

Fostering Computational Thinking Through Unplugged and Robotic Collaborative Game-Based Learning on Primary School Students

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Abstract Computational thinking is considered one of the skills that individuals should possess in current society. The purpose of this study is to explore the potential of implementing unplugged and robotics game-based learning activity in the context of multidisciplinary learning. A total of 27 fourth-grade students at ten years old on average participated in the teaching experiment. Two research questions were evaluated in this study: i.e., the differential effectiveness of the approach between unplugged and robotic collaborative game-based learning in terms of CT skill and science, and ARCS motivation models of game-based learning carried out in the class for the use of learning tools. There were two phases of the learning process: in phase I, students played with an unplugged activity named Meta-Mind Table Game, and in phase II, students played with robots named Meta-Mind Robotic games. Each phase was then analyzed by both mid-test and post-test. The study revealed the inclusion of both unplugged and robotic game-based learning was beneficial to the students. Students were significantly motivated and greatly enhanced in terms of learning effectiveness.

Keywords: *computational thinking, science, unplugged, robotic, collaborative, game-based learning, ARCS Motivation*

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1. Introduction

Computational Thinking (CT) education has received considerable attention throughout the recent decade in all school levels [1,2]. CT skills are one of the competencies that are necessary for the era of the industrial revolution of 4.0 [3]. The concept of CT has long been recognized as an essential topic. Seymour Papert encouraged the cultivation of CT in young age even though we have a few reference points since the 1960s with the phrase "procedural thinking" [4]. Lately, the CT idea has recaptured the expanded essentialness and has been viewed as basic expertise for everyone, not just computer science. CT should be added to child abilities along with reading, writing, and arithmetic [5].

In Europe, 13 countries have been surveyed by the Ministry of Education (MOE) aiming to develop logical thinking and problem-solving skills through CT. Seven out of them are focused on the development of coding and programming skills [6]. Finland and Portugal aim to increase student achievement and interest in mathematics through CT. In Asia, for example, Korea, Taiwan, Hong Kong, and China have launched public curricular

changes to address the current development in CT education [7].

There are many approaches to promote learning CT in young children which led to popular research topics, such as block-based programming [8], robotic programming [9], unplugged activity [10], collaborative game-based learning [11], integrated into STEM [12], from STEM to STEAM [13], board game [7], and so on.

In the aspect of teaching learner CT skills across subjects, including programming, Shih et al. proposed the interdisciplinary game based-learning with the integration of STEAM. A table game was used in this study. The study presented an interdisciplinary learning model that put students in the context of cultural history, where they need knowledge of history, geography, mathematics, and natural sciences to work and cooperatively compete to achieve the goals. Students' critical thinking, creative thinking, CT, problem-solving abilities, as well as cooperative and competitive game strategies were used and enhanced in the learning scenario [13]. Playing games provide a playful experience and collaborative learning. Moreover, students can learn how to solve problems effectively and foster CT skills. Several studies have shown that game-based learning can increase student motivation and improve their learning outcomes [11].

Fostering thinking skills can be done in two ways. The first is to provide specific classes and activities that specifically address the thinking skills taught and integrate thinking skills instruction into the regular curriculum [14]. Computer Science Teacher Association (CSTA) argues that the role of CT in learning as a method of solving problems can be transferred and applied in all subjects [15]. To implement this, introducing and preparing teachers explicitly about CT's concept is critical [16]. In order to make CT permeates through other content areas, it is essential to give all teachers adequate knowledge about CT and learn how to incorporate CT into their disciplines.

Regarding the CT cultivation process, unplugged and plugged activities play a significant role in fostering the CT teaching process [17]. Unplugged activities allow learning of CT without using technology [7]. The most popular way to teach CT through unplugged activities is by using the board game [7,18]. Students play collaboratively around a floor-board by strategically solving problems and manipulating their robots accordingly in space. Their active engagement in those unplugged games should raise their motivation for participation and learning. Some researchers have indicated that unplugged activity significantly increases students' CT abilities and provides effective evidence for the development of CT [10].

The concept of CT is parallel to the core of Science, Technology, Engineering, and Mathematics (STEM) disciplines [12]. Integrating CT into STEM curricula gives learners a more realistic perspective. Robots in educational settings have attracted many researchers to study their effects [19,20]. Introducing robots into the classroom is expected to provide multiple benefits in support of learning activities to promote student interest in STEM discipline and can be used to convey technical competencies, such as programming skills [1,21]. Besides, the understudy can get essential cross-over aptitudes, such as day-by-day critical thinking exercises, dynamic, correspondence, collaboration, and may apply to numerous other STEM learning areas [13,17].

Characterizing different parts of CT assessment abilities thought to incorporate complex CT structures and their cooperation between knowledge, science, innovations, and mental components that focus on the cycles experienced by understudies instead of programming codes [22]. A few past investigations have attempted to evaluate CT abilities with a few techniques, for example, utilizing information tests and questionnaire. Besides, the qualitative method can likewise assess CT concepts such as interviews, project analysis, observations, and reflection reports. Therefore, it should pay attention to various aspects of assessments identified with CT abilities since it is preposterous to expect to utilize a solitary technique to assess collaborations between computers, cognitive, learning, and psychological elements [23].

Unlike interactions in digital games using smartphones or computers, playing board games allows face-to-face interactions to expose humans to human expression, physical action, and verbal tones [1]. Thus, playing board games or educational cards as a learning media can foster direct interpersonal interactions between teachers and students, and between students, to the extent that is irreplaceable by the sound and audio effects of digital

games. Besides, playing board-game can cultivate social skills, learn to control emotion, and, most importantly, practice how to interact with others while playing [24]. Some researchers consider single-player game-based learning to be insufficient to produce the desired learning [25]. High interactivity and high-level thinking are two characteristics possessed when playing board games. As a platform, board games enhance interaction, communication, and cooperation between students and develop their higher-order thinking. There are several decades of history applying board games to education [26]. Most studies have found many benefits when using board games in the teaching process that can improve significant teaching outcomes [27].

Using game-based learning in the learning process has numerous constructive outcomes on a study learning motivation. Many previous studies have shown that through educational games, the effectiveness of learning can be improved. Enriched game elements make educational games increasingly popular [28]. On the other hand, several studies found that problem-solving performance and student learning outcomes correlated with several learning involvement components through the game, including perceived interests and attendance [29].

Game-based learning mostly combined with other learning methodologies such as collaborative-based learning, competition-based learning, and problem-based learning. When all of these methodologies are added to the learning process, it increases students' motivation to learn through the games. Besides, the ability to solve problems and communicate will increase significantly [30]. Researchers believe that student creativity can be enhanced by ambiguous task goals and the need to compete to stimulate their brainstorming [31].

Implementing games for encouraging instruction and learning expositions is certainly not a new idea as teachers and analysts have been talking about games for informal training. Game-based learning (GBL) alludes to the utilization of games as instruments to help to instruct and to learn [32]. By playing the game, students can understand a new concept or idea and take on different perspective options or variables to contribute to children's cognitive development [33].

Moreover, GBL has been investigated in science instruction and had impressive consideration in investigating how and why games may be integral assets in study. Because of this trend, a large number of literatures investigated game-based learning in science and discussed GBL advantages for students' information development and commitment to science subjects. Moreover, scholars have been recently investigated for utilizing both computerized and non-advanced games to advance physics learning [34].

This study examines the learning effectiveness of an unplugged and plugged approach through game-based learning activity in primary school students to promote CT in early age-integrated with science. Therefore, the purpose of this study is to answer the following research questions:

1. Is there any significant difference in the learning effectiveness of the approach between unplugged and robotic in terms of CT integrated science unit?

2. What approach, unplugged game-based learning, or only robotic game-based learning, produces better motivational outcomes when introducing CT in the primary education?

2. Methodology

2.1. Design

This study's main objective was structured in two main instruction phases interspersed with pre, mid, and post-test, making a total of three 120 min lesson in three days. Figure 1 and Table 1 describes the learning activity implemented in the construction of this research with research tools.

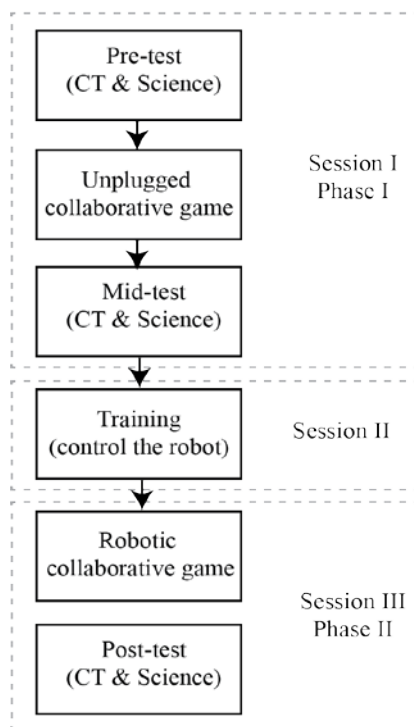


Figure 1. Research Design

In the first day (phase I), the student performed the pre-test to evaluate their previous CT skill and science in insects' life cycle. Then, the first phase instruction students playing with Meta-Mind Table game (unplugged

game activity). Students divided into pairs . After the first phase of instruction, the Mid-test was performed by students to evaluate their CT skills, science in the context of life cycle of insects, and ARCS motivation test to measure their motivation towards the game activity previously implemented.

Once the Mid-test was done, in the second-day, session II, students were trained to control the robots using mBot block-based programming application. Students practiced to control robot movement including turn left, turn right, move forward, and move backward. Students also tested the distance robots can move in the one second, the angle of the robot when it make turns in one second at the preset speed.

On the third day (phase II), students worked with Meta-Mind Robotic Game. Students played games with robot on the big flour maps. Besides, activities such as collaboration, teamwork, communication, and problem-solving were observed to analyze students' behavior during playing the Meta-Mind Robotic game. Each student had a role in the game.

- Scientist: who answers the question appears in QR code and collects cards for the life cycle of insects.
- Planner: who calculates mBot movement including distance, angle, direction, and speed.
- Engineering: who constructs mBot with weapons. The weapons are needed to destroy the collection of insect cards of other teams.
- Programmer: who uses computer and mBlock programming to control robots movements and actions such as turning on lights and making sounds. The programmer controls the robot to where it can go according to the direction planner.

2.2. Participant

The participants consisted of twenty-seven students of 4th year Indonesian primary school education with 9 boys and 18 girls in the age of 10 years old in average. The presence of ICT as a new technology has been widely used in education and learning to improve learning outcomes. To begin with, we investigated students' experience of their use of ICT. Twenty-six out of twenty-seven students (96%) had experience using the computer and sixteen students (59%) had played with robots. None of them learned programming before.

Table 1. Instructional Design

Time Duration	Activity	CT involved	Science content integrated
Day 1 (phase I): 120 min.	Playing Meta-Mind Table game: Students divided into pairs. This game's challenge is to collect the insect's life cycle card in sequence (i.e. butterfly: egg-caterpillar-chrysalis-adult) using arrow card (forward, turn left, turn right) and student should think the best route to collect it.	Sequence, Algorithmics Thinking, Looping, collaboration	The life cycle sequence of insects
Day II (Training): 120 min.	Using mBlock block-based programming to control the mBot robot's movement (go forward, backward, turn left, turn right)	Abstraction, decomposition, debugging,	N/A
Day III (phase II): 120 min.	Playing Meta-Mind Robotic game: students divided into groups of four. The scenario of this game is the same as the game in phase I, but to collect the insect's life cycle in sequence. Students need to control the robot using mBlock block-base programming.	Sequence, Algorithmics Thinking, Abstraction, Looping, conditional, debugging, generalization,	The life cycle sequence of insect

2.3. Instruments

2.3.1. Computational Thinking Test

Developing a substantial and dependable instrument for fundamental CT is testing a result of the absence of agreement in the field in terms of CT definition and its assessment. For this situation, a test was explicitly intended for this examination. The CT test is a multiple-choice test composed of 20 items. It was collected using formative assessment tool Plickers in a maximum time of 40 min. It planned to quantify the improvement level of CT, and it depends on the accompanying operational definition of the development. CT includes the capacity to detail and tackle issues by depending on the central ideas of figuring and utilizing the inalienable rationale of programming fundamentals.

2.3.2. Motivation Test

The most successive way to deal with advanced education has been to support programming learning steadily. The term code-proficiency has been instituted to refer to training students in programming undertakings, from the easiest and generally engaging to the most complex. The construct of the motivation test was measured on 4 points Likert scale from (1=Strongly Agree, 2=Agree, 3=Disagree, 4=Strongly Disagree). The Cronbach's alpha equation was calculated by SPSS statistical analysis software to determine the reliability coefficient. The result was 0.761.

2.4. Procedure

This study examines the learning effectiveness of an unplugged and robotic game-based learning activity to foster computational thinking skills integrated with the science unit. In developing CT-related skills, this study's instructional session was designed with a 3-day lessons as described in the design section, with 120 minutes per day.

2.4.1. Session I, Phase I: Meta-Mind Table game

In Session I, students began to understand what programming is about. CT concepts in terms of Algorithmic thinking, sequence, decomposition, and looping are taught to integrate with science in the Meta-Mind Table game.

Objectives:

- Comprehend the troubles of interpreting human language into computer language.
- Understand the sequence of life cycle of insect.
- Use codes and symbols to practice communication of ideas.

A detailed description of each part of the lesson plan is described below:

1. Vocabulary (2 min): CT concept in this lesson is explained: algorithm, sequence, and decomposition.
2. Introduce Meta-Mind Table game (5 min): This section explained how to play the Meta-Mind Table game and integrate with the CT concept. In the Meta-Mind Table game, the concept of algorithmic thinking and sequence are interpreted in the life cycle e.g. life cycle of mosquito: egg-tadpole-

tadpole with legs-froglet-adult. And the process of life cycle is a loop.

3. Practice together (60 min): Student are divided into pairs. Communication, collaboration and team work are observed.

2.4.2. Session II: Training Control the Robot

In Session II, students were trained to control the robot using mBlock programming. The instruction includes: "move forward", "move backward", "turn right", "turn left", "play sound", and "turn on light". After, student practiced together.

Objectives:

- Connect robots to the computer.
- Use drag and drop to give commands on the computer to control the robots.
- Calculate the angle, speed, time, and direction for movements.
- Interpret conditions (if-else statement) in the programming.

The following is a detailed description of each of the parts of the lesson plan:

1. Vocabulary (5 min): decomposition, algorithmic thinking and condition statemen are explained as CT concepts.
2. Robot Introduction (30 min): Introduce the robot and connect the robot with the computer.
3. Practice together (60 min): Students practice to control the robot by following the instructions given.
4. Evaluation (25 min): Evaluate what students have learned in this section.

2.4.3. Session III, Phase II: Meta-Mind Robotic game

In this section, students played the Meta-Mind Robotic game. This game's instruction is the same as the Meta-Mind Table game, except that students use the robots to collect insects' life cycle cards in sequence in this game.

Objectives:

- Transfer learning of the unplugged game to the robotic game (plugged).
- Comprehend the troubles of interpreting human language into computer language.
- Practice programming to control the robot, communication, collaboration, and teamwork.

The following is detailed description of the part of the lesson plan:

1. Vocabulary (3 min): CT concepts in this lesson are explained: algorithm, programming, loop, sequence, collaboration.
2. Introduction (10 min): the first instruction is divided students into groups consists of four students; in which each student has a role as programmer, planner, scientist, or engineering.
3. Practice together (60 min): Students play Meta-Mind Robotic game together, collaboration, teamwork, communication are needed to achieve the goals.

3. Result

Considering this research's objective, this section shows

the results obtained for groups in each test (Pre-test, Mid-test, and Post-test for each of the proposed areas. The impact related to CT and science in the context of the life cycle unit is presented. Then, the results of the motivation were evaluated towards the game-based learning activities between unplugged game and robotic game.

Using SPSS software, descriptive statistical analysis was used to answer the research questions. To examine whether there are any differences between the pre-test, mid-test, and post-test, the Wilcoxon Signed Ranks Test with alpha set at 0.04 was applied. Besides, to compare between both groups in the post-test, the Mann-Whitney Ranks Test was used.

3.1. Computational Thinking

Regarding CT skills, Table 2 shows the result of the Pre-test and Mid-test. There are significant differences between mean ranks in CT skills for the sake of the mid-test, where Z value result refers to the improvement in the CT skills for students.

Table 2. Computational thinking Pre-test and Mid-test

Computational Thinking	N	Mean Rank	Sum of Ranks	Z	Sig
Negative Ranks	3	5.50	16.50	2.914	.004
Positive Ranks	14	9.75	136.00		

As shown in Table 2, there are significant differences between mean ranks in the CT skills for the sake of the mid-test, where Z value was (2.914) with a significance level at (.004). This result refers to improvement in the CT test for students after playing the Meta-Mind Table game.

Table 3. Computational Thinking Pre-Test and Post-Test

Computational Thinking	N	Mean Rank	Sum of Ranks	Z	Sig
Negative Ranks	3	5.50	16.50	3.226	.001
Positive Ranks	16	10.84	173.50		

Table 3 shows a significant difference between pre-test and post-test, where Z value was (3.226) with a significance level (.001). This result also refers to improvements in the CT test for students after playing Meta-Mind Table game and Meta-Mint Robotic game.

3.2. Engagement in CT and Science

As shown in Table 4, there are significant differences between mean ranks in the science in the context life cycle of insect for the sake of the mid-test, where Z value was (2.821) with a significance level at (.005). This result refers to improvement in the CT test for students after playing Meta-Mind Table game.

Table 4. Science Learning Pre-test and Mid-test

Learning Science	N	Mean Rank	Sum of Ranks	Z	Sig
Negative Ranks	4	10.38	41.50	2.821	.005
Positive Ranks	19	11.75	211.50		

Table 2 shows a significant difference between pre-test and post-test, where Z value was (3.226) with a significance level (.001). This result also refers to learning science in the insects' context life cycle after playing the Meta-Mind Table game and Meta-Mint Robotic game.

Table 5. Learning science Pre-test and Post-test

Learning Science	N	Mean Rank	Sum of Ranks	Z	Sig
Negative Ranks	4	9.75	39.00	2.902	.004
Positive Ranks	18	11.89	214.00		

3.3. Motivation in Game-based Learning

As shown in Table 6, this result found that student attention in the Mid-test was higher after playing the Meta-Mind Table game (3.679) then after playing the Meta-Mind Robotic game (3.401), in the dimension of relevance after playing the Meta-Mind Table game (3.340). In contrast, after playing the Meta-Mind Robotic game (3.259), the mean of the dimension of confidence after playing Meta-Mind Table Game was higher (3.59) than the Robotic game (2.970). The satisfaction dimension shows that (3.474) after playing Meta-Mind Table game and (3.341) after playing Meta-Mind Robotic Game.

Table 6. Motivation test between unplugged and robotic game

Motivation Aspect	Mid-testMot (Unplugged Game)		Post-testMot (Plugged Game)	
	Mean	SD	Mean	SD
Attention	3.679	.575	3.401	.528
Relevance	3.340	.757	3.259	.616
Confidence	3.059	1.151	2.970	.929
Satisfaction	3.474	.689	3.341	.636

Although there is a slight decrease in the Post-test, after students playing with the Meta-Mind Robotic game, the results of both tests splitting them by dimensions (attention, relevance, confidence, and satisfaction) have no significant differences. Most of the students agree that the Meta-Mind Table game and Meta-Mind Robotic game can increase their attention, relevance, confidence, and satisfaction.

The second part with class observation confirmed the student's behavior emphasized collaboration, teamwork, and communication. It was found that during students played Meta-Mind game, and they can work together, communicate, and collaborate in solving challenges in the game. Although it looks more effective when they are in small groups than large groups in Meta-Mind Robotic games. This is because they are focused on their respective roles.

4. Conclusions

This study attempts to give students a CT learning experience by integrating learning science through game-based learning, which innovative, immersive, meaningful,

and clear goals can attract students to participate in knowledge acquisition autonomously and skill practice as strategic collaboration competition. This research allows students to reach wider knowledge and opportunities to get in touch with CT skills and disciplines.

From the result of this study, Meta-Mind Table games and Meta-Mind Robotic games activities can increase the effectiveness of fostering CT. Besides that, student's knowledge of the insect life cycle also increases. When concluding CT skill improvements based on CT tests and through observation in the classroom, such as how students collaborate with others, doing step-by-step to solve the problems, and students can generate patterns that have occurred to be made in solving problems. The research question was answered based on the study's result, which reported statistically significant on student's learning outcomes between pre-test, mid-test, and post-test of CT skill and science learning. There are a number of emerging and comprehensive CT assessment that consider leadership, collaboration and effective communication skills as important ingredients of CT.

The results of motivation for the Meta-Mind Table Game are superior to the Meta-Mind Robotic Game, even though the average comparison of these two activities has the same high value. Based on the observations, they prefer to be in a small group in the unplugged game than in a large group in the robotic game. Small groups are easier to collaborate, communicate, and work together in solving problems and challenges given. In contrast, in large groups in robotic games, on average, children in less group can communicate or work well together because they focus on their respective roles. It is to conclude that the students were significantly motivated and greatly enhanced in terms of learning effectiveness if games was carefully implemented with the instructional design.

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