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Integrating Game-based Learning into Computational Thinking Class for Lower Primary Students: Lesson Design and Course Effect

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ABSTRACT

Computational thinking (CT) has been integrated into K-12 curricula globally. With the growing trend of initiating CT in early childhood education, great effort has been made in developing age-appropriate courses targeting young children. This study aims to introduce an instructional unit of CT instruction for children aged 5-7, Coding Galaxy-Foundation, where unplugged activities and digital game-based learning were applied. A public primary school in Hong Kong was invited for delivering the course, where Grade 1 and Grade 3 students were involved (N=57). Six lessons were selected, covering basic CT concepts including sequences, decomposition, events, relative direction, debugging, loops, pattern recognition, and conditionals. Each lesson consisted of three sections, namely, a) concept introduction with daily-life examples, b) unplugged activities based on puzzles, and c) digital game practices with Coding Galaxy game app. Students' attainment from the course was assessed in both cognitive and attitudinal facets. The results indicated that the course was effective in sustaining students' CT cognitive performance and improving students' coding attitudes, and female and Grade 3 cohorts were the most beneficiaries. Implications for further research and educational practices are discussed.

KEYWORDS

Computational thinking, early childhood education, unplugged activities, digital game-based learning, coding

1. INTRODUCTION

In the digitized society, computing skills have become increasingly important for citizens. In recent years, computational thinking (CT), the major subset of computing, has been integrated into K-12 education to support the future development of young children. CT stemmed from "algorithmic thinking" raised by Seymour Papert in 1980, who describes that it is "the art of deliberately thinking like a computer, according, for example to the stereotype of a computer program that proceeds in a step-by-step, literal, mechanical fashion" (Papert, 1980, p.27). Later, the phrase "computational thinking" became well-known after Jeanette Wing re-proposed the notion in 2006, depicting it as "an approach to solving problems, designing systems, and understanding human behavior, by drawing on the concepts fundamental to computer science" (Wing, 2006, p. 33).

Under Wing's call, CT has been integrated into K-12 curricula on a global scope (Bocconi et al., 2016). More recently, heat can be seen in initiating CT education for younger students (Bers et al., 2018). It was reported that CT education has permeated into elementary school classrooms (Rich et al., 2019) and even kindergartners as young as 4-year-olds could acquire basic CT concepts (Strawhacker et al., 2018). The growing trend of implementing CT in early childhood education necessitates the development of age-appropriate instructional applications to support student learning.

To support CT education, substantive attempts have been made in designing manifold learning tools, encompassing unplugged activities, block-based coding platforms, robotics, and digital coding games (Shute et al., 2017). Among these initiatives, unplugged learning activities and digital games tend to be child-friendly. Unplugged activity is an approach to teaching coding without digital devices but with tangible objects instead (e.g., cards, puzzles) (Bell et al., 2009), which is suitable for young novices to start with (Zhang & Cui, 2021). Digital coding game, on the other hand, offers an entertaining playground to support interactive coding practices (Giannakoulas & Xinogalos, 2018). The platform embraces goal-oriented tasks and instant progression feedback, enabling a low entry bar for young children (Zhang et al., 2021).

Since the outbreak of COVID-19, the world has been going through dynamic changes. In the educational field, the biggest influence lay in the teaching mode, where physical face-to-face instructions have been hindered. Thus, technology-based distance learning has become the main solution to the schooling system (Daniel, 2020). The situation has driven us to explore proper instructional approaches to allow student-centered learning practices. For CT education, due to the portability of tangible materials and the low entry bar of entertaining games, unplugged activities and digital coding games appear to be highly applicable in distance learning and individual practices in home-based settings.

This study aims to introduce an instructional unit implemented during COVID-19, where unplugged activities and digital game-based learning approach were applied in a CT course designed for children aged 5-7. We intend to explore the effectiveness of the course in both cognitive and attitudinal aspects and offer suggestions for CT early childhood education. The study is guided by the following research questions.

RQ1: What was the effect of the course on students' CT cognitive performance?

RQ2: What was the effect of the course on students' coding attitudes?

2. METHOD

2.1. *Participants*

Through convenient sampling, a public primary school in Hong Kong was invited to deliver the course. As the course targeted lower primary students, pupils from Grade 1-3 were invited, and a total of 57 students agreed to participate, comprising of 1st and 3rd graders. Note that this cohort did not have any CT or coding learning experience at school before the intervention, and thus they were considered novices in coding and CT.

2.2. *Lesson Design*

The Coding Galaxy-Foundation course (CG-Foundation) was used. CG-Foundation aims at introducing CT and basic coding concepts to young children, aged 5–7, without any prior experience in coding. Six chapters from the course were taken to conduct six lessons (see Table 1). The course activities and explanations involve age-appropriate everyday examples that children can relate to, emphasizing that the concepts apply to daily problem solving as well as computer coding. In addition to using everyday examples, some activities also connect CT to other school subjects, such as reading and mathematics. The course focuses on exploring CT and coding concepts for problem-solving, instead of using a specific coding tool to learn to program.

Comprehensive teaching materials were provided to teachers to conduct each lesson, highlighting the concepts, objectives, and details for each activity. Each lesson contained three sections, namely, a) concept introduction, b) unplugged activities, and c) digital game practices. First, a CT concept was elaborated with daily life examples (Figure 1). Then, unplugged activities were assigned, embracing board games where students could manipulate tangible objects (e.g., cards) to complete the tasks based on the taught concept (see Figure 2). Students need to identify viable routes and use the available cards to work out the solutions. Lastly, the CG game app was applied (see Figure 3), which contained coding puzzles corresponding to the CT concepts in the lessons. In the game, players can control the character to lead him to the destination with simple coding languages. For each task, related coding commands for the solution were provided, which can be added to the panel on the right through drag and drop.

The overall structure of the game was designed to focus on introducing the topics one at a time, providing a progression from easy to difficult puzzles with one or more concepts involved. Successful completion of the puzzles involved the correct application of the concepts, and the player would be rewarded in the game with stars (see Figure 4). Three stars were awarded for the optimal solution, where an accurate route was executed with the fewest commands while collecting all the crystals. Two stars were awarded for identifying a semi-optimal route or missing collecting some of the crystals. One star was awarded to those who use an inefficient route to the destination, implying a lack of pattern recognition and path optimization skill.

*Table 1.*Selected Lessons and Descriptions.

Lesson	Key concept	Description
1	*Sequences, Decomposition*	Learn the importance of sequences in doing things through decomposing everyday examples, giving clear instructions.
2	*Sequences, Events*	Learn that “events” trigger responses, and reflect on surrounding observations of applications of “events”.
3	*Sequences, Relative direction*	Arrange sequential instructions for routes using relative direction commands, relating to the concept of direction in mathematics.
4	*Debugging*	Find and correct errors in existing instructions.
5	*Loops, Pattern recognition*	Identify patterns in problems, and use loops in setting up solutions.
6	*Conditionals*	Identify conditionals in daily life to make decisions and plans.

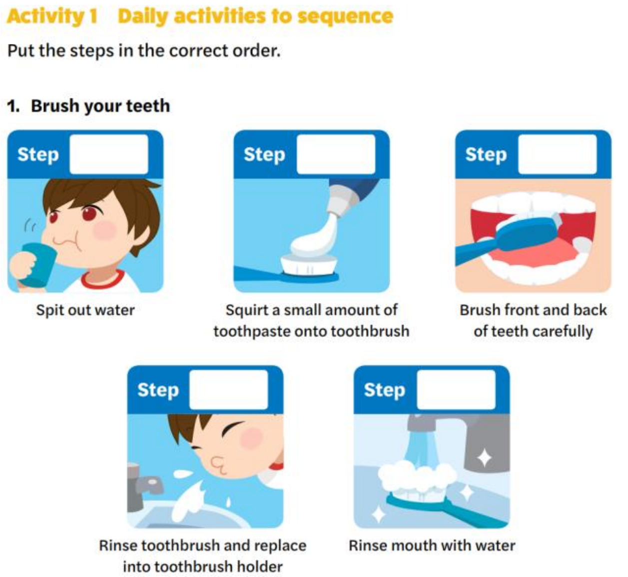

Figure 1. Activity based on Daily Examples.

Figure 2. Unplugged Activities.

Figure 3. CG Game-Puzzle.

Figure 4. CG Game-Rewarding Page.

2.3. Measurements

Two instruments were adopted for this study. The instrument for CT cognitive performance was adapted from Computational Thinking Test for Lower Primary (CTtLP, Zhang et al., 2021). The target age group of CTtLP was 6-9, which is suitable for our participants. Eighteen items were selected, covering the relevant CT concepts of the course. Proper psychometric properties were yielded in the original study in the Chinese context.

For assessing students' coding attitudes, Elementary Student Coding Attitudes Survey (ESCAS) (Mason & Rich, 2020) was adopted. Three factors were selected from the scale, namely, coding confidence, coding interest, and coding utility. The Chinese version of the scale, ESCAS (Chinese), was validated (Zhang et al., 2022), yielding adequate psychometric evidence. Thus, ESCAS (Chinese) was adopted.

2.4. Procedure

Six lessons were administered, covering the six chapters in Table 1. The course was delivered online via ZOOM, due to the pandemic situation. In the first and last lesson, apart from teaching, a pretest and post-test were delivered respectively, consisting of CTtLP and ESCAS (Chinese).

3. RESULT

Due to the age differences, the test results for each grade were extracted, with 27 1st graders and 30 3rd graders, and findings will be reported by grade levels.

3.1. RQ1: Effect on CT Cognitive Performance

The effect on CT cognitive performance was analyzed with paired sample t-test, and the bar chart is presented in Figure 5. For Grade 1, scores decreased slightly from 10.48 (SD=6.10) to 9.37 (SD=4.87), yet not significant (p=0.31). Grade 3 performed better than their Grade 1 counterparts, having a mean of around 11 for both tests, with 11.53 (SD=5.22) and 11.03 (SD=5.42) respectively, while no difference was detected between the tests (p=0.47). This indicates that students' CT cognitive performance remained stable for both grades.

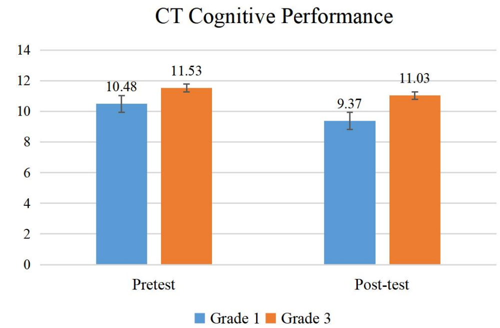

Figure 5. Bar chart of CT performance scores.

3.2. RQ2: Effect on Coding Attitudes

Coding attitudes were measured in three facets, namely, coding confidence, coding interest, and coding utility. Paired sample t-test was used to examine the change in the three dimensions before and after the intervention. Results for coding confidence are displayed in Figure 6. For both grades, an improvement could be seen between pretest and post-test, with 3rd graders yielding a bigger increase from 4.32 (SD=1.44) to 4.70 (SD=1.17). Regarding coding interest (see Figure 7), while no obvious change was detected for 1st graders, an upward trend was observed for 3rd graders, climbing moderately from 4.45 (SD=1.55) to 4.85 (SD=1.13). Similar findings were generated from coding utility (see Figure 8), where Grade 3 students saw significant growth from 4.20 (SD=1.42) to 4.91 (SD=1.21) ($p<0.05$). The results illustrate that Grade 3 students seemed to benefit more from the course, with observed improvement in multiple attitudinal facets towards coding.

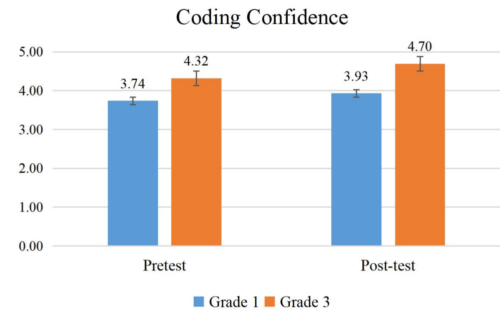

Figure 6. Bar chart of Coding Confidence.

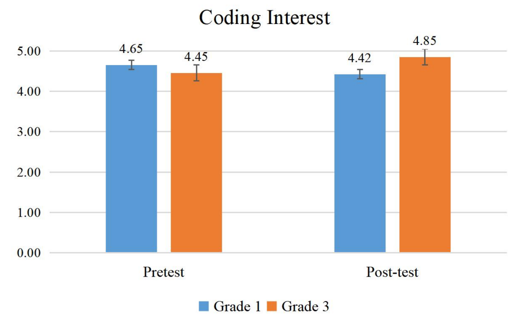

Figure 7. Bar chart of Coding Interest.

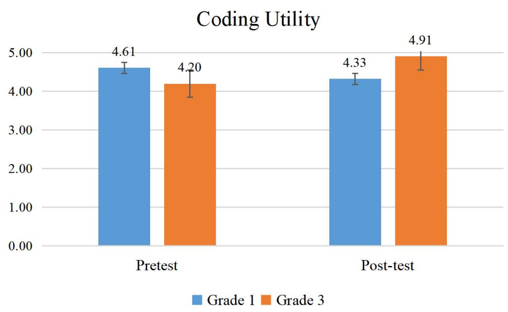

Figure 8. Bar chart of CT Coding Utility.

Further, we identified the pre-post changes across gender groups. While neither gender differences nor apparent changes were seen for coding interest and coding utility, unexpected results were found regarding coding confidence. Figure 9 displays the bar chart of coding confidence, illustrating that there was no difference between gender groups in the pretest, with both groups reporting a score of around 4, whereas in the post-test, females rated their confidence much higher (N=27, mean=4.46, SD=1.31), even surpassing their male counterparts (N=30, mean=4.22, SD=1.28). The results imply that girls might be greater beneficiaries of the course for gaining more confidence in coding afterward.

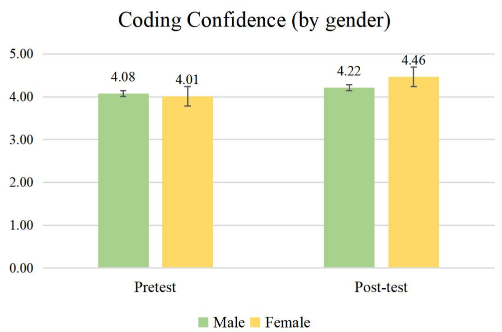

Figure 9. Bar chart of Coding Confidence by Gender.

4. DISCUSSION AND CONCLUSION

This study introduced an instructional unit of a CT course designed for young children aged 5-7, CG-Foundation, where unplugged activities and digital game-based learning approach were applied. Six lessons were taught to Grade 1 and Grade 3 students in a public primary school in Hong Kong. Each lesson was composed of concept introduction, unplugged activities, and digital game practices. Due to the pandemic situation, CG-Foundation was delivered online. The instructional design of the lessons allows for distance teaching, as the portability of unplugged materials and playfulness of digital games enabled student-centered learning practices.

The effectiveness of the course was examined regarding cognitive attachments and attitude change. Results indicate that students' CT performance remained constant. This is understandable under the pandemic case, where children's learning efficiency may be influenced in a home-based learning context. Also, six weekly sessions may be too short to cause dramatic growth. On the other hand, coding attitudes yielded positive results, with female and Grade 3 students being the main beneficiaries. Girls owned more confidence in coding after taking the course, and 3rd graders saw a significant improvement in coding utility and moderate increments in coding confidence and coding utility. Overall, CG-Foundation is an applicable course for lower primary students to learn basic CT concepts, which is viable for both physical and distance learning contexts.

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