IIAI Open Conference Publication Series
IIAI Letters on Informatics and Interdisciplinary Research
Vol.006, LIIR382
DOI: https://doi.org/10.52731/liir.v006.382

<TechTopia> and Robots: Developing Computational Thinking in Young Learners through a Complex Board Game

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Abstract

This study investigates the effectiveness of using the educational complex board game <TechTopia> to enhance computational thinking (CT) skills among upper-grade elementary students. The game integrates interdisciplinary learning, programming, and robot-related scenarios, providing a hands-on experience that encourages students to apply CT concepts such as pattern recognition, algorithm design, and logical reasoning. It incorporates problem-solving tasks similar to those found in the Bebras challenge, allowing students to engage with real-world-inspired puzzles that support the development of core CT abilities. A pre-test and post-test were administered to measure changes in students' CT abilities, and a satisfaction survey was conducted to assess their engagement and learning experience. The results showed significant improvements in CT skills, with students achieving high accuracy rates, especially in tasks related to data representation, algorithmic thinking, and reverse reasoning. The survey also indicated high levels of student satisfaction, with positive feedback on the game's design, collaborative elements, and its impact on their problem-solving abilities. These findings suggest that game-based learning, such as <TechTopia>, can effectively promote computational thinking and enhance students' critical thinking and problem-solving skills.

Keywords: Game-based Learning, Computational Thinking, Bebras, Robots, Complex Board Game

1 Introduction

In this era of global interconnectedness, educational methods, content, and philosophies have undergone significant transformations. Generation Z has been immersed in technology and culture from an early age [1]. This has profoundly influenced education, placing greater emphasis on diverse learning and the integration of technology.

In recent years, many countries have incorporated computational thinking into their national curricula, encouraging students to develop computational thinking skills as part of their learning process, thereby fostering innovation and problem-solving abilities. For example, in 2016, the Computer Science Teachers Association in the United States introduced the K–12 Computer Science Standards, listing computational thinking as one of the five core concepts. In 2013, the United Kingdom revised its curriculum with the aim of enabling students to use computational thinking and creativity to understand and change the world. In 2014, Australia established its Digital Technologies curriculum, emphasizing the use of computational thinking and information systems to define, design, and implement digital solutions. New Zealand followed suit in 2017

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by releasing its Digital Technologies curriculum, identifying computational thinking as one of two key competencies. These initiatives demonstrate that technologically advanced countries have incorporated the cultivation of computational thinking, along with the study of computer science and information technology, into national education.

Taiwan has also followed this trend. In 2018, the Ministry of Education launched the 12-Year Basic Education Curriculum Guidelines. In the Technology domain for junior high schools and general senior secondary schools, two main components of learning performance are "computational thinking" and "design thinking." In 2020, the National Academy for Educational Research published reference guidelines for the development of science and information education curricula in elementary schools, highlighting computational thinking and problem-solving as key learning outcomes in the field of information education.

The importance of computational thinking in today's generation is self-evident. While the use of board games integrated into various curricula has become increasingly common in recent years, instances of using board games specifically to teach computational thinking remain relatively rare. Therefore, this study aims to use innovative board game teaching to cultivate students' computational thinking skills, thereby enhancing their overall literacy to better face future life challenges and connect with the international community.

The purpose of this study is to engage learners in an interdisciplinary game-based learning curriculum with robots that allows them to explore the relationships between different industries and technologies. Students can apply what they've learned in class to develop computational thinking and critical thinking skills. Collaborate and communicate effectively with peers, integrating interdisciplinary knowledge and technological approaches to solve problems efficiently. In line with the research objectives mentioned above, the study proposes the following research questions:

1. What is the effectiveness of using board game teaching to cultivate computational thinking in upper-grade elementary students?
2. What is the level of satisfaction among upper-grade elementary students regarding game-based learning?

2 Approaches to Developing Computational Thinking

With the rapid advancement of digital technology and the growing influence of global information societies, contemporary issues have become increasingly complex and multifaceted. In response to the 21st-century demand for higher-order thinking and problem-solving skills, Computational Thinking (CT) has garnered significant attention in the field of education and is now regarded as one of the essential core competencies [2]. Closely related to programming, CT is viewed not merely as a technical skill, but as a general, interdisciplinary problem-solving approach applicable across various life and professional contexts.

The concept of computational thinking can be traced back to Papert (1996), who explored its roots in mathematical learning and constructivist theory [3]. Papert suggested that thinking and learning through logic similar to that of computers helps learners construct more explicative, comprehensible, and operable knowledge structures [3]. His view transformed the thinking patterns of computer science into educational tools, laying the groundwork for future development of CT.

It was Wing (2006) who formally defined computational thinking as a conceptual term. In her influential article published in Communications of the ACM, she proposed that CT is a problem-solving process based on principles of computer science [2]. She advocated for the integration of

CT thinking strategies into all disciplines to help students develop logical reasoning and practical problem-solving skills. Wing emphasized that CT should be regarded as fundamental as reading, writing, and arithmetic—basic literacy for all citizens [2].

Subsequent scholars have further clarified the core elements and processes of computational thinking. Selby and Woollard (2010), through a literature review, identified five key characteristics of CT: abstraction, decomposition, algorithmic design, evaluation and optimization, and generalization [4]. These five components outline CT as a systematic and logical problem-solving strategy suited to the complex and dynamic nature of real-world problems.

On a more practical level, the Bebras International Challenge on Informatics and Computational Thinking has contributed to the categorization and assessment of CT competencies. The challenge divides CT into eight major dimensions—abstraction, logic, data analysis, decomposition, algorithms, simulation, systematic evaluation, and generalization—and uses challenging tasks to evaluate students' CT performance across cognitive levels [5]. The tasks are also differentiated by difficulty levels and grade groups, highlighting the potential of CT for curriculum design and educational assessment.

The development of computational thinking is influenced by societal needs, technological evolution, and educational paradigms. At its core, CT is not just about solving technical problems, but about cultivating a way of thinking that is systematic, modular, and logical—essential in processing information and addressing complex issues. With ongoing educational reforms and the growth of digital learning, CT has become a key indicator in shaping modern education policies and curricula.

The coding-only approach has been explored by Piatti et al. [6], who proposed the CT-Cube framework, which integrates cognitive, operational, and social dimensions in computational thinking (CT) activities. By utilizing tools such as Scratch and Blockly, students engage in tasks that foster algorithmic thinking and logical reasoning. This approach is theoretically sound and applicable across various age groups. However, it poses challenges for younger children who may lack basic digital literacy, requiring appropriate curriculum design and strong teacher support for effective implementation.

On the other hand, the game-based approach emphasizes an exploratory, game-based method for cultivating CT in young children. Kopcha and Ocak (2023) highlight the use of tasks like story sequencing and puzzle-solving, where children engage in creative problem-solving without the need for advanced technological tools [7]. This method promotes creativity and self-directed learning, but it is less explicit in teaching CT concepts. Its effectiveness largely depends on the teacher's ability to observe and guide students' learning processes.

The integration of robots into educational contexts has been shown to significantly enhance the development of computational thinking (CT) skills. Huang and Shih (2022) demonstrated that incorporating design thinking into a STEM-based robotic game not only fostered interdisciplinary learning but also provided students with opportunities to engage in logical reasoning, problem decomposition, and algorithmic design—core elements of CT [8]. Similarly, Shih et al. (2017) emphasized the value of technology-integrated maker games, where complex board game mechanics and robotic components acted as tangible tools for learners to explore CT concepts through hands-on experimentation and iterative design [9]. These studies highlight the potential of robotics as an effective medium for promoting computational thinking in engaging, interactive learning environments.

The combination of both game-based activities and coding has shown promising results. Falloon (2024) integrates game-like activities—including complex board game elements—with programming logic, using tools like Bee-Bot to guide students through the concepts of control and sequencing [10]. Su and Yang (2023) also emphasize the effectiveness of combining game-like tasks with programming tools, such as ScratchJr, in fostering CT skills in early childhood education [11]. While this hybrid approach enhances engagement and interaction, it requires careful curriculum design and resource allocation to be fully effective.

3 Game Design

3.1 <TechTopia>

<TechTopia> is an educational, strategy-based cooperative game designed around the core theme of digital sustainability. Through immersive gameplay, players develop a nuanced understanding of how technological advancement drives industrial development, thereby enhancing their interdisciplinary knowledge of both fields.

Players are divided into five elemental nations: Metal, Wood, Water, Fire, and Earth, each possessing unique natural resources and specialized developmental focuses, such as construction, transportation, and healthcare. The overarching goal is to strategically utilize technology cards to construct industries, elevate the nation's technology index, and ultimately achieve a state of digital sustainability.

Each team is composed of three players, each taking on one of the following rotating roles:

a. President – Facilitates internal team discussions and issues official declarations.
b. Minister of Foreign Affairs – Handles cross-team communication using bilingual skills.
c. Minister of Technology – Oversees technology card management, route planning, and program development for robot navigation.

One of the core mechanics of <TechTopia> involves navigating a large game map using the Codey Rocky robot, which is programmed via a block-based interface on a tablet. Players must write efficient code to guide the robot along designated roads to specific locations containing technology cards. If the robot fails to reach its destination in a single run, the player must debug and rewrite the program. This aspect of the game directly fosters computational thinking, particularly in the areas of abstraction, logics, decomposition, algorithms, simulation, and systematic evaluation.

The game incorporates nine major industries and eight core technologies. Players must collect, combine, and trade technology cards through cooperation and negotiation in order to develop these industries. For instance, combining Artificial Intelligence (AI), Auto Machine, and the Internet of Things (IoT) enables the development of textile industry. Nations also have industry-specific advantages that provide bonus points, encouraging teams to align their strategic decisions with their national strengths.

By integrating role-based collaboration, programmable robotics, and strategic decision-making, <TechTopia> provides a holistic learning experience that not only simulates real-world digital transformation but also promotes critical 21st-century skills such as computational thinking, teamwork, systems thinking, and interdisciplinary problem-solving.

3.2 Game Objects

The design of <TechTopia> incorporates a diverse set of game components, each serving a distinct pedagogical or strategic purpose. These components collectively construct a learning environment that simulates real-world technological and industrial development processes.

a. National Profiles:

Players are assigned to one of five elemental nations: Metal, Wood, Water, Fire, or Earth, each with a unique background narrative and development focus. Every nation is associated with three major industries categorized by difficulty levels (easy, medium, and hard). When a team successfully constructs one of its designated national industries, it earns double points, encouraging players to adapt their strategies according to their nation's strengths.

b. Technology–Industry Reference Chart:

A comprehensive formula chart (Figure 1) outlines the relationship between technologies and industries, indicating which combinations of technology cards are required to construct specific industries. This reference aids players in making informed decisions regarding exploration and resource exchange.

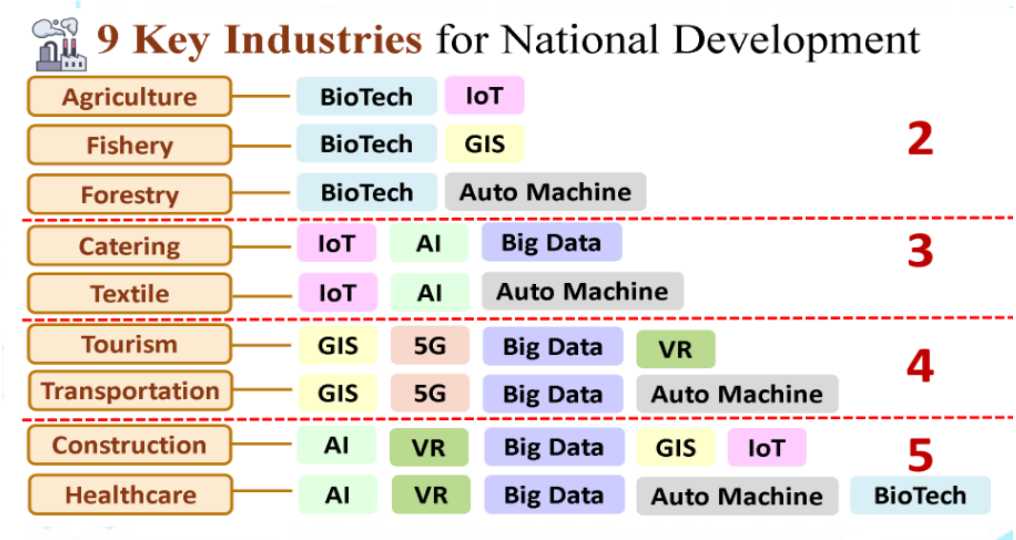

Figure 1: Technology–Industry Reference Chart

c. Game Map:

The game environment consists of a large physical map (Figure 2) measuring 1.7 × 2.4 meters, providing an immersive exploration space. The map features a variety of buildings (e.g., banks, docks, supermarkets) and natural environments (e.g., rivers, parks, mountains), each potentially linked to a specific technology. These locations symbolize real-world applications of technologies and serve as the hiding spots for technology cards. Connecting roads are designated for robot navigation, forming the primary paths for players' movements during gameplay.

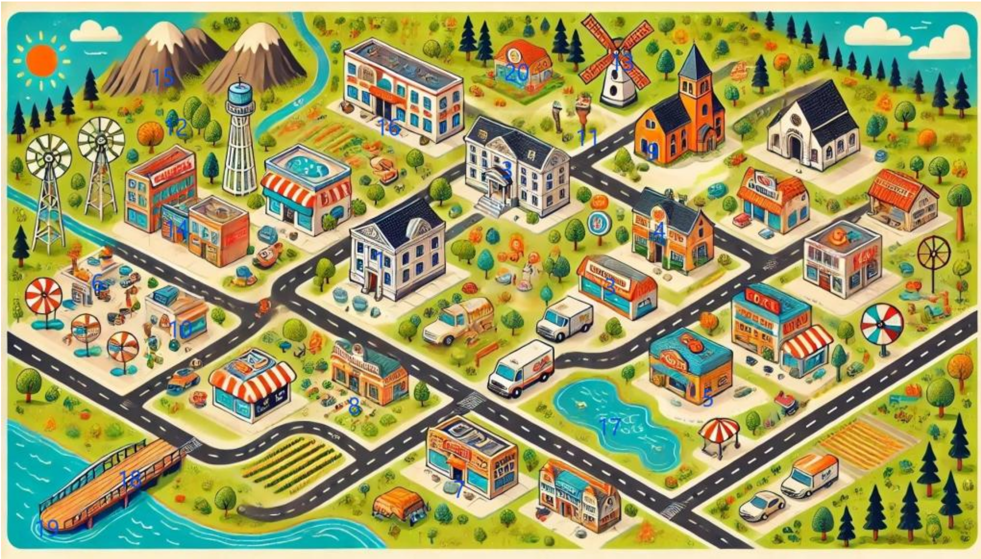

Figure 2: <TechTopia> Game Map

d. Technology Cards:

There are eight categories of technology cards(Figure 3): Biotechnology (BioTech), Internet of Things (IoT), Geographic Information Systems (GIS), Virtual Reality (VR), Artificial Intelligence (AI), Automation (Auto Machine), Big Data, and 5G. These cards are distributed and concealed across the map. Players must interpret the map's visual cues to deduce where specific technologies might be located.

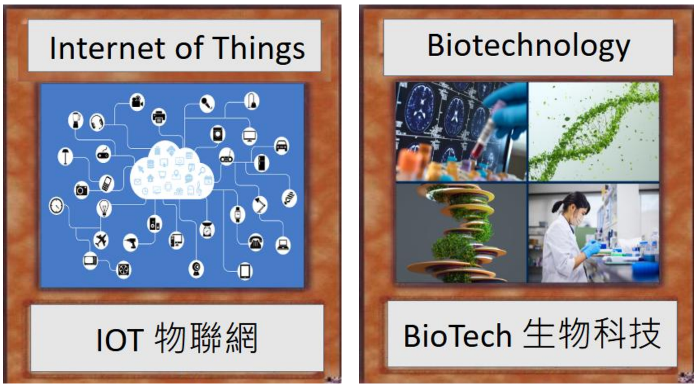

Figure 3: Example of Technology Cards

e. Industry Cards:

Nine types of industry cards are included: Agriculture, Fishery, Forestry, Catering, Textile, Tourism, Transportation, Construction, and Healthcare. Each industry card specifies the number and type of technology cards required for its construction. Industries are also classified by complexity (easy, medium, and hard) with point values adjusted accordingly based on difficulty.

Figure 4: Example of Industry Cards

f. Codey Rocky Robot and Tablet Interface:

Each team is equipped with a Codey Rocky robot (Figure 5), representing their nation's movement across the map. Players use the mBlock app on a tablet to create block-based programs that control the robot's navigation. This interaction introduces students to fundamental programming concepts and enhances computational thinking through hands-on, real-time application.

Figure 5: Codey Rocky Robot

3.3 Game Flow and Mechanics

In <TechTopia>, the gameplay is structured around a team-based, role-play mechanism designed to enhance players' understanding of the relationship between technology and industry. Each team consists of three players who are assigned rotating roles: President, Minister of Foreign Affairs, and Minister of Technology. These roles are rotated across three game rounds, ensuring that each player experiences all responsibilities and develops a holistic understanding of team coordination and strategic planning.

The game progresses through three complete rounds, each divided into five distinct phases (Figure 6).

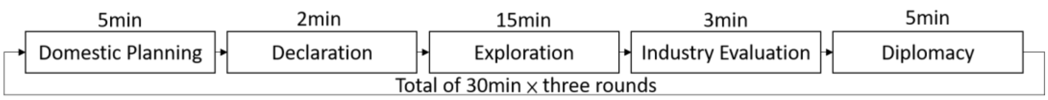

Figure 6: Game Flow

a. Domestic Planning Phase (5 minutes):

In the beginning of each round, the President leads an internal team discussion to determine the team's strategic plan. This includes selecting the target destination on the game map, identifying the industry to be developed, and deciding on the overall approach for the round.

b. Declaration Phase (2 minutes):

Each team publicly announces the specific industry they intend to construct in the current round. This declaration fosters transparency and encourages strategic thinking among teams, as well as anticipation of potential competition or collaboration.

c. Exploration Phase (15 minutes):

The team programs and operates a Codey Rocky robot using a tablet application to navigate the game map. The objective is to reach designated locations and collect technology cards (e.g., AI, Big Data, 5G). Robot movements must comply with map rules, such as following road paths and reaching the destination in a single run. Failure to do so requires the team to rewrite the program and restart the journey. This phase emphasizes computational thinking, programming logic, and problem-solving skills.

d. Industry Evaluation Phase (3 minutes):

After obtaining technology cards, the Game Master evaluates whether each team has successfully combined the required technology cards to form a valid industry. If the combination meets the criteria, the team is awarded the corresponding industry, which contributes to their national technology index.

e. Diplomacy Phase (5 minutes):

Following industry evaluation, teams may engage in technology card exchanges with other nations. This encourages intergroup communication, negotiation skills, and collaborative strategy development.

Across the three rounds, players rotate their roles within the team, ensuring equitable participation and exposure to various aspects of game management. This structure not only simulates real-world policy and decision-making processes but also reinforces players' comprehension of how emerging technologies interrelate with industrial systems in the pursuit of digital sustainability.

4 Research Methods

4.1 Research Structure

This study explores the effectiveness of using <TechTopia> to cultivate computational thinking (CT) in upper-grade elementary students and evaluates their satisfaction. The research was conducted with 30 fifth-grade students from an elementary school. Integrated into the existing block-based programming curriculum, where the game activity was introduced as an additional learning activity toward the end of the semester. The study began with an initial pre-knowledge instruction session focused on block programming, which was delivered over the course of a semester. Before playing the game, a computational thinking pre-test was administered to assess students' baseline CT abilities. Then, the students were introduced to the game <TechTopia>, where they were given instructions on the rules and gameplay. The game itself involved various interactive elements that required students to apply computational thinking concepts such as decomposition, pattern recognition, abstraction, and algorithms. Following the gameplay, students participated in a reflection session to discuss their learning experience and the strategies they used during the game. Finally, a post-test on computational thinking was conducted to measure any improvements in students' CT skills, and a satisfaction survey was administered to evaluate students' perceptions of the game experience. Research Structure is shown in Figure 6.

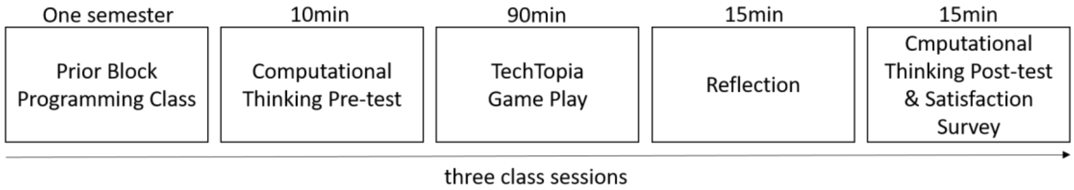

Figure 6: Research Structure

4.2 Research Tools

The study mainly employed quantitative research tools to assess both the development of students' computational thinking and their satisfaction with the learning activity. The primary tools included a pre- and post-test measuring computational thinking skills, adapted from the Bebras Computational Thinking Challenge. The questions in pre- and post-test are the challenges in bebras which features a series of problems and tasks that assess the core computational thinking concepts of Decomposition, Pattern Recognition, Abstraction, and Algorithms. The pre-test and post-test maintain the same underlying concepts, but with different formulations in each test. Pre- and post-test is consist of 7 questions, with a total of 100 points. The pre-test was given before the game to measure students' initial CT abilities, and the post-test was administered afterward to evaluate any changes in their skills. To analyze the effectiveness of the intervention, paired-sample t-tests were used to compare students' pre- and post-test scores.

In addition to the CT tests, a satisfaction survey was designed to gather students' feedback on various aspects of the game-based learning activity. The survey covered ten dimensions, including value, cognition, enjoyment, interaction, difficulty, confidence, identity, innovation, practical application, and expectations. Each of these dimensions was measured through two to three specific questions. Additionally, an open-ended question allowed students to provide qualitative feedback on their experience with the game. The survey responses were analyzed using a five-point Likert scale, and the mean scores for each dimension were calculated to provide a comprehensive view of students' satisfaction. Qualitative feedback from the open-ended questions was analyzed using content analysis to identify recurring themes and provide further insights into students' perceptions and learning experiences.

5 Result

5.1 Learning Effectiveness

The analysis of the seven pre-test (Table 1) CT tasks shows that students performed best on questions involving pattern recognition and abstraction, particularly on easier tasks. In contrast, questions requiring conditional logic, algorithmic optimization, or reverse reasoning had lower accuracy, especially at higher difficulty levels.

Table 1: CT pre-test accuracy

Questions	Difficulty	CT	Correct	Accuracy
Q1	Easy	Pattern Recognition, Abstraction	13	44.8%
Q2	Medium	Algorithmic thinking, Pattern recognition and prediction Pattern Recognition	10	34.5%
Q3	Medium	Data representation, Logical reasoning	11	37.9%
Q4	Medium	Temporal data analysis, Conditional logic	11	37.9%
Q5	Medium	Conditional logic and strategic thinking, Algorithmic thinking	2	6.9%
Q6	Hard	Algorithm design and optimization, Problem decomposition	6	20.7%
Q7	Hard	Data representation, Reverse thinking and logical reasoning	8	27.6%

The post-test results (Table 2) demonstrate significant improvements across all tasks, with students achieving high accuracy rates, particularly in tasks related to pattern recognition, data representation, and logical reasoning. Most notably, Questions 1, 3, and 7 showed a perfect accuracy of 100%, suggesting that students excelled in tasks involving algorithmic thinking, data representation, and reverse reasoning. Additionally, tasks of medium difficulty, such as Q4 and Q6, also saw impressive performance, with accuracy rates reaching 96.6% and 86.2%, respectively.

Table 2: CT post-test accuracy

Questions	Difficulty	CT	Correct	Accuracy
Q1	Easy	Pattern Recognition, Abstraction	26	89.7%
Q2	Medium	Algorithmic thinking, Pattern recognition and prediction Pattern Recognition	29	34.5%
Q3	Medium	Data representation, Logical reasoning	29	100%
Q4	Medium	Temporal data analysis, Conditional logic	28	96.6%
Q5	Medium	Conditional logic and strategic thinking, Algorithmic thinking	25	86.2%
Q6	Hard	Algorithm design and optimization, Problem decomposition	28	96.6%
Q7	Hard	Data representation, Reverse thinking and logical reasoning	29	100%

The improvement from the pre-test to the post-test (Table 3) reflects a clear progression in students' ability to apply computational thinking strategies effectively. This shift suggests that the learning activities successfully enhanced their understanding of key CT aspects such as algorithm design and optimization, conditional logic, and pattern recognition. The high performance across various task types indicates that students have internalized and applied these concepts more effectively, especially in more challenging tasks that required higher-order reasoning and strategic thinking.

Table 3: CT pre- and post-test paired sample T-test

Total Grade	N	Means	SD	t	p
Pre-test	29	30.07	19.215	-15.513^{***}	.000
Post-test	29	95.59	8.654		

$^{***}p < .001$

5.2 Satisfaction

The survey results indicate that students responded positively to the <TechTopia> activity. In terms of their experience using the robot Codey Rocky, students generally agreed that learning to operate the robot and design programs was beneficial for their future learning (M=4.2), found programming engaging (M=4.3), and looked forward to more hands-on opportunities in future activities (M=4.2), although some students still found the robot somewhat difficult to operate (M=3.2). Regarding the game design aspect, students reported that the rules were easy to understand (M=4.2), the challenges were interesting (M=4.4), and they enjoyed collaborating and interacting with peers during the tasks (M=4.1). As for the development of computational thinking (CT), most students indicated that the activity helped them understand the problem-solving process (M=4.2), increased their confidence (M=4.1), and improved their problem-solving ability (M=4.2), while also expressing interest in continuing to learn related skills (M=4.1). Overall, the average satisfaction scores across all three dimensions were above 4.1, demonstrating the activity's effectiveness in promoting learning and engagement.

6 Conclusion

This study explored the use of the <TechTopia> game as an innovative approach to cultivating computational thinking (CT) in upper-grade elementary students. The results indicate significant improvements in students' CT skills, particularly in areas such as algorithmic thinking, pattern recognition, and data representation. The post-test demonstrated enhanced accuracy across various task types, suggesting that the game successfully helped students internalize and apply key computational thinking concepts, especially in more complex tasks. Additionally, students reported high satisfaction with the game-based learning experience. They found the game engaging, collaborative, and beneficial for developing critical problem-solving skills. These findings highlight the effectiveness of game-based learning in fostering computational thinking and suggest that incorporating interactive, hands-on experiences like <TechTopia> can be a valuable tool for promoting 21st-century skills in education.

Acknowledgement

This study is supported in part by the National Science and Technology Council of Taiwan, under NSTC 112-2423-H-008-003-.

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