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An Empirical Study of the Computational Thinking Learning Game, "Online Robot City"

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Abstract: Having strong computational thinking (CT) skills is key for students studying computer science (CS) and STEM-related fields. However, relying too heavily on programming languages can hinder students' understanding and application of CT concepts. Therefore, to effectively promote the learning of CT, this study conducted a quasi-experimental design to integrate two different questioning strategies into the Online Robot City game for teaching purposes. The study aimed to explore the impact of using the 5W1H strategy and the context-based concept mapping strategy for information gathering and problem decomposition on students' achievement in CT and on their learning behavior patterns. The results are expected to respond to the importance of different learning approaches, in particular the context-based thinking method like the context-based concept mapping strategy proposed in this study, which may make relatively more contributions to CT learning achievement and self-efficacy.
Keywords: Computational thinking, self-efficacy, 5W1H, context-based concept mapping strategy.

1. Introduction

Computational thinking (CT) is a problem-solving skillset essential for the next generation. To help students acquire these skills, CT must be integrated into K-12 education (Avcı & Deniz, 2022). CT is a widely used concept in K-12 computer science (CS) education, with different experts giving it diverse meanings. Possessing CT skills is vital for students to excel in CS and STEM fields (Sneider et al., 2014).

To teach CT in K-12, educators must create an environment that fosters students' CT skills while providing appropriate support and resources (Voogt et al., 2015). Programming using "Scratch" is effective in terms of enhancing students' understanding and application of CT concepts (Resnick et al., 2009), but teaching CT should also develop abstract thinking and algorithmic concepts (Voogt et al., 2015). This requires interdisciplinary education and the design of relevant teaching materials and activities. Brennan and Resnick (2012) argued that CT should be a core discipline, not just a skill. They suggested that students learn computer science principles beyond programming to improve their CT skills. Lye and Koh (2014) cautioned that over-reliance on programming may hinder CT understanding. Many programs claim to teach programming skills, but few explore the thinking process used in CT (Shute et al., 2017). According to Lu and Fletcher (2009), teaching CT should use familiar concepts instead of programming languages to help students learn concepts like abstraction and algorithms.

Studies show that teaching CT through instructional strategies is effective. Kuo and Hsu (2020) suggested using interactive learning strategies to teach CT as they can improve learners' abilities. Hwang et al. (2015) found that teaching CT through game design improves CT abilities and STEM learning. These pedagogical strategies are widely used in K-12 education. Programming may be too difficult for some students, so it is important to develop appropriate ways to teach CT to students at different stages (Bers et al., 2014). Board games can be a suitable alternative.

Scholars have proposed strategies to cultivate students' CT abilities. Papert (1999) developed Logo programming language tools for teaching, advocating that students can develop CT and problem-solving abilities through games. Resnick et al. (2009) developed the Scratch programming language to teach CT through gamification and creativity. They advocated for students to learn by designing and sharing their own games and projects. The Online Robot City board game requires programming commands to control robots and complete tasks (Kuo & Hsu, 2020). Programming concepts include sequences, loops, conditionals, and functions (Garfield, 1994). These studies highlight the importance of teaching CT through games and programming to engage students in learning.

Board games can be enjoyable and useful for teaching, but their suitability varies among students due to their different learning styles and needs (Kebritchi, 2010). Playing board games alone may lack depth and breadth (Li, 2007), and factors like class size and material preparation can affect their effectiveness. Limited student interaction can decrease motivation to learn. To enhance motivation and learning effectiveness, increasing instructional interactivity is recommended (Newlin & Wang, 2002). Despite its advantages such as overcoming spatial limitations and promoting collaboration (Khorsandi et al., 2012), online teaching also has drawbacks such as technological constraints, lack of belongingness, anxiety, and reduced engagement (Xie et al., 2020). Regardless of the format, providing additional scaffolding and effective strategies to support learning CT is essential. Blended learning, combining online and classroom approaches, along with concept maps and the 5W1H strategy, can aid students in understanding and applying learning content, improving outcomes and motivation (Lin & Sekiguchi, 2020).

This study had two groups of young students (average age of 10) use two different questioning strategies. One questioning strategy was 5W1H while the other was context-based concept mapping. The participants adopted different questioning strategies before using Online Robot City, which is an online CT game-based learning system to carry out structural programming logic to solve the tasks in the game. We wanted to explore the following two research questions by conducting an empirical study:

1）Did the students applying different questioning strategies for gathering information and problem decomposition before using structural programming logic to solve the tasks in the game make significant improvement in their CT learning achievement and self-efficacy?

2）Did the students applying different questioning strategies for gathering information and problem decomposition before using structural programming logic to solve the tasks in the game have different behavioral patterns?

Online Robot City provides an alternative and useful tool and method for cultivating the CT skills of students in a physical classroom. By comparing the two teaching strategies through the game, a better solution can be found for interpreting the online CT board game.

2. Literature Review

2.1. Computational Thinking

Learning CT is vital for today's students so they can use computer science concepts to solve problems and understand human behavior (Wing, 2006). Early CT training fosters independent thinking and problem solving. CT's applicability spans subjects and daily life. To adapt to the information society, students need both creative and digital literacy skills and effective CT and technology usage (Hsu et al., 2018). Programming access allows deep thinking and intellectual growth (Papert, 1980). Brennan and Resnick (2012) found that skills like sequences, loops, and conditionals transfer to other languages, and tools facilitating understanding of these concepts can cultivate CT abilities. Bers (2018) stressed visibility in CT tool design, enabling immediate feedback during the design process. Hsu and Chen (2022) proposed a CT board game as an interactive, visible way for novices to learn CT. Erdogan et al. (2022) indicated that board games require verification of each player's moves in order to ensure compliance with the rules and to identify winning strategies. However, when students' actions cannot be verified in real time, it can negatively impact the fairness and smoothness of the game. Therefore, an educational robot board game needed to be developed.

2.2. Educational Robot Board Games

Educational robots (ERs) have gained popularity in classrooms, as they are considered as effective tools for fostering students' CT skills (Hsu et al., 2022). ERs are increasingly recognized as tools to develop CT competences (Chevalier et al., 2022). To apply CT practically, programming is usually used. However, this alone is insufficient for learning. Clear guidance is also necessary (Chevalier et al., 2022). Chevalier et al. (2022) suggested that there are few effective strategies for promoting "CT practice" and "CT perspectives," with most strategies focusing on "CT concepts."

Kuo and Hsu (2020) proposed that Educational Robot Board Games (ERBG) correspond to structural programming, including sequential structure, conditional structure, repetitive structure, and the modeling concept of calling a procedure in programming languages. Therefore, combining ER with board game to propose effective teaching strategies to promote the implementation of CT is worth researching.

2.3. The 5W1H model

ERBG with shared gamified elements make learning fun, and instructors can add their content to the games. This type of instruction uses game rules like earning points, collecting badges, and leaderboards to motivate students, keep them engaged, and encourage communication. This approach leads to better learning results and satisfaction (Hsu et al., 2023). However, students may experience cognitive load when learning via ERBG (Sweller et al., 1990). Therefore, Hamborg et al. (2019) proposed the 5W1H strategy to help students understand the main events, describing who did what, when, where, why, and how. This simplifies and structures the entire event, making it easier to see and analyze. The usage environment, functions, and methods of the product are examined using the 5W1H method, which helps clarify the aim of promoting the potential use of ERBG in education (Yang et al., 2019).

However, even though the 5W1H strategy can effectively help students decompose problems and collect information about the context, functions, and methods of ERBG, parallel messages lack a linear sequence and causal relationships (Jinks & Jinks, 2019). Therefore, more contextual guidance strategies may be needed to deepen learning.

2.4. Concept mapping

Novak and Gowin (1984) introduced concept maps as a visualization tool for knowledge networks. CT involves abstraction and automation (Weiwei et al., 2015), and concept maps can clarify knowledge relationships in teaching (Chen et al., 2021). However, CT often requires problem decomposition and algorithms (Lockwood & Mooney, 2017). Concept maps have limitations without structured patterns (Conceição et al., 2017). "Context-based concept mapping" integrates multiple aspects to enhance concept understanding (Ksibi et al., 2013). Cañas et al. (2012) emphasized that teachers' content and conditions impact students' learning outcomes. Research on context-based concept mapping to cultivate CT abilities and visualize cognitive processes is essential for students to effectively solve tasks in the game.

2.5. Learning Behaviors

The cultivation of CT is a gradual process. Numerous studies have shown that through various courses, CT skills can be significantly improved. However, this cannot represent the true level of students' CT (Xu et al., 2019). CT involves utilizing fundamental concepts of computer science to solve problems, design systems, and understand human behavior (Weiwei et al., 2015). Examining students' learning performance and comparing their learning behavior in different contexts is crucial to identify potential challenges and provide insights into curriculum implementation and support for instructors (Hsu et al., 2022). Chao (2016) mentioned that students' behavior and strategies of solving computational problems in a visual programming environment may affect their problem-solving performance. Therefore, it is necessary to further explore the behavioral patterns of novice programmers in a visual programming environment, and to investigate the differences in their strategies and performance in solving computational problems among different behavioral patterns. Hence, it is worth exploring various methods, such as learning behavior analysis, to examine CT ability.

3. Method

3.1. Participants

The study included 54 fourth- and fifth-grade students in northern Taiwan, of whom 27 learned CT with Online Robot City and context-based concept mapping, and 27 learned with Online Robot City and 5W1H thinking. A teacher with over 10 years of experience guided the groups. Students worked in pairs during the game.

3.2. Instructional Design

The study used Online Robot City, a board game involving robot city construction. Two groups of students used different CT questioning strategies: context-based concept mapping and the 5W1H approach. The experimental group integrated context-based concept mapping before employing structural programming logic in the game (Figure 1).

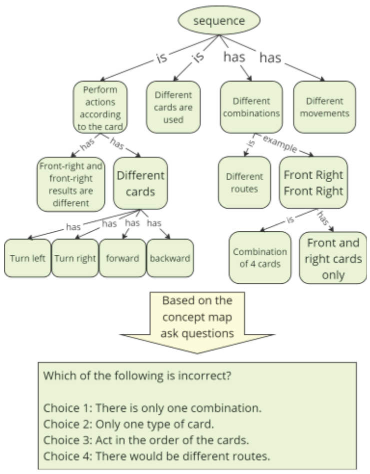

Figure 1 context-based concept map.

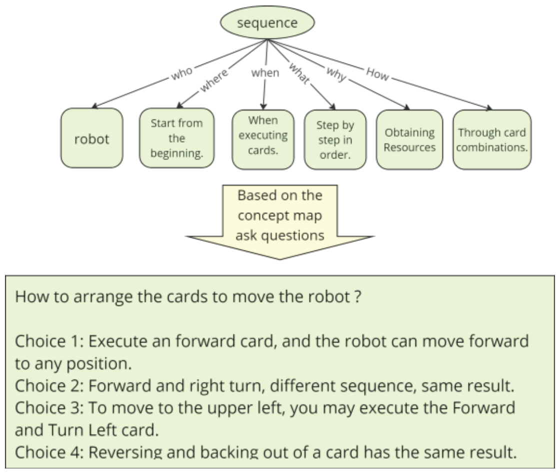

Figure 2 5W1H strategies

The control group used the 5W1H approach for gathering information and problem analysis, followed by structural programming in the game (Figure 2). Before the study, both groups received instructions on control card use and robot operation, including game rules and CT concepts. The game allowed students to practice concepts like repetition and conditional statements using repeat and condition cards. Students had to control their robots to obtain resources on the map, using up to eight control cards at a time to control the number of steps. Precise landing on correct positions was necessary for scoring. The game encouraged teamwork, objective identification, planning, and logical thinking, promoting CT learning in pairs and during competitions.

3.3. Research Process

A quasi-experimental design with robot teaching was implemented for 1 hour/week over 10 weeks. Students whose average age is 10 completed pretest surveys, then were split into experimental and control groups. Both groups participated in the same teaching sessions by the same teacher in the same classroom. Posttest surveys and behavior analysis followed. Both groups spent the same amount of time.

3.4. Instruments

We designed a CT achievement test based on the Bebras International CT Test (Dagiene & Stupuriene, 2016), using a learning achievement test to assess students' CT abilities. The CT test on sequential concepts, repeated concepts, and selection included 34 multiple-choice questions. A technology education teacher with over 10 years of experience in CT education and programming was invited to verify the CT test. The two scholars ensured the reliability of the test and ensured that the questions containing CT characteristics were related to the learning content of CT board games. To reduce testing effects, the order of items in the pretest and posttest was switched, and additional questions were added to the posttest. Figure 3 is an example of a Bebras competition, involving the concept of flowcharts in structured programming and the traveling robot problem. Figure 4 is an example of the pretest design for this study, covering the learning content of the CT chess game. Figure 5 is an example of the posttest design for this study, covering the learning content of the CT chess game.

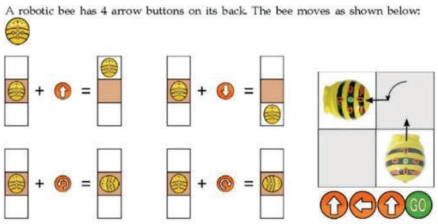

Figure 3 Bebras International CT Test (Dagiene & Stupuriene, 2016)

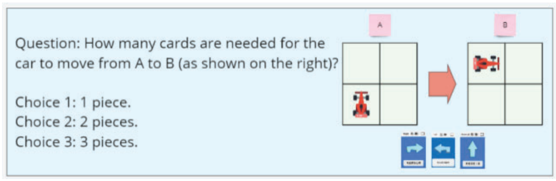

Figure 4 Example of a pretest design for this study.

Figure 5 Example of a posttest design for this study.

To evaluate students' self-efficacy in computational thinking, this study used the Computational Thinking Scale (CTS) developed by Korkmaz et al. (2017), using a 5-point

Likert scale (1 = "strongly disagree", 5 = "strongly agree") to assess students' creativity, algorithmic thinking, collaboration, and critical thinking. The Cronbach's alpha value was 0.82, indicating satisfactory reliability.

3.5. Learning Behavior Analysis

This study explores the CT learning behavior of students in ERBG, based on actual operations recorded of student behavior (e.g. moving ER after peer discussion). Through system recording, analysis of learning behavior is conducted and the analysis content is encoded. The encoding is then converted into GSEQ format data and analyzed using Sequence Analysis GSEQ Version 5.0 to explain whether there is significant correlation between behaviors.

4. Proposed Contribution

The teaching design of this study was divided into three stages: sequential, repetitive, and conditional structures. The study aims to observe the impact of different questioning strategies on students' CT learning during the teaching process. The study is expected to echo the findings of Hsu et al. (2022), who found that students made significant progress in CT through teaching-based methods and customized educational robot activities. By analyzing students' learning behavior, the study hopes to observe students' CT behavior and misconceptions, such as the inability to use algorithmic cards. Teachers can use teaching prompts to correct students' misconceptions. Overall, the study aims to transform students' CT learning from focusing on programming language features to logical structures and thinking strategies.

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