

Iterative Problem Solving in the Integration of Design Thinking and Game-Based Learning into Enhancing Computational Thinking and AI Literacy

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Abstract: This study examines the effects of combining design thinking with game-based learning (GBL) in an educational environment focused on improving learning achievement, computational thinking skills, and artificial intelligence literacy. Using a one-group pretest-posttest design, this study engaged sixth-grade students to measure the impact of these instructional strategies on their learning achievement. Statistical analyses revealed that students' academic performance improved significantly, with a large effect size (Cohen's $d = 0.90$); computational thinking skills improved significantly, with a small effect size (Cohen's $d = 0.20$); and artificial intelligence literacy improved significantly, with a small effect size (Cohen's $d = 0.35$). These results highlight the potential of combining design thinking with GBL to not only engage students, but also to significantly improve a wide range of educational outcomes in order to prepare them to meet the needs of the digital future. This study highlights the importance of combining design thinking with interactive learning models to optimize student learning and development in current educational environments.

Keywords: Game-Based Learning, Computational Thinking, Artificial intelligence literacy education, Design Thinking

1. Introduction

In recent years, the incorporation of innovative pedagogical methods has changed educational trends. Design Thinking has become a particularly influential approach due to its potential to improve learning outcomes across educational fields. This student-centered, iterative approach to problem solving is being increasingly used in the classroom (Liedtka & Ogilvie, 2011).

Design thinking in education not only fosters students' creativity and innovation, but also equips them with critical thinking and problem-solving skills. According to educational research, adopting this approach significantly improves student engagement, academic achievement, and the development of computational thinking skills.

The popularization of digital technology has facilitated the integration of design thinking and game-based learning (GBL) to create interactive learning environments. Research has shown that combining GBL with design thinking not only makes learning more engaging, but also improves educational outcomes in terms of deepening understanding and maintaining complex concepts (Lengyel, 2020).

This paper explores the impact of implementing a combination of design thinking and game-based learning models in educational environments. It explores how this approach can affect academic performance, improve computational thinking skills, and develop artificial intelligence literacy, in order to help prepare students for an increasingly digital world. While the integration of AI-based image recognition technologies in educational settings has been explored, there is still a lack of research that combines computational thinking, design thinking, and AI literacy into one curricular framework. This study seeks to fill this gap by introducing an

innovative curriculum that integrates these elements. The continuing development of instructional strategies will allow this area of research to continue to be an important area of research for optimizing student learning and development (Wong, 2024).

2. Literature Review

2.1 Game-Based Learning

Game Based Learning (GBL) utilizes game elements in the educational environment to create engaging and interactive learning experiences. It improves learning by utilizing the motivating factors of competition, challenge and immediate feedback in games (Hartt et al., 2020). Research has shown that GBL can increase student engagement, provide immediate feedback, and offer personalized learning paces, making it an effective tool in various educational contexts (Gillespie, 2022).

GBL has been widely researched and applied to improve learning motivation and engagement, particularly in mathematics and computer science. By incorporating interactive and competitive game elements, GBL facilitates students' understanding and application of complex concepts (Kalogiannakis et al., 2021). Game-based learning has significant effects in computer science education, especially on developing students' computational thinking (CT).

Studies indicate that learning through games can enhance students' motivation and engagement, helping them learn complex concepts and skills in an interactive and enjoyable environment (Kaldarova et al., 2023). For example, in elementary and secondary education, using block-based programming tools like Scratch and Blockly to teach basic programming not only helps students intuitively grasp programming logic, but also fosters their creativity and problem-solving abilities (Panskyi & ROWINSKA, 2021).

2.2 Computational Thinking

Learning to think computationally is an important skill for modern learners. Computational thinking is widely recognized as an element of each child's education that is essential (Wing, 2006). Brennan and Resnick (2012) found that using tools to facilitate students' understanding of the concepts of sequences, loops, and conditionals is one way to develop students' CT skills. The process of CT teaching methods needs to be visible, with children receiving immediate feedback.

Authors (2022) suggested that CT board games are interactive games which allow students to engage in discussion with a partner and make their thinking visible through the mechanics of the game. The divisible steps and specific actions in the game tasks are helpful to students.

2.3 Artificial intelligence literacy education

Artificial Intelligence Literacy Education is an emerging field that aims to empower students with the knowledge and skills to understand, interact with and develop AI technologies. It covers a wide range of competencies, including technical skills, ethical considerations, and social implications. The goal is to develop a comprehensive understanding of AI that will enable students to navigate and contribute to a world increasingly shaped by intelligent systems (Černý, 2024). Incorporating AI literacy into K-12 education has shown promising results in improving students' computational thinking and problem-solving skills, making it an important part of modern education (Casal-Otero et al., 2023).

Effectively combining GBL and CT methods in AI literacy education requires further empirical research. This research is particularly necessary to explore how game-based learning, block-based programming, and AI applications can be integrated across different age groups and subjects. To better understand AI models from interdisciplinary learning, it is important to define them as computational systems that simulate intelligent behavior through

learning data to make smart decisions. In educational activities, these models adapt content to student interactions and improve AI literacy by allowing students to interact with and analyze intelligent systems. Designing more integrated curricula to promote comprehensive student development, especially in AI literacy, is essential. Such studies will help establish more holistic and effective educational strategies, fostering students' overall growth in modern educational environments.

3. Teaching Activity Design

This teaching activity utilizes the design thinking approach to guide students, working in pairs, to create tabletop game cards that control robot movements. The activity comprises five stages: Empathy, Define, Ideate, Prototype, and Test (Lee & Park, 2021). The curriculum developed in this study allows programming commands to be interpreted through physical interactions. This process not only helps students understand the steps of design thinking, but also encourages them to think creatively and solve practical problems.

3.1 Teaching Process

- Empathize
 - Purpose: Understand the needs and ideas of the students.
 - Practice: Interact with students to stimulate their ideas on robot card design. Guide students to observe successful robot tabletop games on the market (such as "RoboRally") to understand how game play is facilitated through card design.
- Define
 - Purpose: Clarify the design challenges and objectives.
 - Practice: Design a set of cards that are easy to understand and fun to use, allowing players to control the robot's movements (forward, left turn, right turn) and which facilitate computer vision recognition. Ensure the cards are intuitive, aesthetically pleasing, and functional.
- Ideate
 - Purpose: Guide students to innovate in their card designs.
 - Practice: Encourage students to think freely and suggest card designs using different shapes, colors, and symbols. Based on brainstorming results, draw several card sketches.
- Prototype
 - Purpose: Create and test card prototypes.
 - Practice: Select the most promising designs from the sketches and manually create preliminary card prototypes. Consider each card's shape, color, and outline to ensure clear functionality and easy recognition. The students were tasked with designing game cards to interact with an image recognition model of AI. Each group created unique cards that were then used to train the model to effectively recognize different commands. This hands-on experience with AI technology not only helped to deepen the understanding of computational thinking, but also allowed students to directly observe the impact of their designs on AI performance.
- Test
 - Purpose: Validate the model's confidence in predicting the cards by interacting with a trained image recognition model, thereby enhancing students' high-level thinking skills.
 - Practice: Students will be tested using cards they have designed to observe confidence and accuracy the AI model has in recognizing the cards. Students will need to select cards that may be difficult for the AI to recognize accurately and test them against those cards. Through this process, students can not only observe the prediction results of the cards, but also assess the confidence of the model in recognizing them. Based on the feedback of the confidence value, the student will decide whether the card needs to be redesigned or the training parameters of the model need to be adjusted to improve the accuracy and confidence of the recognition.

Through repeated testing, students not only learn the relationship between card design features and model prediction confidence, but also return to the nature of problem solving. By analyzing and solving problems, they develop their own problem-solving and high-level thinking skills.

Through the practice of Design Thinking, students are guided to develop creativity and problem-solving skills in designing board game cards. The program encourages students to empathize with needs and define challenges, building a foundation for creative thinking. In the process, students transformed their creativity into actual card designs to satisfy real needs. Through the testing phase, students not only ensure that the model can accurately recognize the cards, but also reflect on and optimize the design based on the confidence value of the recognition results. This comprehensive learning experience provides students with an in-depth understanding of the design thinking process, while developing the critical thinking and high-level skills they need to solve complex problems.

4. Teaching Activity Design

4.1 Participants

This study utilized a single-group pretest-posttest design through the use of the AI2 Robot City curriculum, shown as Figure 1. We randomly enrolled 31 sixth-grade students from northern Taiwan in the course. The average age of the students was 12 years old, with 16 boys and 15 girls. The course was taught by a senior professional teacher with 18 years of teaching experience.



Figure 1. Participants practice on the AI2 Robot City interdisciplinary curriculum.

4.2 Experimental procedure

Before the learning activity began, students were introduced to the learning tasks. All students completed the pretest of the Artificial Intelligence Literacy questionnaire, the Computational Thinking Skills questionnaire, and the Learning Achievement Test. The course began with an introduction to image recognition and machine learning. Students then used a search engine to gather information online and create hand-drawn cards for a board game. They then built an image recognition model using their hand-drawn cards, packaged the trained model, integrated it into a block-based program, and installed it to run on a phone. Students then completed a self-assessment questionnaire on design thinking, and participated in image recognition and computational thinking board games. At the end of the learning activities, students completed a posttest of their learning achievement and filled out a posttest questionnaire. The experimental process is shown in Figure 2. In addition, we recorded the students' interaction process during the board game activity.

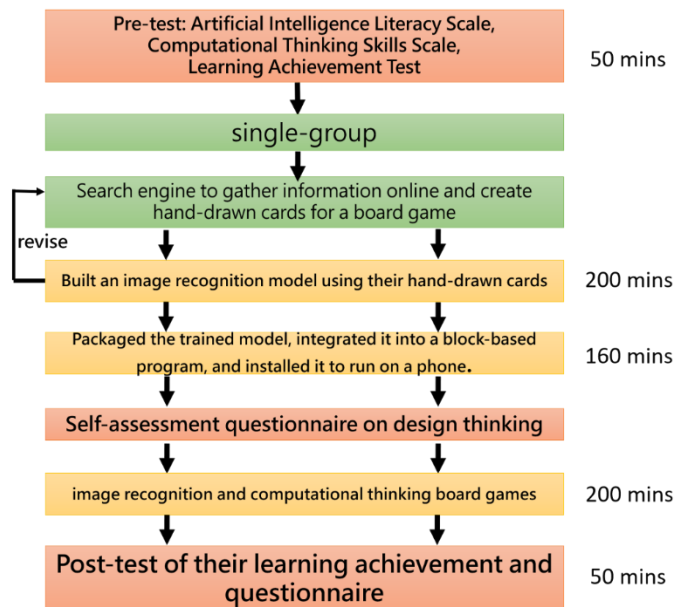


Figure 2. Experimental procedure

4.3 Measuring instruments

The measurement tools used in this study include the Learning Achievement Test, the Computational Thinking Skills questionnaire, and the Artificial Intelligence Literacy questionnaire. The Learning Achievement Test consisted of 20 questions, including 18 multiple-choice questions with four options each and 2 matching questions, with a maximum score of 100 points.

The learning process also included programming with block-based coding paired with a computational thinking board game to cultivate students' computational thinking. Therefore, both the pretest and posttest assessed students' achievements in computational thinking. The Computational Thinking Skills Scale, developed by Yağcı (2019), was used to measure three dimensions: Problem Solving, Creative Thinking, and Algorithmic Thinking, with six, four, and five items, respectively. Their Cronbach's alpha values were .96, .93, and .82, respectively. This questionnaire uses a 5-point Likert scale (5 = *strongly agree*; 1 = *strongly disagree*).

Before the board game activity, students trained cards using artificial intelligence image recognition technology. Consequently, both the pretest and posttest assessed students' Artificial Intelligence Literacy. The questionnaire was translated and adapted from existing scales (Carolus et al., 2023) to ensure that students could enhance their AI literacy through this implementation. It covers dimensions such as Use & Apply AI, Know & Understand AI, Detect AI, AI Ethics, and Create AI. Their Cronbach's alpha values were .93, .87, .77, .75, and .92, respectively. This questionnaire uses a 5-point Likert scale (5 = *strongly agree*; 1 = *strongly disagree*).

We used SPSS for Windows 26 to analyze the quantitative data and generate descriptive and inferential statistics.

5. Result

5.1 Analysis of learning achievement

The paired *t* test was employed to analyze the students' learning achievements, as shown in Table 1. The means and standard deviations were 13.39 and 3.25 for the pretest, and 16.10 and 2.70 for the posttest. The results indicated that there was a significant promotion from the pre-test to the posttest of learning achievement ($t = -6.78$, $p < .001$) with a large effect size (Cohen's $d = 0.90$) (Cohen, 1988).

Table 1. *Paired t-test results of learning achievement.*

Learning achievement	Mean	SD	<i>t</i>	<i>d</i>
Pretest	13.39	3.25	-6.78***	0.90
Posttest	16.10	2.70		

*** $p < .001$

5.2 Analysis of Computational Thinking Skills

The paired *t* test was employed to analyze the Computational Thinking Skills of the students, as shown in Table 2. The means and standard deviations were 3.80 and 0.71 for the pretest, and 3.95 and 0.76 for the posttest. The result indicated that there was a significant improvement from the pre-test to the posttest of computational thinking skills ($t = -2.51$, $p < .05$) with a small effect size (Cohen's $d = 0.20$) (Cohen, 1988).

Table 2. *Paired t-test results of Computational Thinking Skills.*

Computational Thinking Skills	Mean	SD	<i>t</i>	<i>d</i>
Pretest	3.80	0.71	-2.51*	0.20
Posttest	3.95	0.76		

* $p < .05$

5.3 Analysis of Artificial Intelligence Literacy

The paired *t* test was employed to analyze the AI Literacy of the students, as shown in Table 3. The means and standard deviations were 3.73 and 0.70 for the pretest, and 3.99 and 0.78 for the posttest. The result indicated that there was a significant improvement from the pre-test to the posttests of AI literacy ($t = -4.23$, $p < .001$) with a small effect size (Cohen's $d = 0.35$) (Cohen, 1988).

Table 3. *Paired t-test results of Artificial Intelligence Literacy.*

AI Literacy	Mean	SD	<i>t</i>	<i>d</i>
Pretest	3.73	0.70	-4.23***	0.35
Posttest	3.99	0.78		

*** $p < .001$

6. Discussion and Conclusion

The empirical findings of our study echo those explored in the literature review, specifically game-based learning (GBL), computational thinking (CT), and artificial intelligence literacy education. These strands of our theoretical framework greatly influenced the design and effectiveness of our educational interventions.

First, our findings resonate with concepts presented in the literature on GBL, which emphasizes engagement and interaction as core drivers of educational success. To further integrate the iterative problem solving phases into the learning activities of design thinking for the interdisciplinary curriculum contributed to improving learning achievement, computational thinking skills of the sixth grader students. At the same time, hands-on interaction with AI technology through the iterative testing as well as problem solving combined with game-based learning greatly improved the AI literacy of the students. Research by Gillespie (2022) and Hartt et al. (2020) highlighted that the use of game elements in educational settings can greatly increase student engagement and facilitate understanding of complex academic content. These insights align with the improvements in academic performance we observed after the intervention, as we utilized a similar approach to engagement.

In our instructional design, combining a design thinking approach with a game-based learning (GBL) model significantly improved learning effectiveness. This blended approach not only enriched the students' learning experience through increased engagement and interactivity, but also significantly improved their computational thinking skills and artificial intelligence literacy. These findings emphasize the efficacy of design thinking as a powerful pedagogical tool in education, promising to enhance educational practices and student achievement across disciplines (Simeon et al., 2020).

Second, as Brennan and Resnick (2012) emphasized, the role of computational thinking in education is critical, especially in developing problem-solving skills and understanding sequences and conditioning. This aligns with our findings that computational thinking skills are significantly improved through design thinking activities that integrate similar cognitive challenges and problem-solving tasks.

Finally, the importance of AI literacy as explored by Černý (2024) and Casal-Otero et al. (2023) is echoed in our findings. Comprehensive AI literacy education is crucial for students to effectively acquire and interact with AI technologies. The increase in students' AI literacy after the intervention confirms the necessity and effectiveness of incorporating AI concepts into the curriculum, which is consistent with the goals of AI literacy education.

These results validate the effectiveness of integrating GBL, CT, and AI literacy into educational strategies, emphasizing the outcomes of interactive, instant-feedback learning environments that enhance student engagement and achievement. This study provides an overall score for computational thinking skills and AI literacy in the post-tests, but future analyses could examine those factors at different stages separately. That would allow the researchers to achieve accurate assessment of each educational intervention. Future research should continue to explore these approaches with the aim of refining and optimizing the integration of these educational practices to maximize student development and prepare for the increasingly complex needs of the digital age.

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