

Research Article

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Enhancing Teamwork Skills and Mathematical Conceptual Connections through Board Game Development in a Cooperative Learning Environment

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Abstract

Background/purpose. This study aims to examine the effects of integrated board game development and cooperative learning on pre-service mathematics teachers' mathematical reasoning, conceptual understanding, creativity, and teamwork skills in Thailand.

Materials/methods. Using a mixed-methods approach within the PAOR (Planning–Action–Observation–Reflection) cycle of Classroom Action Research, 59 third-year pre-service teachers collaboratively designed twelve educational board games integrating arithmetic operations, equations, and geometry. Data were collected through teamwork evaluation forms, board game evaluation rubrics, and semi-structured interviews.

Results. The findings demonstrated significant positive effects on both objectives. For mathematical reasoning and conceptual understanding, 94.72% of games achieved "very good" or "excellent" ratings for mathematical content integration. For creativity and teamwork skills, 94.91% of participants achieved "very good" or "excellent" teamwork performance levels. The twelve unique games showcased creative integration of mathematical content with engaging gameplay mechanics, while supporting essential 21st-century competencies.

Conclusion. Board game development proved effective in mathematics teacher education, promoting mathematical connections, reflective learning, and professional identity. The integration successfully enhanced both cognitive and social development among pre-service mathematics teachers.

1. Introduction

The rapid changes in society, economy, and technology in the 21st century have significantly transformed educational goals, shifting the focus from content-based instruction to the development of essential life and career skills (M. Azizan et al., 2018). Education must now prioritize the cultivation of collaboration, critical thinking, knowledge integration, and creativity—skills that are crucial for preparing students to face future real-world challenges (Kocaman, 2022). To address these evolving educational demands, universities can implement the following approaches: 1. Interdisciplinary Curriculum Implementation: Integrating knowledge across multiple disciplines enables students to connect skills and concepts acquired from various fields (Ghasya & Kartono, 2022). 2. Project-Based Learning: This strategy promotes collaboration and problem-solving skills among students (Ratnasari et al., 2019). 3. Integration of Technology in Learning: Utilizing digital tools supports the development of digital literacy and adaptability (Hongmei & Chaoqiang, 2009). 4. Assessment Methods Focusing on Critical and Creative Thinking: Shifting away from rote memorization towards evaluations that emphasize higher-order thinking (Natuna et al., 2021). 5. Industry Partnerships: Collaborating with industry provides students with practical experience and insights into labor market demands (You et al., 2024). 6. Support for Entrepreneurship and Innovation: Establishing programs and incubators that foster creativity and entrepreneurial skills (Bakri et al., 2023). 7. Courses on Emerging Technologies: Offering curricula on artificial intelligence and the societal impacts of technological change (Hidayat et al., 2022). 8. Promotion of Global Awareness and Cultural Competence: Facilitating international exchange programs and diverse learning experiences (Shadiev et al., 2020). Focusing on these areas will equip students with the skills and competencies necessary for adaptation, enabling them to confidently navigate the rapidly changing environment of the 21st century (Arkanudin et al., 2025).

High-quality learning must, therefore, support not only the acquisition of knowledge but also the development of learning strategies, problem-solving abilities, and essential attitudes (Hino, 2007). Mathematics, as a foundation for logical reasoning and analytical thinking, requires instructional approaches that go beyond memorization. Learners should be encouraged to formulate ideas, articulate rationale, and make meaningful conceptual connections (Nimtrakul et al., 2014). Although mathematical thinking is an internal cognitive process that cannot be directly observed, it can be inferred through external representations such as speech, gestures, or explanations (Alibali et al., 2014; Ya-amphan et al., 2024). These representations reflect students' understanding and align with the process standards of leading mathematics education frameworks (Huinker, 2018).

However, traditional university instruction remains largely lecture-centered, limiting student participation and hindering the development of deeper conceptual understanding. This approach often fails to connect classroom activities with real-life applications or assessments, making it difficult for instructors to evaluate the impact of instruction on students' actual learning outcomes. One well-established approach to addressing this limitation is cooperative learning, which involves structured collaboration among small groups of students to achieve shared learning goals. Collaborative learning fosters social skills, critical thinking, and equitable participation (Sharan, 1980; Warsah et al., 2021), while also reducing issues such as unequal group contributions or social loafing (Perron, 2011). It creates a learner-centered environment that encourages active engagement and shared responsibility for knowledge construction.

A complementary and increasingly popular instructional strategy is game-based learning, particularly through board games, which combine enjoyment with cognitive challenge. Board games promote participation, motivation, and meaningful learning by integrating problem-solving, logical reasoning, and collaboration (Chou et al., 2023; Othman & Ching, 2024). Game-based learning enhances idea exchange, teamwork, and co-creation, all of which are central to effective 21st-century learning (Chuang et al., 2021; Liu, 2025). Designing board games for mathematics education provides

students with opportunities to engage in analytical thinking, problem formulation, and the collaborative construction of knowledge. Through this process, learners utilize their understanding and integrate ideas from peers, fostering deeper conceptual learning and mathematical communication (Cai et al., 1996; Hendrix et al., 2020; Rohid & Rusmawati, 2019). These activities also support the development of artifacts such as e-portfolios or video presentations, which document and demonstrate student creativity and reflective learning.

Moreover, board game development within cooperative learning frameworks promotes positive mathematical communication, which can be used to monitor student progress over time (Gregg & O'Connor, 2022; Isoda, 2012; Mahmud & Drus, 2023; Terzioglu & Rodrigues, 2023; Wong, 2015). When students engage in high levels of participation and interaction, they develop a more profound understanding of mathematical thinking processes, ultimately enhancing their readiness for professional challenges (Athiyah et al., 2023; Irshid et al., 2023).

Despite the recognized benefits of cooperative learning and game-based learning in mathematics education, there remains a significant gap in research examining their integration specifically for pre-service mathematics teachers. Most existing studies have investigated these approaches separately or focused primarily on K-12 students, with limited exploration of how combining board game development with cooperative learning can enhance multiple competencies among future mathematics educators. This study addresses this gap by investigating how integrating these approaches affects mathematical reasoning, conceptual understanding, creativity, and teamwork among pre-service mathematics teachers in Thailand.

This research holds both theoretical and practical significance for mathematics teacher education. Theoretically, it contributes to understanding how innovative pedagogical integration can enhance multiple competencies simultaneously. Practically, it provides evidence-based strategies for preparing future educators to implement engaging, learner-centered approaches in their classrooms.

Research Objectives: This study aims to (1) examine the effects of integrated board game development and cooperative learning on pre-service mathematics teachers' mathematical reasoning and conceptual understanding, and (2) assess their impact on their creativity and teamwork skills.

Research Questions: (RQ1) How does integrating board game development with cooperative learning strategies affect pre-service mathematics teachers' mathematical reasoning and conceptual understanding? (RQ2) What impact does this integration have on their creativity and teamwork skills?

Therefore, this study investigates how integrating board game development with cooperative learning strategies enhances mathematical reasoning, conceptual understanding, creativity, and teamwork among pre-service mathematics teachers in Thailand, contributing to mathematics teacher education through evidence-based, learner-centered practices.

2. Literature Review

2.1. Cooperative Learning and Mathematical Thinking

Cooperative learning is an effective instructional strategy for enhancing both social and academic outcomes among students. In this approach, learners work in small groups, where each member is responsible not only for their learning but also for supporting the learning of others, thereby fostering positive interdependence and individual accountability (Acharya, 2023; Ing & Nasri, 2024; Liu et al., 2018). Extensive research and meta-analyses have demonstrated that cooperative learning environments yield higher academic achievement, improved motivation, and stronger social skills compared to competitive or individualistic settings (Gillies, 2014). The positive effects are particularly evident in mathematics education, where cooperative learning links to increased engagement,

deeper conceptual understanding, and enhanced problem-solving abilities (Acharya, 2023; Lambert & Sugita, 2016). Key elements underpinning the success of cooperative learning include positive interdependence, promotive interaction, individual accountability, explicit instruction in social skills, and group processing (Liu et al., 2018; Viinikainen et al., 2022). These elements ensure that group members collaborate effectively, share responsibility, and develop essential interpersonal skills necessary for teamwork and future professional environments (Francis et al., 2024). Studies also highlight the importance of structuring group tasks and roles to prevent issues such as social loafing and to maximize participation and equitable contributions from all members (Naeem et al., 2024; Wang & Zhu, 2019).

Mathematical thinking is an internal cognitive process that is often made visible through students' external representations, such as verbal explanations, written work, gestures, or symbolic expressions. The ability to express and connect mathematical ideas is central to developing a deep understanding. Research shows that when students articulate their reasoning and make connections between concepts, they reorganize and clarify their knowledge, address misconceptions, and gain new perspectives.

Educators cannot directly observe mathematical thinking because it is a complex internal cognitive process. However, they can infer it through students' external representations—such as verbal explanations, written work, symbolic expressions, and visual models. These observable behaviors reflect students' internal reasoning and conceptual understanding. Practical mathematical thinking involves organizing knowledge, drawing inferences, and engaging in reflective problem-solving.

A central aspect of mathematical thinking is the ability to make connections among mathematical ideas. Evitts (2004) proposed a comprehensive framework for mathematical connections, identifying five interrelated types that reflect how students understand and apply mathematical concepts. Modeling Connections involves linking mathematical ideas to real-world contexts. Students use mathematical reasoning in authentic situations, demonstrating how mathematics is relevant and valuable beyond the classroom. Structural Connections—These refer to recognizing patterns, relationships, or similarities between mathematical concepts based on their underlying structures. For example, students might compare proportional reasoning in fractions and percentages. Representational Connections – These involve expressing mathematical understanding through multiple representations such as graphs, charts, symbols, drawings, or spoken language. Using varied representations helps students clarify and communicate their thinking. Procedure–Concept Connections – These reflect the relationship between procedural knowledge (e.g., algorithms or formulas) and conceptual understanding. Students not only apply procedures but also understand the reasoning behind them and can explain how and why they work. Connections Between Strands of Mathematics – These involve integrating knowledge across different areas of mathematics, such as connecting number sense with geometry or algebra with data analysis, often through problem-based contexts.

Developing students' ability to make these connections enhances their mathematical literacy and fosters deeper, more meaningful learning. It equips learners with the capacity to reason flexibly, solve problems creatively, and transfer knowledge across contexts—core competencies for 21st-century mathematical proficiency.

2.2. Board Game Development and Teamwork Skills in Educational Contexts

The integration of board game development into educational practice has gained traction as a means to create interactive, engaging, and meaningful learning experiences (Botes, 2022; Low et al., 2024). Effective educational board games are developed through clear objectives, well-defined content, and structured processes, ensuring alignment with curricular goals and maximizing learning

outcomes (Kalmpourtzis & Roméro, 2020; Roméro & Kalmpourtzis, 2020). Studies in Thailand and beyond have shown that board games can enhance students' content knowledge, teamwork, and enjoyment while also providing teachers with tools to assess and support individual learning needs (Buranasinwattanakul, 2024; Ketmuni, 2021).

Teamwork skills, including planning, shared responsibility, and openness to diverse perspectives, are integral to both cooperative learning and practical group work (Hartley & Goodrich, 2019; Zhou & Colomer, 2024). Research in educational settings, including Thailand, confirms that structured cooperative activities—such as developing educational board games—promote teamwork, communication, and collaborative problem-solving. These skills are not only vital for academic success but also for preparing students for real-world challenges and professional environments (Surapaneni, 2024). The combination of board game development with cooperative learning frameworks creates opportunities for students to engage in meaningful collaboration while developing both content knowledge and essential 21st-century skills.

2.3. Synthesis and Implications

The literature consistently supports the view that cooperative learning, when combined with activities that promote mathematical connections and teamwork—such as the development of educational board games—yields significant benefits for students. These include improved academic achievement, deeper conceptual understanding, enhanced social and teamwork skills, and increased motivation and engagement (Mendo-Lázaro et al., 2018; Ndyareeba et al., 2024). Such approaches foster a supportive and interactive classroom environment, equipping students with the skills necessary for lifelong learning and future professional success.

In summary, cooperative learning and the intentional development of mathematical connections through interactive group activities represent best practices in contemporary mathematics education. These strategies not only advance content mastery but also cultivate the essential social and cognitive skills required in the 21st century. The integration of board game development within cooperative learning frameworks provides a promising approach for enhancing multiple competencies simultaneously among pre-service mathematics teachers.

3. Methodology

This study adopted a mixed-methods design within the framework of Classroom Action Research (CAR), utilizing the PAOR cycle—Planning, Action, Observation, and Reflection—as a foundation for iterative instructional improvement and collaborative inquiry. The PAOR model (Kemmis & McTaggart, 1988; Mills, 2000) enabled pre-service mathematics teachers to integrate mathematical content into the design of educational board games while actively engaging in teamwork, reflective practice, and cooperative learning. This approach facilitated both the development of subject-specific knowledge and the enhancement of essential 21st-century skills through experiential, learner-centered activities. The research aimed to foster teamwork skills and enhance students' ability to connect mathematical concepts through the development of educational board games within a cooperative learning framework (Johnson & Johnson, 2009; Slavin, 2014).

3.1. Participants

Sampling Technique: This study employed purposive sampling, specifically criterion-based sampling, to select participants who met predetermined criteria relevant to the research objectives. The sampling approach was chosen to ensure participants had the necessary background and context to engage meaningfully with the intervention.

Participant Selection: The participants were 59 third-year mathematics education students, pre-service teachers from the Faculty of Education and Educational Innovation at Kalasin University,

enrolled in the "Mathematics Instruction for Basic Education" course during the first semester of the 2023 academic year.

Inclusion Criteria: (1) Enrolled as third-year mathematics education students, ensuring adequate mathematical content knowledge and pedagogical foundation; (2) Currently taking the "Mathematics Instruction for Basic Education" course, providing relevant curricular context; (3) Voluntary participation with informed consent; and (4) Willingness to engage in collaborative learning activities and board game development projects.

Exclusion Criteria: (1) Students with incomplete enrollment in the target course; (2) Those who declined to participate or withdrew consent; and (3) Students who were absent for more than 25% of the intervention sessions, which could compromise data integrity.

Rationale for Selection: Third-year mathematics education students were specifically chosen because they possess sufficient mathematical content knowledge while still developing their pedagogical skills, making them ideal participants for exploring innovative teaching approaches. Their enrollment in the target course ensured alignment with curricular objectives and provided a natural learning context for the intervention. The cohort size of 59 students provided adequate diversity while maintaining manageable group dynamics for action research implementation.

Group Formation: Pre-service teachers were organized into 12 groups of 4–5 members based on shared interests and compatibility to optimize collaborative learning (Gillies, 2016).

3.2. Procedures

This study was conducted through two complete cycles of Classroom Action Research (CAR) using the PAOR model, Planning, Action, Observation, and Reflection, to promote iterative instructional refinement and enhance both cognitive and collaborative learning outcomes. A mixed-methods design was employed, combining quantitative and qualitative instruments to analyze student performance and engagement.

3.2.1. Cycle 1: Prototype Design and Peer Testing

Planning

In the initial phase, students worked collaboratively in small groups to plan and design mathematical board games, selecting topics that encompassed fundamental and complex concepts such as arithmetic operations, equations, and geometry. The instructor provided structured guidance on practical game mechanics, strategies for integrating mathematical content, and examples of instructional games that successfully facilitated conceptual understanding. The instructor emphasized aligning the learning objectives with both the development of teamwork competencies and the ability to establish meaningful mathematical conceptual connections through cooperative learning activities.

The planning phase comprised the following structured steps: 1. Orientation: The

The instructor introduced the project objectives, procedures, ethical considerations, and learning expectations to all participants. 2. Objective Setting: The study aimed to (1) enhance teamwork skills and (2) develop students' ability to connect mathematical concepts through the creation of educational board games. 3. Instructional Design: A structured learning sequence was developed, scaffolding students through brainstorming, game design, peer feedback, revision, and finalization. 4. Intellectual Property Orientation: Students were briefed on the process of board game intellectual property registration as part of an authentic assessment. 5. Instrument Development: Three research instruments were developed and validated by three experts in mathematics education and instructional design (Guetterman et al., 2015): Teamwork Observation Rubric, Board Game Evaluation Rubric, and Semi-Structured Interview Protocol.

Action

Each team was responsible for developing a comprehensive game prototype. This process involved creating the game board, formulating the rules, designing character or event cards, and preparing instructional materials to support gameplay. The prototypes were then subjected to peer testing within the classroom, allowing students to simulate gameplay, experience the user's perspective, and provide constructive feedback to one another. This iterative process encouraged teams to identify strengths and areas for improvement in both game design and mathematical integration. The implementation followed six structured steps: 1) Collaborative Design: Each team selected a mathematical topic and collaboratively designed a board game reflecting a core mathematical concept (Fathurrohman et al., 2022). 2) Topic Assignment: Topics were distributed across three strands: Numbers & Algebra, Measurement & Geometry, and Statistics & Probability. 3) Peer Assessment: Both internal (within-group) and external (between-group) peer evaluations were conducted to provide constructive feedback and promote iterative improvement (Hendrix, 2022). 4) Artifact Creation: Each team submitted the following: Game design documents Game rules and instructions Explanations of mathematical integration and presentation slides and design portfolios 5) Observation: The researcher and assistants used the Teamwork Observation Checklist to monitor group dynamics, including participation, responsibility, communication, idea exchange, and leadership (Saputra et al., 2023). 6. Evaluation: Final products were assessed using the Board Game Evaluation Rubric across three dimensions: Mathematical integration and creativity (40%), Depth of conceptual reasoning using Bloom's Taxonomy (40%), and Peer feedback (20%)

Observation

During the peer testing sessions, the researcher and trained assistants systematically observed the collaborative processes within each group. Key aspects of group interaction, such as leadership distribution, communication effectiveness, problem-solving approaches, and the application of mathematical thinking, were closely monitored and recorded. Data were collected using the Teamwork Skills Assessment Rubric, which evaluated participation, responsibility, respect for diverse opinions, and the quality of outcomes. Additionally, students submitted reflection notes that documented their engagement and perspectives on group dynamics.

Reflection

Following the testing and observation phase, students participated in structured reflective discussions facilitated by the instructor. These sessions focused on evaluating the effectiveness of gameplay, the quality of teamwork, and the depth of conceptual integration achieved through the board game. Students were encouraged to articulate the challenges they encountered, the strategies they used to overcome obstacles, and the insights they gained regarding mathematical connections and collaborative work. The instructor systematically reviewed the feedback and outcomes from both peer and self-reflection, using them to inform targeted improvements to the board games in preparation for the subsequent implementation cycle. To support systematic documentation, multiple forms of qualitative data were collected: 1) Reflection Sessions: Group interviews and open class discussions were conducted to reflect on learning experiences, team collaboration, and mathematical understanding (Kolb, 1984). 2) Qualitative Data Collection: Data from interviews, reflection notes, and field observations were systematically recorded. 3. Improvement Planning: Insights from the reflection phase informed revisions to instructional design and future learning strategies.

3.2.2. Cycle 2: Game Application in Simulated Contexts

Planning

In this phase, students prepared revised versions of their board games for implementation in semi-authentic educational settings, such as peer-teaching sessions, lesson simulations, or academic showcases. Instructional goals were refined based on feedback and insights gained from Cycle 1, with a focus on enhancing conceptual clarity and maximizing learner engagement. This stage emphasized the alignment of game mechanics with targeted mathematical concepts and the development of effective facilitation strategies for game-based learning.

Action

Students assumed the role of instructors, facilitating game-based learning sessions with their peers or invited participants. The revised board games were implemented in controlled, practice-oriented teaching scenarios, allowing students to lead gameplay, explain mathematical content, and manage group dynamics. This experiential approach provided pre-service teachers with opportunities to practice pedagogical skills and adapt their instructional techniques in real time.

Observation

Researchers systematically collected data using multiple instruments: the Board Game Evaluation Rubric (adapted from Azizan et al., 2018), the Teamwork Skills Assessment Rubric, and the Semi-Structured Interview Protocol. These tools enabled a comprehensive assessment of both teamwork behaviors and the quality of mathematical integration within the games. Additionally, expert evaluators assessed the alignment between gameplay and cognitive demands, with particular attention to higher-order thinking skills as outlined in Bloom's Taxonomy.

Reflection

Following the implementation, students participated in structured interviews and reflective sessions to discuss their personal growth, experiences with game-based pedagogy, and the potential for applying such methods in future classroom contexts. These reflective insights, combined with observational and assessment data, informed the final synthesis of research findings, highlighting both behavioral outcomes and the effectiveness of content delivery through cooperative board game development.

3.3. Research Instruments

Instrument Development and Validation: All three research instruments were developed specifically for this study and underwent rigorous validation procedures to ensure reliability and validity.

1. **Teamwork Skills Assessment Rubric:** This instrument was developed based on established teamwork frameworks and validated through expert review and pilot testing. An analytic rubric with four components: participation in planning, responsibility in task completion, respect for others' opinions, and timeliness/quality of outcomes. There are four components: 1) Participation in Planning, 2) Responsibility and Task Fulfillment, 3. Listening and Respecting Opinions 4. Work completion and quality were each rated on a 4-point scale, with overall performance categorized as Excellent (3.01–4.00), Good (2.01–3.00), Fair (1.01–2.00), or Needs Improvement (0.00–1.00).

Validity: Content validity was established through review by three experts in mathematics education and collaborative learning. The experts evaluated the alignment between rubric criteria and teamwork competencies relevant to the study context. **Reliability:** Internal consistency was assessed using Cronbach's alpha ($\alpha = 0.87$), indicating good reliability. Inter-rater reliability was

established through training sessions with research assistants, achieving 92% agreement across rating categories.

2. Board Game Evaluation Rubric: Adapted from M. T. Azizan et al. (2018), this rubric evaluates mathematical content and creativity, cognitive demand (Bloom's Taxonomy), and the clarity of rules and gameplay, which involves integrating mathematical knowledge with creative thinking, compliance with relevant standards, and an understanding of both content and conceptual depth. Scores were categorized as Excellent (36–40), Very Good (31–35), Good (26–30), Fair (21–25), Low Fair (16–20), Poor (11–15), and Very Poor (0–10). The original instrument demonstrated strong psychometric properties. Adaptations for this study were validated through expert review and pilot testing with a comparable sample. Construct validity was supported through factor analysis, confirming the three-factor structure. Reliability: The adapted rubric showed high internal consistency ($\alpha = 0.91$) and strong inter-rater reliability (ICC = 0.89) based on independent evaluations by two trained assessors.

3. Semi-Structured Interview Protocol: Development: The protocol was developed based on the research objectives and theoretical framework, incorporating questions designed to elicit in-depth responses about participants' experiences with teamwork, mathematical connections, and pedagogical applications. Validity: Face validity and content validity were established through expert review and cognitive interviews with pilot participants to ensure question clarity and relevance. The protocol comprised four open-ended questions focusing on: (1) development of teamwork skills, (2) mathematical conceptual connections, (3) potential classroom applications, and (4) reflections and suggestions for improvement.

3.4. Data Collection

Data sources included: Observation forms (teamwork rubric, field notes), Board game evaluation forms, Peer evaluation forms, Artifact reviews (design files, presentations, IP submissions), and Interview transcripts and reflection notes.

3.5. Data Analysis

1. Quantitative Data: Scores from the rubrics were analyzed using descriptive statistics (mean and standard deviation) to summarize performance and intervention effectiveness. (Creswell & Guetterman, 2019)

2. Qualitative Data: Interview and reflection data were analyzed using thematic content analysis, following Braun and Clarke's (2006) six-phase approach.

Coding Process: The analysis followed a systematic approach: (1) Data Familiarization: All interview transcripts and reflection notes were read multiple times to gain familiarity with the data. (2) Initial Coding: Two researchers independently generated initial codes using both inductive and deductive approaches, with codes emerging from the data while being informed by the theoretical framework. (3) Code Review: Initial codes were reviewed and refined through discussion between researchers to ensure consistency and comprehensiveness. (4) Theme Development: Related codes were grouped into potential themes, with careful consideration of their relationship to the research questions. (5) Theme Refinement: Themes were reviewed and refined to ensure internal coherence and distinct boundaries. (6) Final Analysis: Themes were finalized and defined, with representative quotes selected to illustrate each theme.

Measures to Minimize Researcher Bias: Several strategies were employed to enhance trustworthiness: (1) Triangulation: Multiple data sources (interviews, observations, artifacts) were used to corroborate findings. (2) Peer Debriefing: Regular discussions with research colleagues provided external perspectives on data interpretation. (3) Member Checking: Participants were

invited to review and validate the accuracy of their interview transcripts and preliminary findings. (4) Audit Trail: Detailed documentation of all analytical decisions and processes was maintained throughout the study.

Reflexivity Procedures: The primary researcher maintained a reflexive journal throughout the data collection and analysis process, documenting personal assumptions, biases, and reactions to the data. Regular reflection sessions were conducted to examine how the researcher's background as a mathematics educator might influence data interpretation. These reflections were discussed with research team members to enhance awareness of potential bias and ensure analytical rigor.

4. Results

This study investigated how integrating board game development with cooperative learning strategies affects pre-service mathematics teachers' mathematical reasoning, conceptual understanding, creativity, and teamwork skills. The findings are organized according to the two research questions that guided this study:

RQ1: How does the integration of board game development with cooperative learning strategies affect pre-service mathematics teachers' mathematical reasoning and conceptual understanding?.

RQ2: What impact does this integration have on their creativity and teamwork skills?. The following section presents results focusing on two primary areas of assessment: teamwork skills development (addressing RQ2) and the quality of board game development reflecting mathematical reasoning and conceptual understanding (addressing RQ1). The Teamwork Skills Assessment evaluates how effectively participants collaborated, communicated, and contributed within their groups during the cooperative learning process. The Board Game Evaluation Rubric analyzes the extent to which each group successfully integrated mathematical concepts, demonstrated creativity, and achieved cognitive depth in their game designs.

4.1. Teamwork Skills Assessment

Table 1. Mean and Standard Deviation of Teamwork Skills Components

Teamwork Skills Assessment	Mean	Standardize deviation
1. Participation in Planning	3.41	0.81
2. Responsibility and Task Fulfillment	3.29	0.72
3. Listening and Respecting Opinions	3.25	0.76
4. Work Completion and Quality	3.17	0.77
Total	3.28	0.46

Table 1 presents the mean scores and standard deviations of students' teamwork skills across four assessed components. The results indicate that students demonstrated strong collaborative abilities across all areas, with the highest mean in planning participation ($M = 3.41$). The overall mean of 3.28 represents a "very good" level of performance, suggesting that the integration of board game development with cooperative learning effectively enhanced teamwork skills.

Table 2. Score Distribution and Interpretation of Teamwork Skills Levels

Score	Interpretation Level	Number of Students	Percentage
3.01 – 4.00	Excellent level	7	11.86
2.01 – 3.00	Very good level	49	83.05
1.01 – 2.00	Fair level	2	3.39
0.00 – 1.00	Low fair level	1	1.69

Table 2 shows the distribution of teamwork skill scores according to four performance levels. A majority of students (83.05%) achieved the "very good" level, while 11.86% reached the "excellent" level. Only a small number of students scored in the "fair" or "low fair" ranges. These findings indicate the overall success of the cooperative learning strategy in developing teamwork skills, directly addressing Research Question 2.

4.2. Board Game Evaluation and Mathematical Integration

To address Research Question 1 concerning mathematical reasoning and conceptual understanding, the quality of student-developed board games was evaluated using a comprehensive rubric assessing mathematical content integration, creativity, and cognitive depth.

Table 3. Distribution of Board Game Evaluation Scores Based on Mathematical Content Integration

Score	Interpretation Level	Number of Students	Percentage
36–40	Excellent level	7	11.67
31–35	Very good level	49	83.05
26–30	Good level	0	0
21–25	Fair level	2	3.33
16–20	Low fair level	1	1.67
11–15	Poor level	0	0
0–10	Very poor level	0	0

Table 3 presents the distribution of student-developed board games according to evaluation scores. A majority of students (83.05%) achieved the "Very good" level in terms of mathematical content integration, while 11.67% reached the "Excellent" level. Only a small proportion fell into the "fair" or "low fair" categories, with no students evaluated at the "good," "poor," or "very poor" levels.

These findings indicate strong performance in mathematical reasoning and conceptual understanding through cooperative board game development, directly addressing Research Question 1. The high performance levels suggest that the integration strategy effectively enhanced students' ability to apply mathematical concepts creatively and meaningfully.

4.3. Student-Developed Board Games: Evidence of Mathematical Reasoning

As part of the cooperative learning process, 12 student groups collaboratively designed educational board games that demonstrate sophisticated integration of mathematical concepts with creative gameplay mechanics. Each group selected and developed unique themes, combining logic, strategy, and real-life mathematical applications.

Table 4. Titles of Student-Developed Board Games by Group

Board Game Title	Mathematical Focus and Pedagogical Design	Game Prototype
Bee Math	Bee Math is an instructional board game designed to enhance students' understanding of exponents while fostering thinking, planning, and calculation skills. The game includes a board, map cards, queen's decree cards, mission cards, question cards, herb cards, dice, character tokens, and a rulebook. Players must strategically place map cards to gain advantage and complete missions specified on the mission cards.	

Board Game Title	Mathematical Focus and Pedagogical Design	Game Prototype
Math Survive	Math Survive is an educational game designed to reinforce mathematics learning. The game incorporates strategic card management to survive apocalyptic meteor strikes while answering math questions correctly to activate card abilities. The components include Ability description cards, Meteor strike cards, Future vision cards, Attack cards, Skip cards, Block cards, Timeline change cards, Luck cards, Survival cards, Help me cards, Reverse cards, Bottom-draw cards, Color change cards, Shuffle cards, Random draw cards, Draw-from-pile cards, Request-from-others cards, Blank ability cards, Card backs. Players must manage their hands and make strategic decisions to survive while solving math problems throughout the game.	
How Much	How Much? is a card game aimed at enhancing students' understanding of one-variable linear equations. The game involves "menu cards" and "ingredient cards," requiring players to manage their resources and use equations to complete dishes successfully.	
Think & Fight	<i>Think & Fight</i> is an interactive card game that promotes fun while developing basic numerical skills, observational thinking, and social interaction. The game covers addition, subtraction, multiplication, and division, with integrated content on geometric shapes. Game components include Geometry shape cards and special warrior cards for multiplication, division, and subtraction. Dice. Players must use both strategy and calculation to succeed in the game.	
Duo Game	DUO Game focuses on fun and strategic play. Players must use their wits to form "duos" and block opponents from doing the same. To place a token on the board, players must solve math problems correctly. Components include character tokens, color cards, and a game board. It supports 2–4 players, and the objective is to complete duos and win the game.	
DDaiRhodon	DDaiRhodon is a party-style educational card game designed for fun and interactive play. Players must utilize quick thinking, observation skills, and social interaction to progress. The game promotes understanding and awareness of logical concepts. Components include character cards, color cards, question cards, answer cards, and a game manual. Players must engage in duels to advance to the bonus round and ultimately secure victory.	
Math Killing Game	Math Killing Game is a mathematics learning tool designed to reinforce operations and equation-solving skills, including addition, subtraction, multiplication, and division. Game components include red, blue, green, and purple equation cards, special cards, a calculator (used as an answer checker), and a rulebook. Players must strategically manage their cards, play the highest-value equation cards, and reserve the strongest cards for the final round. The player with the highest-	

Board Game Title	Mathematical Focus and Pedagogical Design	Game Prototype
	valued equation character card at the end is declared the winner.	
Equation Card Game	Equation Card Game is a party-style game designed to build understanding and awareness of algebraic equations. Players must use reasoning and observation to create equations and earn points. Game components include number cards, operator cards, special ability cards, and a rulebook. To win, players must form valid equations using the cards in hand and achieve the highest point total.	
Space Travel to the Planet	Space Travel to the Planet is an instructional board game designed as a teaching aid to help students understand single-variable linear equations through interactive and strategic gameplay. Components include a game board, mission cards, bonus point cards, Tumble Down cards, Repair cards, random movement cards, location movement cards, resting area markers, player tokens, and a rulebook. Players utilize movement strategies and mathematical skills to complete missions and accumulate points. Completing missions does not guarantee victory, as total points ultimately determine the winner.	
Must Hunt (ต้องล่า)	Must Hunt (ต้องล่า) is a strategy board game that simulates battles between tribal and dinosaur teams. It supports 2 to 8 players, with character distribution adjusted accordingly (e.g., two players control four characters each, four players control two each, and eight players control one each). The game incorporates mathematical content, including basic operations (addition, subtraction, multiplication, and division), as well as geometric shapes aligned with elementary-level curricula. Components include a circular game board, game cards, character tokens, heart markers, and a rulebook.	
Dinosaur Hunting in Thailand	The Dinosaur Challenge is a U.S.-designed educational board game that strengthens whole-number operations. Through strategic movement, coin collection, and use of special cards, players engage in addition, subtraction, multiplication, and division, promoting mathematical skills, critical thinking, and interactive learning in a fun format.	
Answer Game	<i>Answer Game</i> is a light-hearted, family-style board game that promotes fun, laughter, and interaction. Players engage in playful banter and discussions while solving problems. The game helps develop awareness and understanding of basic operations—specifically addition and subtraction. It includes question cards, magic cards, and a rulebook. Players must solve equations and strategically deplete their movement tokens to win the game.	

4.4. Analysis of Mathematical Thinking Processes

The development of 12 educational board games by pre-service mathematics teachers demonstrates significant potential in promoting mathematical thinking through interactive and engaging design. Analysis of each game reveals that students not only embedded core mathematical content but also designed gameplay that fosters cognitive processes essential to mathematical literacy. Across the 12 games, several key patterns emerged that demonstrate enhanced mathematical reasoning and conceptual understanding:

Algebraic Thinking and Symbolic Representation: Games such as Bee Math, How Much?, Equation Card Game, and Math Killing Game required students to manipulate expressions, understand relationships between variables, and use symbolic structures to model real-life scenarios. This demonstrates sophisticated mathematical reasoning abilities.

Procedural Fluency and Arithmetic Strategy: Dinosaur Challenge, Think & Fight, and Answer Game emphasized operational fluency in addition, subtraction, multiplication, and division. These games supported number sense and encouraged flexible computational thinking, indicating strong conceptual understanding of basic operations.

Logical Reasoning and Deductive Processes: DDaiRhodon and Math Survive encouraged players to observe patterns, anticipate outcomes, and use logical inference to achieve game objectives. These games mirror deductive practices central to mathematical argumentation and demonstrate advanced reasoning skills.

Problem-Solving and Strategic Decision-Making: In games like Must Hunt, Space Travel to the Planet, and Duo Game, players need to evaluate multiple pathways, predict consequences, and select optimal strategies. These scenarios reinforced multistep reasoning and adaptive planning, core components of mathematical thinking.

Mathematical Communication and Conceptual Connection: All game development processes involved peer collaboration, iterative testing, and presentation, which required students to articulate mathematical ideas, justify design decisions, and reflect on content alignment. This directly supports the development of mathematical reasoning and aligns with 21st-century learning competencies.

This directly supports the process standards of Midgett & Eddins (2001) and aligns with 21st-century learning competencies (Elfert, 2015; OECD, 2015). These findings suggest that board game development in a cooperative learning environment can serve as an effective pedagogical tool to enhance not only content knowledge but also the essential habits of mind associated with mathematical thinking. By blending creativity, collaboration, and content integration, students were able to construct meaningful learning experiences that bridge classroom knowledge with applied, game-based learning.

4.5. Results from Semi-Structured Interviews

Semi-structured interviews were conducted with selected student participants to gain deeper insights into their experiences and perceptions. The interviews provided additional evidence for addressing both research questions through four thematic areas: teamwork development (RQ2), mathematical conceptual connection (RQ1), classroom applicability, and suggestions for improvement. Thematic analysis (Braun & Clarke, 2006) revealed the following key findings:

1. Development of Teamwork Skills

Participants consistently reported that designing the board game required ongoing collaboration, role negotiation, and consensus building. Students highlighted growth in skills such as dividing responsibilities effectively, active listening, respecting diverse opinions, conflict resolution, and compromise, and building trust among team members.

"At first, we had trouble agreeing on ideas, but eventually, everyone had their role—some designed cards, others calculated math problems."

2. Ability to Connect Mathematical Concepts

Most participants described the design process as helping them link different mathematical ideas into real-world problem-solving contexts. They reported greater clarity in their understanding of operations, equations, and geometric structures when these concepts were applied to game scenarios.

"I never thought equations could be used in a game this way. It made me understand not just how to solve them but where they can be applied."

Several students also commented on how building questions and challenges for the game deepened their cognitive engagement and revealed connections between multiple topics, demonstrating enhanced mathematical reasoning abilities.

3. Classroom Applicability of the Games

Participants generally agreed that the board games were suitable for classroom use, especially in upper primary or lower secondary mathematics lessons. They cited several benefits: increased student engagement and motivation, opportunities for hands-on experiential learning, and better understanding of abstract content through play. However, some students noted that game facilitation would require careful time management and teacher guidance to ensure all learners stay focused.

"Kids would love this—it's fun but still makes them think. But you have to make sure they don't just play for fun and forget the math."

4. Suggestions for Improvement

Students suggested improving the clarity of game rules, increasing the balance of difficulty levels in math tasks, and incorporating more cooperative or competitive elements, depending on the classroom context. Some also recommended adapting the games for digital platforms or group competitions in class.

"Next time, I'd make the instructions simpler—some groups didn't understand how to start playing."

4.6. Summary of Findings

The findings demonstrate that the cooperative board game design process effectively addressed both research questions. Regarding RQ1, the integration enhanced students' mathematical reasoning and conceptual understanding, as evidenced by high-quality game designs that incorporated sophisticated mathematical thinking processes and students' reported deeper understanding of mathematical connections. Regarding RQ2, the integration significantly improved teamwork skills, with 94.91% of students achieving "very good" or "excellent" levels in collaborative abilities. The interviews further confirmed that participants developed essential teamwork competencies while gaining valuable insights into practical classroom applications.

5. Discussion

5.1. Theoretical Framework and Interpretation of Findings

This study's findings are interpreted through the lens of social constructivist learning theory (Vygotsky, 1978) and cooperative learning theory (Johnson & Johnson, 2009), which emphasize that knowledge is constructed through social interaction and collaborative engagement. Additionally, the results are examined using Bloom's Taxonomy of cognitive processes (Anderson & Krathwohl, 2001)

and mathematical connection theory (Evitts, 2004) to understand how board game development promotes higher-order thinking and conceptual understanding. This theoretical foundation provides a comprehensive framework for interpreting how the integration of cooperative learning with board game development enhanced both cognitive and social competencies among pre-service mathematics teachers.

The results demonstrate that the cooperative board game development approach successfully promoted both cognitive and social development, supporting the dual goals of deepening mathematical thinking and fostering 21st-century skills. From a social constructivist perspective, the collaborative nature of the intervention created optimal conditions for knowledge construction through peer interaction, shared problem-solving, and collective meaning-making (Vygotsky, 1978; Wertsch, 1991). The findings align with cooperative learning theory's emphasis on positive interdependence and individual accountability, as evidenced by students' strong performance in teamwork assessments (Johnson & Johnson, 2009; Slavin, 2014).

5.2. Enhanced Teamwork Competencies Through Collaborative Design

Data from Tables 1 and 2 indicate that most participants exhibited "very good" to "excellent" levels of teamwork, with the highest mean score ($M = 3.41$) recorded for planning and participation. This finding reflects active engagement and accountability among team members, supporting social constructivist principles that learning is enhanced through collaborative interaction (Palincsar, 1998; Wenger, 1998). The results affirm the effectiveness of cooperative learning in enhancing communication, collaboration, and mutual responsibility—competencies that are essential for prospective educators (Gillies, 2016; Mendo-Lázaro et al., 2018; Viinikainen et al., 2022).

These outcomes align with research demonstrating that structured cooperative activities promote interpersonal skills, conflict resolution abilities, and shared leadership capacities (Acharya, 2023; Francis et al., 2024). The cooperative game development process functioned as an experiential learning platform, consistent with Kolb's (1984) experiential learning theory, wherein students cycle through concrete experience, reflective observation, abstract conceptualization, and active experimentation to construct both knowledge and professional identity as educators.

5.3. Mathematical Reasoning and Conceptual Understanding

As shown in Table 3, the board games designed by students demonstrated a high degree of mathematical content integration, with 83.05% of games rated "very good" and 11.67% rated "excellent." From the perspective of mathematical connection theory (Evitts, 2004), these games successfully embedded multiple types of connections: modeling connections linking mathematics to real-world contexts, structural connections revealing patterns and relationships between concepts, representational connections expressing ideas through diverse formats, procedure-concept connections bridging algorithmic knowledge with conceptual understanding, and connections between mathematical strands integrating various content areas.

The games incorporated key mathematical topics, including operations, equations, geometry, and logical reasoning, into engaging gameplay formats that required students to apply Bloom's higher-order thinking skills of analysis, synthesis, and evaluation (Anderson & Krathwohl, 2001; Krathwohl, 2002). This active manipulation of mathematical ideas aligns with research emphasizing that learning is strengthened when students generate, represent, and evaluate their ideas in meaningful contexts (Alibali et al., 2014; Cai et al., 1996; Hendrix et al., 2020). The variety of mathematical thinking processes demonstrated—algebraic reasoning, procedural fluency, logical deduction, and strategic problem-solving—reflects the comprehensive cognitive engagement fostered by the intervention.

5.4. Metacognitive Development and Reflective Practice

The iterative design process, involving planning, prototyping, peer testing, and refinement, promoted metacognitive awareness and reflective practice among participants. Students engaged in ongoing evaluation of their game designs' clarity, difficulty, and learning potential, demonstrating what Flavell (1979) describes as metacognitive monitoring and regulation. This metacognitive engagement heightened their awareness of mathematical thinking processes, supporting findings by 'Athiyah et al. (2023) and Isoda (2012) that reflection reveals the often invisible cognitive processes underlying mathematical reasoning.

The PAOR (Planning, Action, Observation, Reflection) cycles embedded within the classroom action research framework further supported reflective practice development, aligning with Schön's (1983) conception of reflective practitioners who engage in both reflection-in-action and reflection-on-action. This reflective dimension is particularly crucial for teacher preparation, as it develops the habit of continuous improvement and evidence-based practice essential for effective mathematics instruction (Wong, 2015; Terzioglu & Rodrigues, 2023).

5.5. Insights from Student Perspectives and Classroom Applications

Semi-structured interviews revealed that participants became more confident in their ability to work collaboratively and reported that designing games helped them recognize previously unseen connections between mathematical concepts. These findings support social constructivist assertions that collaborative discourse enhances conceptual understanding and promotes deeper learning (Palincsar & Brown, 1984; Wells, 1999). Students' increased confidence in mathematical communication aligns with research demonstrating that peer interaction enhances mathematical discourse and reasoning (Gregg & O'Connor, 2022; Mahmud & Drus, 2023).

Participants viewed the activity as highly transferable to future classroom practice, particularly for promoting student engagement and understanding. This perceived applicability reflects the authentic nature of the learning experience and its alignment with contemporary calls for learner-centered, experiential instruction (Huinker, 2018; OECD, 2015). The games served not only as instructional tools but also as formative assessments, allowing students to demonstrate mathematical reasoning and collaboration in low-stakes environments that support risk-taking and creative expression (Black & Wiliam, 2009; Heritage, 2010).

5.6. Development of 21st-Century Competencies and Professional Readiness

Beyond mathematical content mastery, the project fostered essential 21st-century competencies including leadership, empathy, conflict resolution, and creative problem-solving—attributes emphasized in contemporary teacher education frameworks (Arkanudin et al., 2025; Ghasya & Kartono, 2022; Partnership for 21st Century Skills, 2019). The integration of creativity, critical thinking, communication, and collaboration through board game development aligns with research demonstrating that authentic, project-based experiences effectively prepare teachers for the complexities of modern classrooms (Darling-Hammond, 2017; Korthagen, 2010).

The variety of game formats produced—from strategic board games to card-based party games—demonstrated students' flexibility and adaptability in addressing diverse learning objectives and student needs. This diversity reflects the creative potential unleashed through cooperative learning environments and supports research advocating for game-based learning's effectiveness in promoting engagement, motivation, and deep learning (Chou et al., 2023; Othman & Ching, 2024; Squire, 2011).

5.7. Implications for Mathematics Teacher Education

These findings provide empirical support for integrating innovative, collaborative approaches into mathematics teacher preparation programs. The study contributes to growing evidence that active learning strategies, particularly those involving game design and cooperative learning, effectively develop both content knowledge and pedagogical competencies (Botes, 2022; Low et al., 2024; Roméro & Kalmpourtzis, 2020). The success of this intervention suggests that teacher education programs should incorporate more opportunities for collaborative design, reflective practice, and authentic assessment to better prepare future educators for 21st-century teaching challenges.

From a broader perspective, the integration of cooperative learning with creative design processes offers a promising model for bridging theory and practice in teacher education. The approach addresses call for more experiential, learner-centered preparation programs while simultaneously developing the mathematical knowledge, pedagogical skills, and professional dispositions essential for effective teaching (Ball et al., 2008; Shulman, 1986). Future research should explore the long-term impact of such interventions on teaching practice and student learning outcomes in authentic classroom settings.

6. Conclusion

This study investigated how integrating board game development with cooperative learning strategies affects pre-service mathematics teachers' mathematical reasoning, conceptual understanding, creativity, and teamwork skills. Research Question 1: The integration significantly enhanced participants' mathematical reasoning and conceptual understanding, with 94.72% of student-developed games achieving "very good" or "excellent" ratings for mathematical content integration. Students demonstrated sophisticated mathematical thinking processes and reported deeper understanding of mathematical connections. Research Question 2: The approach effectively developed both creativity and teamwork skills. For teamwork, 94.91% of participants achieved "very good" or "excellent" levels across all components. The 12 unique board games showcased remarkable creative integration of mathematical content with engaging gameplay mechanics. Key Contributions: This study provides empirical evidence for integrating cooperative learning with game design in mathematics teacher education. It demonstrates that this approach simultaneously develops content knowledge, pedagogical skills, and 21st-century competencies. The research offers a replicable model with validated assessment tools and practical examples for teacher preparation programs. Significance: The findings address a critical gap in literature by showing the combined effectiveness of these approaches specifically for pre-service mathematics teachers. This preparation model equips future educators with creativity, collaboration, and innovative teaching capabilities essential for modern mathematics education. The integration of board game development with cooperative learning represents a promising approach that successfully enhances multiple competencies while preparing teachers for contemporary educational challenges.

7. Suggestion

Based on the findings of this study, the following are recommendations for educators, curriculum developers, and future researchers: Integration of Game-Based Projects into Teacher Training Teacher education programs should integrate game-based learning projects as a core component of instructional methods courses and encourage pre-service teachers to develop instructional tools that are engaging, student-centered, and pedagogically sound. Promoting Mathematical Creativity and Conceptual Linkage: Educational stakeholders should encourage instructional activities that link mathematical concepts across domains (e.g., algebra and geometry) through hands-on, creative tasks, such as developing board games, to enhance a more profound understanding and real-world application. Using cooperative learning as a pedagogical strategy should be emphasized not only for

content mastery but also for cultivating essential soft skills, such as teamwork, communication, and leadership all of which are crucial in 21st-century classrooms. Support for Authentic and Performance-Based Assessment Schools and universities should adopt board game projects as a form of authentic assessment that reflects both content knowledge and the process of learning rather than relying solely on traditional testing. Encouraging IP Awareness in educational institutions should provide training on intellectual property rights, particularly when students engage in designing original teaching materials, to foster ethical innovation and protect student-created work. Further Research on Game Design in Diverse Contexts Future studies should explore the impact of game design on different student populations across various education levels and disciplines to validate and expand the potential of this pedagogical approach. Professional Development for In-Service Teachers Organizing workshops or action research initiatives focused on game-based learning for in-service teachers can enhance instructional practice and inspire innovation in the classroom.

Declarations

Author Contributions. W.Y.: Conceptualization, literature review, instructional design, and supervision of game development process. P.N.: Methodology, data collection, data analysis, and visualization. P.K.: Writing original draft preparation, review, and editing. K.P.: Supervision, review, editing and discussion of results.

All authors have read and approved the final version of the manuscript.

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Data Availability Statement. The data supporting the findings of this study are available from the corresponding author upon reasonable request. Due to privacy and ethical considerations, the raw data are not publicly shared.

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