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Development of Computational Thinking Concepts in Scratch Programming

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Abstract: Young learners can use block-based programming environments to develop their computational thinking (CT), but as previous studies suggest, students' CT concepts development should not be taken for granted. This paper presents a study of the development of CT concepts of repetition, conditionals, and sequences in senior primary school students through an interest-driven curriculum in a four-day Scratch programming summer camp. The participants were 30 students, 17 boys and 13 girls, who had just finished grade 4. A mixed methods design was used, with quantitative data to examine the effectiveness of the curriculum in developing students' CT concepts and qualitative data to explore the students' learning when creating their final projects. Based on the pre- and post-test results of a CT concepts test, significant improvements were found for each of the concepts, with a particularly large effect size on repetition. This was in line with the design of the curriculum, which placed slightly more emphasis on repetition. An analysis of the students' final projects indicated that the girls' groups were more likely to choose the theme of storytelling over creating a card. In general, the students tended to use the concepts and features that were taught more in the curriculum, and were able to use them in a creative way in their final projects.

Keywords: Computational thinking concepts, Concept development, Primary school students, Project outcomes, Scratch programming

1. Introduction

The development of students' digital creativity is an important educational goal in the 21st century. Pioneers such as Seymour Papert laid the foundations for this goal along with the seminal paper by Wing, who suggested that computational thinking (CT) should be an essential skill for everyone (Wing, 2006). CT has since been incorporated into K-12 education worldwide (Tang, Chou, & Tsai, 2019), and the development of visual block-based programming environments such as Scratch has allowed even young learners to develop CT by using these environments (Brennan & Resnick, 2012). Although promising results have been achieved in students' CT development, empirical studies have revealed that students can still encounter difficulties in learning CT concepts when using these block-based environments (Zhang & Nouri, 2019). This paper presents a study of the development of senior primary school students' CT concepts through an interest-driven curriculum with a focus on the core CT concepts of repetition, conditionals, and sequences, in a four-day Scratch programming camp.

2. Literature Review

CT involves "solving problems, designing systems, and understanding human behavior, by drawing on the concepts fundamental to computer science" (Wing, 2006, p.33). Brennan and Resnick (2012) proposed a CT framework consisting of three dimensions: 1) the CT concepts students engaged with in programming; 2) the CT practices developed through engaging with the concepts; and 3) the perspectives formed about the world and oneself through CT activities. As block-based programming environments have become increasingly popular in recent years, studies have been conducted into students' learning of CT concepts, as reviewed in the following section.

2.1 CT concepts development when using block-based programming environments

Among the various CT concepts that can be found in the literature, sequences, repetition (loops), and conditionals were identified as the basics for young learners (Zhang & Nouri, 2019). Franklin et al. (2017) found that a high percentage of grade four to grade six students were able to finish tasks related to sequences, and concluded that the concept was accessible to students at grade four or even earlier. The concept of repetition may be more difficult for students (Grover & Basu, 2017), and they may not know the conditions and procedures required to terminate a loop (Grover, Pea, & Cooper, 2015), but some students were found to improve their understanding of repetition after learning in Scratch (Meerbaum-Salant, Armoni, & Ben-Ari, 2013). Meerbaum-Salant et al. (2013) found that students were able to grasp the concept of conditionals, but they may not fully understand the concept, particularly when the conditional block was combined with other blocks, such as nested within a forever loop (Lye & Koh, 2018). These studies suggest that it cannot be assumed that students' understanding of CT concepts will necessarily improve when using a block-based programming environment.

2.2 Research questions

In this study, we examined the effectiveness of an interest-driven curriculum in developing students' understanding of key CT concepts. The research questions were: 1) Did primary students' CT concepts improve significantly after attending a four-day Scratch programming summer camp? How did they apply the concepts they had learned in the summer camp in the final projects they created?

3. The Curriculum

The curriculum was designed to develop the CT competency of Primary 4 students and encourage their digital creativity. Based on Brennan and Resnick's (2012) CT framework, it involves interest-driven learning activities that trigger, immerse, and extend their interest in computational thinking and foster their learning habits (Kong, 2016) using Scratch programming. The Interest-driven Creator (IDC) theory indicates that it is important to arouse learners' interest while increasing their computational thinking capabilities and enforcing learning habits (Kong, 2016). Thus, developing CT concepts with guided learning resources and creative tasks that encourage their creativity is essential. These learning habits can be further extended through the primary 5 and 6 curricula, which are not covered in this paper. This curriculum consists of seven units and a final project, as shown in Figure 1.

1. Creative Computing		✓	✓		✓		✓
2. Dancing Cat			✓		✓		✓
3. Make a Maze Game	✓		✓	✓		✓	
4. Tell a Joke		✓	✓		✓		
5. Tell a Story		✓	✓		✓		
6. Make Magic	✓		✓	✓	✓	✓	✓
7. Computational Arts			✓		✓		✓
Final Project	Game	Digital Narrative	Digital Animation	With Physical Computing	Sequences	Conditionals	Repetition
	Types of Activities				CT Concepts		

Figure 1. Computational thinking curriculum for Primary 4 students

This curriculum was designed to engage students through step-by-step guided activities, including creating games, stories, animations, and integrating physical computing objects for arousing students' interests (Farris & Sengupta, 2016). After completing the seven units, the students paired up to design and implement their own projects using the CT concepts they had learned. They could either create a card or tell a story. This enabled them to apply their CT capabilities and digital creativity.

Sequences, repetition, and conditionals are the three core CT concepts taught in the curriculum, as shown in Figure 1. Four of the seven units in the curriculum involved **repetition**, and this was reinforced through authentic learning experiences to consolidate the learners' understanding. In particular, the "Computational Arts" unit required learners to draw a square by duplicating the codes for drawing a line and then turning 90 degrees to the right four times. By asking the students whether a

pattern could be identified and what could help to simplify the task, they were able to see the actual value of repetition. **Sequences** relate to the order of code blocks. In Scratch, "broadcasting" can be regarded as a type of sequences that addresses the time-dependent issue, particularly in projects that involve digital narratives and animations, such as storytelling. The units of "Tell a Joke" and "Tell a Story" allowed students to understand the CT concept of sequences, and how they could articulate a story smoothly and sequentially. **Conditionals** were involved in the two game-making units "Make a Maze Game" and "Make Magic." Here, interactions with users were enabled based on algorithms specified as conditions. The interest of the learners was aroused through playing the games and was further extended as they became immersed in coding and debugging.

4. Methodology

4.1 Research Method

A mixed methods design was implemented, with quantitative data to examine the development of students' CT concepts, and qualitative data to assess their learning when creating projects.

4.2 Participants and the summer camp

The participants were 30 primary students, 17 boys and 13 girls, who had just finished grade 4 at the same school. Their average age was 10. Over the four days, they were taught by an instructor who was involved in the development of the curriculum. Their school teacher was in the classroom but was not involved in the teaching. The seven units were taught in the first two days and the morning of the third day, and the students completed their projects over the third and fourth days. They then presented their projects. In completing the projects, students worked in pairs, which were assigned by their school teacher. The total instructional time, including the students' presentations, was around 16 hours.

4.3 CT concepts test

A multiple-choice CT concepts test was developed to assess student learning in the summer camp. This involved three categories of CT concepts: 1) "repetition", running the same sequence several times; 2) "conditionals", decision-making based on conditions; and 3) "sequences", identifying the steps of a task. As mentioned, these are all important concepts in the design of the curriculum. The test contained 14 items, with 4 "repetition", 6 "conditionals", and 4 "sequences" items respectively. For example, in a conditionals item, students were presented with codes with an if-then block, and were asked to select what would happen when the codes were executed. The test lasted for 30 minutes. The overall consistency of the test, as indicated by the Cronbach alpha in the post-test of this study, was 0.70.

4.4 Students' projects and classroom observation

The projects created by students were first analyzed by examining the choice of project themes, and second, by examining the blocks in the Scratch projects to determine the CT concepts applied. Besides, during the project presentation of students, a researcher sat at the back of the classroom and took field notes as a form of non-participant observation. The notes consisted of the description of the events and the thoughts of the researcher (Creswell, 2015). The notes helped us understand how the students applied the concepts they had learned and their digital creativity in completing the projects.

4.5 Procedures

The students answered the CT concepts test at the beginning of the first day of the camp (pre-test). Then at the end of the fourth day, they answered the test again (post-test). Each time they had 30 minutes to complete the test. They were told to finish the test alone and no discussion was allowed.

5. Results

5.1 CT concepts

We averaged the correctness of all items to represent an overall score for the CT concepts. We also averaged the correctness of items of the categories of repetition, conditionals, and sequences respectively. Table 1 gives the results of the paired sample t-tests, which indicated significant improvements for the CT concepts test as a whole and for individual concepts. To examine the effect size of each comparison, we calculated the Cohen's d, with a value of .20, .50, and .80 indicating a small, medium, and large effect size respectively. The results in Table 1 suggest a large effect for repetition and a medium effect for conditionals and sequences.

Table 1. *Paired t-tests of CT concepts with effect sizes*

	Pre-test		Post-test			Effect size
CT concepts	Mean	SD	Mean	SD	t-value	(Cohen's d)
Repetition	.63	.31	.83	.27	4.25***	.78
Conditionals	.66	.27	.73	.28	2.84**	.52
Sequences	.59	.15	.68	.21	2.26*	.41
Overall	.63	.18	.75	.19	5.11***	.93

*: p<.05; **: p<.01; ***: p<.001

To examine whether there was any gender difference in the learning gains of the students in terms of CT concepts, an Analysis of Covariance (ANCOVA) on the post-test scores, with the corresponding pre-test scores as covariates, was conducted. The gender differences were not significant for any of the concepts, implying that both boys and girls gained similarly in terms of each CT concept.

5.2 Analysis of student projects

The project groups consisted of six groups of girls, eight of boys, and one mixed group. Projects under the theme of "birthday card" could further be differentiated into those applying features learned in computational arts and those applying other Scratch features. Four of the six girls' groups chose storytelling in their projects, as did the mixed group. One girls' group chose birthday card with computational arts and the other chose birthday card with other Scratch features. The choice of theme of the boys' groups was more diverse, with three choosing storytelling, five choosing birthday card with computational arts, and two choosing birthday card with other Scratch features. Table 2 presents how the CT concepts or Scratch features appeared in the projects. "Repetition" appeared in all projects of birthday card using computational arts. The use of "conditionals" was not that frequent in any project category. "Broadcast" as a form of "sequences" appeared in all projects with computational arts, two thirds of the birthday card projects using other Scratch features, and half of the storytelling projects.

Table 2. *Percentage of projects with the appearance of concepts*

	% of appearance			
CT concepts/ Scratch features	Storytelling projects (n=8)	Birthday card using computational arts (n=4)	Birthday card with other Scratch features (n=3)	All projects (n=15)
Repetition	37.5%	100%	33.3%	53.3%
Conditionals	12.5%	25%	0%	13.3%
Broadcast	50%	100%	66.7%	66.7%

5.3 Student learning in projects

Students' learning could also be indicated in the classroom observations of their project presentations. One of the boys' groups created a project under the birthday card theme by using

what they had learned in the computational arts unit. Their program began with the drawing of two snowflake patterns simultaneously, one at the top and the other at the bottom of the screen, as shown in the left of Figure 2. After drawing the patterns across the screen, the letters "HAPPY BIRTHDAY" appeared, as shown in the right of Figure 2.

Figure 2. Birthday card by drawing two snowflake patterns at the top and bottom simultaneously

In their presentation, the students mentioned that the most difficult part was to synchronize the drawing of the two patterns. As Figure 2 shows, the upper pattern consisted of squares, which took less time to draw than the pattern at the bottom consisting of circles. The students addressed this problem by intentionally manipulating the number of loops, creating redundant squares at the top so that the drawing times required for both top and bottom patterns became similar. Thus, although only 12 squares were needed to draw the snowflake pattern at the top, by trial and error they increased this to 32 squares for synchronizing the drawing time. This suggested that they were able to apply what they had learned about the concept of repetition and use it creatively to address their specific problem.

6. Discussion

In this paper, the development of students' understanding of CT concepts is examined through an interest-driven curriculum in a four-day Scratch programming camp. The results of the CT concepts test indicated significant improvement in the understanding of all the concepts assessed. A large effect size was found for the concept of repetition, which was in line with the curriculum design in which students were exposed to the concept of repetition in several units. The concept of conditionals was covered in two of the units, significant improvement was still found, although the effect size was not as large as that of repetition. The appearance of CT concepts and Scratch features in the students' final projects was also in line with the design of the curriculum, as repetition and broadcast had a higher percentage of appearance than conditionals. These results imply that the application and development of CT concepts are strongly affected by the curriculum design, which supports the literature suggesting that the development of students' understanding of CT concepts should not be taken for granted (Zhang & Nouri, 2019), and the design of the curriculum is critical.

When examining the choice of project themes, it was found that the girls' groups were more likely to choose storytelling. Other studies have suggested that storytelling could be a possible strategy for enhancing girls' interest in CT activities (Burke & Kafai, 2012). However, the difference in gender preference for project themes did not appear to affect the students' conceptual development, as there was no gender difference in the improvement in the understanding of any of the CT concepts. Thus, although storytelling projects may not involve the concept of repetition as much as projects with computational arts (see Table 2), the girls in this study still improved their understanding of the concept of repetition as much as the boys did. Thus, storytelling could be embedded in the curricular design to enhance the learning interest of girls, and such a design would not limit their development of the understanding of CT concepts.

Developing digital creativity is an important educational goal in the 21st century. The case presented in this study suggests that students were able to apply the CT concepts they had learned, and even use them creatively in their projects. They manipulated the number of loops to create redundant squares so that the drawing time could be synchronized, but they had not been taught this in the curriculum. Thus, in solving the synchronization problem they faced, they applied the concept of repetition creatively. The results suggest that with sufficient time to explore and create their own final

projects and with the solid foundation of CT concepts developed in previous units, students are able to apply their CT knowledge and exercise digital creativity.

6.1 Limitations

One limitation of this study was that it involved a pre-post design, with no control group included for comparison, hence the development of students' CT concepts might not be due to the curriculum but other factors. However, the t-test results suggested that the students improved more on the concept of repetition than conditionals, which was in line with the curriculum design. Moreover, as the setting was in a four-day summer camp, the results might not be generalizable to other contexts. Hence further studies are needed to see whether the curriculum is effective in an ordinary classroom context.

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