et al. (2021) suggested. Future research could explore the feasibility of incorporating logged data or employing a combination of methods to enhance the precision of media use measurements.
7. *Broad Understanding of Games*. Our study only focuses on one type of board game, potentially overlooking the differences between diverse types. Future research could employ a more diverse approach, considering diverse types of games (e.g., paper-based versus virtual game environments or Augmented Reality) to provide additional insights into their effects on education. The meta-analysis conducted by Arztmann et al. (2023) highlights the difference between paper-based games and virtual game environments, potentially yielding different effects.

Data availability Data will be made available at a reasonable request.

Declarations

Conflicts of interest The authors declare that they have no conflict of interest.

References

Adipat, S., Laksana, K., Busayanon, K., Asawasowan, A., & Adipat, B. (2021). Engaging students in the learning process with game-based learning: The fundamental concepts. *International Journal of Technology in Education*, *4*(3), 542–552. https://doi.org/10.46328/ijte.169.

Agonafir, A. M. (2023). Using cooperative learning strategy to increase undergraduate students' engagement and performance. *Educational Action Research*, *31*(5), 1–17. https://doi.org/10.1080/09650792.2023.2231512.

Alejandria, L. N., Bajenting, J. M. S., Pacatan, M. A. L. D., & TomasJr, A. D. (2023). The Use of Educational Board game as a Supplemental Tool in Learning Periodic table of elements among Senior High School Students. *American Journal of Education and Technology*, *2*(1), 60–67. https://doi.org/10.54536/ajet.v2i1.1292.

Alfaro-Ponce, B., Patiño, A., & Sanabria-Z, J. (2023). Components of computational thinking in citizen science games and its contribution to reasoning for complexity through digital game-based learning: A framework proposal. *Cogent Education*, *10*(1), 2191751. https://doi.org/10.1080/2331186X.2023.2191751.

Aliyu, F. (2020). The TIMSS Grade 8 Student's Science Achievement: A comparative study between Malaysia, Singapore, and Japan. *Learning Science and Mathematics*, *15*(December), 149.

Alsawaier, R. S. (2018). The effect of gamification on motivation and engagement. *The International Journal of Information and Learning Technology*, *35*(1), 56–79. https://doi.org/10.1108/IJILT-02-2017-0009.

Alt, D. (2023). Assessing the benefits of gamification in mathematics for student gameful experience and gaming motivation. *Computers & Education, 200*, 104806. https://doi.org/10.1016/j.compedu.2023.104806.

Arayapisit, T., Pojmonpiti, D., Dansirisomboon, K., Jitverananrangsri, K., Poosontipong, D., & Sipiyaruk, K. (2023). An educational board game for learning orofacial spaces: An experimental study comparing collaborative and competitive approaches. *Anatomical Sciences Education*. https://doi.org/10.1002/ase.2257.

Ariffin, A. (2021). Effects of Student collaboration on ESL Learners' Vocabulary Development. *Asian Journal of University Education*, *17*(1), 177–191.

Arufe Giráldez, V., Sanmiguel-Rodríguez, A., Ramos Álvarez, O., & Navarro-Patón, R. (2022). Can gamification influence the academic performance of students? *Sustainability*, *14*(9), 5115. https://doi.org/10.3390/su14095115.

Arztmann, M., Hornstra, L., Jeuring, J., & Kester, L. (2023). Effects of games in STEM education: A meta-analysis on the moderating role of student background characteristics. *Studies in Science Education*, *59*(1), 109–145. https://doi.org/10.1080/03057267.2022.2057732.

Assapun, S., & Thummaphan, P. (2023). Assessing the Effectiveness of Board Game-based learning for enhancing problem-solving competency of Lower secondary students. *International Journal of Instruction*, *16*(2), 511–532. https://doi.org/10.29333/iji.2023.16228a.

Ateş, H. (2024). Designing a self-regulated flipped learning approach to promote students' science learning performance. *Educational Technology & Society*, *27*(1), 65–83. https://doi.org/10.30191/ETS.202401_27(1).RP05.

Aura, I., Järvelä, S., Hassan, L., & Hamari, J. (2023). *Gamified city for 6th graders: The effect of gameful experience on students' 21st century readiness in Finland*. Proceedings of DiGRA 2023. https://urn.fi/URN:NBN:fi:tuni-202401311994.

Azmat, M., & Ahmad, A. (2022). Lack of social interaction in online classes during COVID-19. *Journal of Materials and Environmental Science*, *13*(2), 185–196.

Bozkurt, A., & Sharma, R. C. (2020). Education in normal, new normal, and next normal: Observations from the past, insights from the present and projections for the future. *Asian Journal of Distance Education*, *15*(2), i–x.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, *3*(2), 77–101. https://doi.org/10.1191/1478088706qp063oa.

Candan, F., & Başaran, M. (2023). A meta-thematic analysis of using technology-mediated gamification tools in the learning process. *Interactive Learning Environments*, 1–17. https://doi.org/10.1080/10494820.2023.2172589.

Cardinot, A., & Fairfield, J. A. (2022). Game-based learning to engage students with physics and astronomy using a board game. In *Research Anthology on developments in Gamification and Game-based learning*. *IGI Global, 9*(1), 785–801. https://doi.org/10.4018/IJGBL.2019010104.

Chan, P., Van Gerven, T., Dubois, J. L., & Bernaerts, K. (2023). Study of motivation and engagement for chemical laboratory safety training with VR serious game. *Safety Science*, *167*, 106278. https://doi.org/10.1016/j.ssci.2023.106278.

Chen, K. Z., & Chi, H. H. (2022). Novice young board-game players' experience about computational thinking. *Interactive Learning Environments*, *30*(8), 1375–1387. https://doi.org/10.1080/10494820.2020.1722712.

Chen, P., Yang, D., Metwally, A. H. S., Lavonen, J., & Wang, X. (2023a). Fostering computational thinking through unplugged activities: A systematic literature review and meta-analysis. *International Journal of STEM Education*, *10*(1), 47. https://doi.org/10.1186/s40594-023-00434-7.

Chen, Y. C., Hou, H. T., & Wu, C. H. (2023b). Design and development of a scaffolding-based mindtool for gamified learning classrooms. *Journal of Educational Computing Research*, *61*(1), 3–29. https://doi.org/10.1177/07356331221101081.

Chiang, F. K., Wang, S., & Tang, Z. (2022). Design and evaluation of a Board Game in Food and Nutrition Education. *Education Sciences*, *12*(3), 162. https://doi.org/10.3390/educsci12030162.

Chou, C. P., Chen, K. W., & Hung, C. J. (2021). A study on flipped learning concerning learning motivation and learning attitude in language learning. *Frontiers in Psychology*, *12*, 753463. https://doi.org/10.3389/fpsyg.2021.753463.

Christopoulos, A., & Mystakidis, S. (2023). Gamification in Education. *Encyclopedia*, *3*(4), 1223–1243. https://doi.org/10.3390/encyclopedia3040089.

Cook-Chennault, K., Villanueva Alarcón, I., & Jacob, G. (2022). Usefulness of Digital Serious games in Engineering for Diverse Undergraduate Students. *Education Sciences*, *12*(1), 27. https://doi.org/10.3390/educsci12010027.

Darling-Hammond, L., Flook, L., Cook-Harvey, C., Barron, B., & Osher, D. (2020). Implications for educational practice of the science of learning and development. *Applied Developmental Science*, *24*(2), 97–140. https://doi.org/10.1080/10888691.2018.1537791.

de Hei, M., Tabacaru, C., Sjoer, E., Rippe, R., & Walenkamp, J. (2020). Developing intercultural competence through collaborative learning in international higher education. *Journal of Studies in International Education*, *24*(2), 190–211. https://doi.org/10.1177/1028315319826226.

Dehghanzadeh, H., Farrokhnia, M., Dehghanzadeh, H., Taghipour, K., & Noroozi, O. (2023). Using gamification to support learning in K-12 education: A systematic literature review. *British Journal of Educational Technology*. https://doi.org/10.1111/bjet.13335.

Deng, Z. A. (2023). A quantitative overview of the approaches influencing traditional and new teaching methods on technical college students. *Soft Computing*. https://doi.org/10.1007/s00500-023-08276-9.

Dessie, E., Gebeyehu, D., & Eshetu, F. (2024). Motivation, conceptual understanding, and critical thinking as correlates and predictors of metacognition in introductory physics. *Cogent Education*, *11*(1), 2290114. https://doi.org/10.1080/2331186X.2023.2290114.

Díaz, I., González, E. J., González-Miquel, M., & Rodríguez, M. (2024). Application of serious games in chemical engineering courses. *Education for Chemical Engineers*, *46*, 22–32. https://doi.org/10.1016/j.ece.2023.10.002.

Dziob, D. (2020). Board game in physics classes—A proposal for a new method of student assessment. *Research in Science Education*, *50*(3), 845–862. https://doi.org/10.1007/s11165-018-9714-y.

Engeström, Y. (2001). Expansive learning at work: Toward an activity theoretical reconceptualisation. *Journal of Education and work*, *14*(1), 133–156. https://doi.org/10.1080/13639080020028747.

Eriksson, M., Kenward, B., Poom, L., & Stenberg, G. (2021). The behavioral effects of cooperative and competitive board games in preschoolers. *Scandinavian Journal of Psychology*, *62*(3), 355–364. https://doi.org/10.1111/sjop.12708.

Ferdig, R. E., Baumgartner, E., Hartshorne, R., Kaplan-Rakowski, R., & Mouza, C. (Eds.). (2020). *Teaching, technology, and teacher education during the COVID-19 pandemic: Stories from the field*. Association for the Advancement of Computing in Education.

Fernando, P. A., & Premadasa, H. S. (2024). Use of gamification and game-based learning in educating Generation Alpha: A systematic literature review. *Educational Technology & Society*, *27*(2), 114–132. https://doi.org/10.30191/ETS.202404_27(2).RP03.

Fiş Erümit, S. (2021). The distance education process in K–12 schools during the pandemic period: Evaluation of implementations in Turkey from the student perspective. *Technology Pedagogy and Education*, *30*(1), 75–94. https://doi.org/10.1080/1475939X.2020.1856178.

Fonseca, I., Caviedes, M., Chantré, J., & Bernate, J. (2023). Gamification and Game-based Learning as Cooperative Learning tools: A systematic review. *International Journal of Emerging Technologies in Learning (iJET)*, *18*(21), 4–23.

Gennari, R., Matera, M., Melonio, A., Roumelioti, E., Delprino, F., Filaferro, M., Gennaioli, G., & Menabue, V. (2019). Interactive nature: designing smart devices for nature exploration by children.

In *Proc. of the Biannual Conference of the Italian Chapter of SIGCHI 2019-Adjunct Proceedings, CLEUP (CHItaly'19)* (pp. 67–70). ACM, New York, NY. USA. https://doi.org/10.1145/nnnnnnn.nnnnnnn.

Gök, M., & İnan, M. (2021). Sixth-grade students' experiences of a digital game-based learning environment: A didactic analysis. *JRAMathEdu (Journal of Research and Advances in Mathematics Education)*, *6*(2), 142–157. https://doi.org/10.23917/jramathedu.v6i2.13687.

Hayati, M. N., Fatkhurrohman, M. A., & Aprillia, N. (2022). The Sciencemopoly Game to improve junior high school students' learning motivation on the digestive system topic. In *AIP Conference Proceedings* (Vol. 2600, No. 1, p. 020008). AIP Publishing LLC. https://doi.org/10.1063/5.0117688.

Högberg, J., Hamari, J., & Wästlund, E. (2019). Gameful Experience Questionnaire (GAMEFULQUEST): An instrument for measuring the perceived gamefulness of system use. *User Modeling and User-Adapted Interaction*, *29*(3), 619–660. https://doi.org/10.1007/s11257-019-09223-w.

Hassan, R., Jafferi, N. A., Boon, Y., Ahmad, J., Hassan, Z., & Bajuri, M. R. (2022). Professional learning community's practices: Exploring malaysian primary school teacher strategies. MOJEM: *Malaysian Online Journal of Educational Management, 10*(4), 74–91.

Hou, H. T., Wu, C. S., & Wu, C. H. (2023a). Evaluation of a mobile-based scaffolding board game developed by scaffolding-based game editor: Analysis of learners' performance, anxiety and behavior patterns. *Journal of Computers in Education*, *10*(2), 273–291. https://doi.org/10.1007/s40692-022-00231-1.

Hou, H. T., Fang, Y. S., & Tang, J. T. (2023b). Designing an alternate reality board game with augmented reality and multi-dimensional scaffolding for promoting spatial and logical ability. *Interactive Learning Environments*, *31*(7), 4346–4366. https://doi.org/10.1080/10494820.2021.1961810.

Hung, C. Y., Lin, Y. T., Yu, S. J., & Sun, J. C. Y. (2023). Effects of AR-and VR-based wearables in teaching English: The application of an ARCS model-based learning design to improve elementary school students learning motivation and performance. *Journal of Computer Assisted Learning*. https://doi.org/10.1111/jcal.12814.

Hwang, G. J., Wu, P. H., & Chen, C. C. (2012). An online game approach for improving students' learning performance in web-based problem-solving activities. *Computers & Education*, *59*(4), 1246–1256. https://doi.org/10.1016/j.compedu.2012.05.009.

Hymel, S., & Katz, J. (2019). Designing classrooms for diversity: Fostering social inclusion. *Educational Psychologist*, *54*(4), 331–339. https://doi.org/10.1080/00461520.2019.1652098.

Janakiraman, S., Watson, S. L., Watson, W. R., & Newby, T. (2021). Effectiveness of digital games in producing environmentally friendly attitudes and behaviors: A mixed methods study. *Computers & Education*, *160*, 104043. https://doi.org/10.1016/j.compedu.2020.104043.

Kaimara, P., Deliyannis, I., Oikonomou, A., & Fokides, E. (2021). Waking up in the morning (WUIM): A smart learning environment for students with learning difficulties. *Technologies 2021*, *9*(3), 50. https://doi.org/10.3390/technologies9030050.

Kaimara, P., Deliyannis, I., & Oikonomou, A. (2022). Content Design for Inclusive Educational environments. *Inclusive Digital Education* (pp. 97–121). Springer International Publishing. https://doi.org/10.1007/978-3-031-14775-3_6.

Kalogiannakis, M., Papadakis, S., & Zourmpakis, A. I. (2021). Gamification in science education. *A Systematic Review of the Literature Education Sciences*, *11*(1), 22. https://doi.org/10.3390/educsci11010022.

Khoushaini, N. A. M., Mohd, S. M., Kamarudin, S., Jan, N. M., & Wahab, A. N. (2022). Trend on gamification approach in learning and teaching. In *E-Proceeding Insan Junior Researchers International Conference 2021* (iJURECON 2021), Nilai, Malaysia (pp. 50–53)

Khan, M. N., Ashraf, M. A., Seinen, D., Khan, K. U., & Laar, R. A. (2021). Social media for knowledge acquisition and dissemination: The impact of the COVID-19 pandemic on collaborative learning driven social media adoption. *Frontiers in Psychology, 12*, 648253.

Komalawardhana, N., & Panjaburee, P. (2023). Trends and development of technology-enhanced personalised learning in science education: A systematic review of publications from 2010 to 2022. *Journal of Computers in Education*, 1–22. https://doi.org/10.1007/s40692-023-00276-w.

Kumar, P., Sahani, J., Rawat, N., Debele, S., Tiwari, A., Emygdio, A. P. M., & Pfautsch, S. (2023). Using empirical science education in schools to improve climate change literacy. *Renewable and Sustainable Energy Reviews*, *178*, 113232. https://doi.org/10.1016/j.rser.2023.113232.

Kuo, W. C., & Hsu, T. C. (2020). Learning computational thinking without a computer: How computational participation happens in a computational thinking board game. *The Asia-Pacific Education Researcher*, *29*, 67–83. https://doi.org/10.1007/s40299-019-00479-9.

Lameras, P., & Arnab, S. (2021). Power to the teachers: An exploratory review on artificial intelligence in education. *Information*, *13*(1), 14. https://doi.org/10.3390/info13010014.

Lebron, M., Swab, R. G., & Bruns, R. (2024). Students as game designers and developers: Developing cooperative strategy board games to teach team leadership skills. *Organization Management Journal*, ahead-of-print, *21*(1), 41–48. https://doi.org/10.1108/OMJ-03-2023-1783.

Leontiev, A. N. (1981). The problem of activity in psychology. In J. V. Wertsch, & Trans (Eds.), *The concept of activity in soviet psychology* (pp. 37–71). M.E. Sharpe.

Li, F., Wang, X., He, X., Cheng, L., & Wang, Y. (2022). The effectiveness of unplugged activities and programming exercises in computational thinking education: A Meta-analysis. *Education and Information Technologies*, *27*(6), 7993–8013. https://doi.org/10.1007/s10639-022-10915-x.

Li, J., Lin, Y., Sun, M., & Shadiev, R. (2023). Socially shared regulation of learning in game-based collaborative learning environments promotes algorithmic thinking, learning participation and positive learning attitudes. *Interactive Learning Environments*, *31*(3), 1715–1726. https://doi.org/10.1080/10494820.2020.1857783.

Lin, Y. T., & Cheng, C. T. (2022). Effects of Technology-Enhanced Board Game in Primary Mathematics Education on Students' learning performance. *Applied Sciences*, *12*(22), 11356. https://doi.org/10.3390/app122211356.

Lin, Y. C., & Hou, H. T. (2022). The evaluation of a scaffolding-based augmented reality educational board game with competition-oriented and collaboration-oriented mechanisms: Differences analysis of learning effectiveness, motivation, flow, and anxiety. *Interactive Learning Environments*, *32*(2), 502–521. https://doi.org/10.1080/10494820.2022.2091606.

Lin, H. C. K., Lin, Y. H., Wang, T. H., Su, L. K., & Huang, Y. M. (2021). Effects of incorporating augmented reality into a board game for high school students' learning motivation and acceptance in health education. *Sustainability*, *13*(6), 3333. https://doi.org/10.3390/su13063333.

Lochmiller, C. R. (2021). Conducting thematic analysis with qualitative data. *The Qualitative Report*, *26*(6), 2029–2044. https://doi.org/10.46743/2160-3715/2021.5008.

Madariaga, L., Allendes, C., Nussbaum, M., Barrios, G., & Acevedo, N. (2023). Offline and online user experience of gamified robotics for introducing computational thinking: Comparing engagement, game mechanics and coding motivation. *Computers & Education*, *193*, 104664. https://doi.org/10.1016/j.compedu.2022.104664.

Mat, H., & Yusoff, N. A. N. (2019). The Effect of Edutainment on higher Order thinking skills among Year five students. *International Journal of Academic Research in Progressive Education and Development*, *8*(4), 55–65. https://doi.org/10.6007/IJARPED/v8-i4/6435.

Melo, C., Madariaga, L., Nussbaum, M., Heller, R., Bennett, S., Tsai, C. C., & van Braak, J. (2020). Educational technology and addictions. *Computers & Education, 145*, 103730. https://doi.org/10.1016/j.compedu.2019.103730.

Meekaew, K., & Yasri, P. (2020). MicroEvo: An educational game to enhance high school students' learning performance of microevolution. *International Journal of Innovation Creativity and Change*, *13*(8), 1333–1345.

Miculob, O., Caballo, M. L., Alivio, J. M., & Epong, S. M. (2022). ATP (Adenosine triphosphate) Quest: Board game on Cellular respiration for Face-to-face and remote learning. *International Journal of Science Education and Teaching*, *1*(3), 128–159.

Montejo Bernardo, J. M., & Fernández González, A. (2021). Chemical Battleship: Discovering and learning the periodic table playing a didactic and Strategic Board game. *Journal of Chemical Education*, *98*(3), 907–914. https://doi.org/10.1021/acs.jchemed.0c00553.

Montiel, I., Delgado-Ceballos, J., Ortiz-de-Mandojana, N., & Antolin-Lopez, R. (2020). New ways of teaching: Using technology and mobile apps to educate on societal grand challenges. *Journal of Business Ethics*, *161*, 243–251. https://doi.org/10.1007/s10551-019-04184-x.

Musick, G., Freeman, G., & McNeese, N. J. (2021). Gaming as family time: Digital game co-play in modern parent-child relationships. *Proceedings of the ACM on Human-Computer Interaction*, *5*(CHI PLAY), pp1–25. https://doi.org/10.1145/3474678.

Navarro-Espinosa, J. A., Vaquero-Abellán, M., Perea-Moreno, A. J., Pedrós-Pérez, G., Martínez-Jiménez, M. P., & Aparicio-Martínez, P. (2022). Gamification as a promoting Tool of Motivation for creating sustainable higher Education Institutions. *International Journal of Environmental Research and Public Health*, *19*, 2599. https://doi.org/10.3390/ijerph19052599.

Nordin, N., Nordin, N. R. M., & Omar, W. (2022). REV-OPOLY: A study on Educational Board game with web-based Augmented reality. *Asian Journal of University Education*, *18*(1), 81–90. https://doi.org/10.24191/ajue.v18i1.17172.

Novak, R. T., Bailey, E. G., Blinsky, B. D., Soffe, B. W., Patterson, D., Ockey, J., & Jensen, J. L. (2022). Verbalised studying and elaborative interrogation in the virtual classroom: Students with social anxiety prefer working alone, but working with a peer does not hurt their learning. *Journal of Microbiology & Biology Education*, *23*(1), e00232–e00221. https://doi.org/10.1128/jmbe.00232-21.

Parks, M. B. (2023). An Original-Design Board Game to Increase Student Comprehension of Cellular Respiration Pathways. *CourseSource 10*, 1–8. https://doi.org/10.24918/cs.2023.6.

Parry, D. A., Davidson, B. I., Sewall, C. J., Fisher, J. T., Mieczkowski, H., & Quintana, D. S. (2021). A systematic review and meta-analysis of discrepancies between logged and self-reported digital media use. *Nature Human Behaviour*, *5*(11), 1535–1547. https://doi.org/10.1038/s41562-021-01117-5.

Perez-Aranda, J., Medina-Claros, S., & Urrestarazu-Capellán, R. (2023). Effects of a collaborative and gamified online learning methodology on class and test emotions. *Education and Information Technologies*, *29*, 1823–1855. https://doi.org/10.1007/s10639-023-11879-2.

Phang, F. A., Khamis, N., Nawi, N. D., & Pusppanathan, J. (2020). TIMSS 2019 Science Grade 8: Where is Malaysia standing? *ASEAN Journal of Engineering Education*, *4*(2), 37–43. https://doi.org/10.11113/ajee2020.4n2.10.

Picciano, A. G. (2021). Theories and frameworks for online education: Seeking an integrated model. *A guide to administering distance learning* (pp. 79–103). Brill.

Pintrich, P., Smith, D., García, T., & McKeachie, W. (1991). *A manual for the use of the motivated strategies for learning questionnaire (MSLQ)*. University of Michigan.

Qureshi, M. A., Khaskheli, A., Qureshi, J. A., Raza, S. A., & Yousufi, S. Q. (2023). Factors affecting students' learning performance through collaborative learning and engagement. *Interactive Learning Environments*, *31*(4), 2371–2391. https://doi.org/10.1080/10494820.2021.1884886.

Qiao, S., Yeung, S. S. S., Zainuddin, Z., Ng, D. T. K., & Chu, S. K. W. (2023). Examining the effects of mixed and nondigital gamification on students' learning performance, cognitive engagement and course satisfaction. *British Journal of Educational Technology, 54*(1), 394–413. https://doi.org/10.1111/bjet.13249.

Rahma, H., Leng, C. O., & Mashudi, R. (2020). Innovative Educational practice for impactful teaching strategies through scaffolding method. *Asian Journal of University Education*, *16*(4), 53–60.

Rashid, S. A., Iksan, Z. H., Razak, A., Yusof, K., A., & Salleh, M. (2021). Reviewing Science Education Research in Socioculture Perspective. *Borneo International Journal of Education (BIJE)*, *2*, 1–8. https://jurcon.ums.edu.my/ojums/index.php/bije/article/view/4108.

Rahmawati, S. (2022). Indonesian students' motivation in online learning: A case study at translating and interpreting course (Doctoral Dissertation, Universitas Siliwangi).

Renau, M. L. R. (2023). Exploring methodological approaches in secondary education in Castellón, Spain: A comparative analysis of traditional, blended, and innovative teaching. *Futurity Education*, *3*(4), 232–254. https://doi.org/10.57125/FED.2023.12.25.14.

Rodríguez-Ferrer, J. M., Manzano-León, A., Aguilar-Parra, J. M., & Cangas, A. (2023). Effectiveness of gamification and game-based learning in Spanish adolescents with dyslexia: A longitudinal quasi-experimental research. *Research in Developmental Disabilities*, *141*, 104603. https://doi.org/10.1016/j.ridd.2023.104603.

Rogti, M. (2024). The effect of mobile-based interactive multimedia on thinking engagement and cooperation. *International Journal of Instruction*, *17*(1), 673–696. https://doi.org/10.29333/iji.2024.17135a.

Safkolam, R., Madahae, S., & Saleah, P. (2024). The effects of inquiry-based learning activities to understand the nature of science of science student teachers. *International Journal of Instruction*, *17*(1), 479–496. https://doi.org/10.29333/iji.2024.17125a.

Sellami, A. L., Al-Ali, A., Allouh, A., & Alhazbi, S. (2023). Student attitudes and interests in STEM in Qatar through the Lens of the Social Cognitive Theory. *Sustainability*, *15*(9), 7504. https://doi.org/10.3390/su15097504.

Silalahi, R. M. (2019). Understanding Vygotsky 's zone of proximal development for learning. *Polyglot: Jurnal Ilmiah*, *15*(2), 169–186. https://doi.org/10.19166/pji.v15i2.1544.

Singh, C. K. S., Lebar, O., Kepol, N., Rahman, R. A., & Mukhtar, K. A. M. (2017). An observation of classroom assessment practices among lecturers in selected Malaysian higher learning institutions. *Malaysian Journal of Learning and Instruction, 14*(1), 23–61. https://doi.org/10.32890/mjli2017.14.1.2.

Sousa, V. E. C., Matson, J., & Dunn Lopez, K. (2017). Questionnaire adapting: Little Changes Mean a Lot. *Western Journal of Nursing Research*, *39*(9), 1289–1300. https://doi.org/10.1177/0193945916678212.

Sousa, C., Rye, S., Sousa, M., Torres, P. J., Perim, C., Mansuklal, S. A., & Ennami, F. (2023). Playing at the school table: Systematic literature review of board, tabletop, and other analog game-based learning approaches. *Frontiers in Psychology*, *14*, 1160591. https://doi.org/10.3389/fpsyg.2023.1160591.

Stark, E. (2019). Examining the role of motivation and learning strategies in student success in online versus face-to-face courses. *Online Learning*, *23*(3), 234–251. https://doi.org/10.24059/olj.v23i3.1556.

Suhaili, A., Osman, K., Effendi, M., & Matore, E. M. (2020). Issues and challenges of subject Leadership Competency for Malaysian head of Science Panels (HoSP). *International Journal of Academic Research in Progressive Education and Development*, *9*(2), 229–241. https://doi.org/10.6007/IJARPED/v9-i2/7296.

Sun, L., Guo, Z., & Hu, L. (2023). Educational games promote the development of students' computational thinking: A meta-analytic review. *Interactive Learning Environments*, *31*(6), 3476–3490. https://doi.org/10.1080/10494820.2021.1931891.

Syamsuddin, S. (2022). History and phenomenology of Islamic Education in Mualaf Villages. *Khalifa: Journal of Islamic Education*, *6*(1), 43–72.

Taşkın, N., & Kılıç Çakmak, E. (2023). Effects of gamification on behavioral and cognitive engagement of students in the online learning environment. *International Journal of Human–Computer Interaction*, *39*(17), 3334–3345. https://doi.org/10.1080/10447318.2022.2096190.

Teppo, M., Soobard, R., & Rannikmäe, M. (2021). Grade 6 & 9 student and teacher perceptions of teaching and learning approaches in relation to Student Perceived Interest/Enjoyment towards Science Learning. *Journal of Baltic Science Education*, *20*(1), 119–133. https://doi.org/10.33225/jbse/21.20.119.

Tocaimaza-Hatch, C. C., & Santo, J. (2020). Social interaction in the Spanish classroom: How proficiency and linguistic background impact vocabulary learning. *Language Teaching Research*, *27*(5), 1142–1166. https://doi.org/10.1177/1362168820971468.

Tsai, Y. L., & Tsai, C. C. (2020). A meta-analysis of research on digital game-based science learning. *Journal of Computer Assisted Learning*, *36*(3), 280–294. https://doi.org/10.1111/jcal.12430.

Tsai, J. C., Liu, S. Y., Chang, C. Y., & Chen, S. Y. (2021). Using a board game to teach about sustainable development. *Sustainability*, *13*(9), 4942. https://doi.org/10.3390/su13094942.

Unger, K., & Novak, J. (2011). *Game development essentials: Mobile game development*. Delmar Learning.

Urrea, C., Delong, K., Diaz, J., Klopfer, E., Thompson, M., Wagh, A., Gardony, J., Anderson, E., & Kundargi, R. (2022). MIT full STEAM ahead: Bringing Project-Based, collaborative learning to remote learning environments. *University and School Collaborations during a Pandemic: Sustaining Educational Opportunity and Reinventing Education*, 299–319. https://library.oapen.org/bitstream/handle/20.500.12657/50966/978-3-030-82159-3.pdf#page=296.

Valiente, C., Swanson, J., DeLay, D., Fraser, A. M., & Parker, J. H. (2020). Emotion-related socialisation in the classroom: Considering the roles of teachers, peers, and the classroom context. *Developmental Psychology*, *56*(3), 578. https://doi.org/10.1037/dev0000863.

Virata, R. O., & Castro, J. D. L. (2019). Augmented reality in science classroom: Perceived effects in education, visualisation and information processing. In *Proceedings of the 10th International Conference on E-Education, E-Business, E-Management and E-Learning* (pp. 85–92). ACM. https://doi.org/10.1145/3306500.3306556.

Vygotsky, L. S. (1978). *Mind in society*. Harvard University Press.

Wang, M., & Zheng, X. (2021). Using game-based learning to support learning science: A study with middle school students. *The Asia-Pacific Education Researcher*, *30*, 167–176. https://doi.org/10.1007/s40299-020-00523-z.

Yang, K. L., & Chen, C. Y. (2023). Effects of non-digital games integrated with digital games for advancing fifth graders' spatial reasoning abilities. *Education and Information Technologies*, 29, 6341–6356. https://doi.org/10.1007/s10639-023-12096-7.

Zeybek, N., & Saygı, E. (2024). Gamification in education: Why, where, when, and how? A systematic review. *Games and Culture*, *19*(2), 237–264. https://doi.org/10.1177/15554120231158625.

Zhang, R., & Zou, D. (2022). Types, features, and effectiveness of technologies in collaborative writing for second language learning. *Computer Assisted Language Learning*, *35*(9), 2391–2422. https://doi.org/10.1080/09588221.2021.1880441.

Zhu, M., & Zhang, K. (2023). Promote collaborations in online problem-based learning in a user experience design course: Educational design research. *Education and Information Technologies*, *28*(6), 7631–7649. https://doi.org/10.1007/s10639-022-11495-6.

Zourmpakis, A. I., Kalogiannakis, M., & Papadakis, S. (2023). Adaptive gamification in science education: An analysis of the impact of implementation and adapted game elements on students' motivation. *Computers*, *12*(7), 143. https://doi.org/10.3390/computers12070143.