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REGULAR ARTICLE

Designing Unplugged and Plugged Activities to Cultivate Computational Thinking: An Exploratory Study in Early Childhood Education

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Abstract Educators and policy makers have increasingly recognized the importance of computational thinking (CT). Despite the growing body of CT literature, how to cultivate CT is still underexplored and undertheorized in early childhood education. Informed by Piaget's Theory of Cognitive Development, this exploratory study was conducted with a focus on three CT skills: pattern recognition, sequencing, and algorithm design. The framework for the study was developed in two stages. First, we designed two sets of unplugged activities (relying on tangible materials), aiming to (1) provide students with more concrete experiences of CT and (2) equip them with the necessary vocabularies/instructions for the subsequent plugged activity (with a digital device). The theoretical foundation for such an unplugged and plugged design comprised Piaget's Theory of Cognitive Development and Asher's Total Physical Response. In the second stage, we offered our CT course in a kindergarten in Hong Kong, involving six teacher participants and a total of 11 students from K1 to K3 (aged 3 to 6). After 10 h of CT training, almost all students demonstrated their mastery of pattern recognition and sequencing. However, the K1 students could only partially complete the tasks of algorithm design while the others generally reached the target level of achievement. Strengthening preschoolers' training on CT language and differentiated instruction are some possible strategies to improve the CT instructions.

Keywords Computational thinking · Activity design · Early childhood education · Preschoolers

Introduction

In the last decade, computational thinking (CT) has attracted much attention from educators and researchers in various education contexts (Hsu et al. 2018; Grover and Pea 2013; Shute et al. 2017). Leveraging the concepts (e.g., algorithmic thinking) in computer science, CT is a way to address real-world situations and solve problems (Buitrago Flórez et al. 2017). Undoubtedly, CT is essential for programmers and people in the field of computing and information science. With the extensive application of computing and computers, CT becomes a basic skill for everyone today (Chen et al. 2017; Grover and Pea 2013). Wing (2006) even stated that CT is as important as reading, writing, and arithmetic competencies.

Educators and policy makers have realized the importance of CT education. Recently, curricular reforms have been launched to promote CT education in several Asian regions, such as China, Hong Kong, and Taiwan. In Hong Kong, for example, the Education Bureau (2016) advocated equipping students with CT skills. As Buitrago Flórez et al. (2017) asserted, CT skills must be taught at an earlier age in order to initiate students' cognitive development. In 2017, the Bureau further published a supplementary document of primary school curriculum, kicking off CT education in Hong Kong primary education (see Education Bureau 2017 for a review). Indeed, there is evidence that students can start learning CT at the primary school level (Hsu et al. 2018; Lye and Koh 2014; Shute et al. 2017). In children's earlier years, several early studies done in some western countries have suggested that

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children as young as 4 to 6 years old can build and program simple robotics projects (Cejka et al. 2006; Kazakoff et al. 2013). However, the feasibility of cultivating CT in early childhood education is still underexplored compared to the primary and secondary school levels in the Asian region (see Hsu et al. 2018; Shute et al. 2017 for a review). More recent research work on CT education in children's early years is required (Manches and Plowman 2017).

Learning CT well is not necessarily easy for young learners because it requires a deep understanding of problem-solving, computer programming, and handling abstract concepts (Buitrago Flórez et al. 2017; Looi et al. 2018). As a result, they may not be able to cope with the cognitive-challenging CT tasks. How can we address this challenge? Recently, Looi et al. (2018) use "unplugged" or technology-free activities that enable some ninth graders to physically manipulate the object to explore computational concepts, such as sorting. Their students were asked to sort several cups from lightest to heaviest. They found that their unplugged CT activities could serve as scaffolding to promote students' CT learning. In early childhood education, however, research to explore using both unplugged and plugged activities together for cultivating CT remains limited and undertheorized.

This exploratory study aims to overcome the research gap by (1) designing CT activities for early childhood education and (2) documenting the findings as the groundwork for future CT education in preschool settings. The framework for the study is thus developed in two stages. First, we draw upon Piaget's Theory of Cognitive Development, Asher's Total Physical Response, and relevant literature to support the design of CT activities for preschoolers (aged 3 to 6). The first stage of our study contributes to our knowledge of how we can teach CT—more specifically pattern recognition, sequencing, and algorithm design—in early childhood education. Second, we present our intervention in a kindergarten in Hong Kong, involving six teachers and their classes. The following research questions guided the second stage of our study:

1. How do preschoolers perform in the CT activities?
2. How do preschool teachers perceive the CT activities?

Conceptual Framework

We first draw on Piaget's Theory of Cognitive Development as a theoretical foundation for our study. Following that, we provide an overview of the CT literature. This section continues to discuss the importance of language acquisition in CT education. More specifically, a widely used language learning strategy in early childhood education, called Total Physical Response (Asher 1977), is adopted. Based on the theory and relevant literature, several CT activities for preschoolers are developed.

Theory of Cognitive Development

According to Piaget's Theory of Cognitive Development, people pass through four primary stages of development: sensorimotor, preoperational, concrete operational, and formal operations. His contribution on cognitive development provides educators with crucial insights into how students learn in different ages. Educators can thus design learning activities according to students' stage of cognitive development. Some researchers, however, do not regard Piaget's theory as an unproblematic one. They, more popularly known as the Neo-Piagetians (e.g., Robbie Case and Kurt Fischer), challenge Piaget's work and attempt to create theories that address the criticisms (see Young 2011 for a review). Case (1992), for example, believed that the age-related nature of Piaget's theory does not appear to be correct. In his words, Piaget's picture of cognitive development is "too monolithic, universal, and endogenous" (p. 10). Feldman (2004) compared the theories of Piaget and Case. He pointed out that there are four large-scale stages in Case's theory that superimpose directly onto the aforementioned stages of Piaget but with different labels for three of the four stages; Case further divided these stages into substages. Despite this new idea to challenge Piaget's work, the Piagetian stages still serve as general guides to cognitive development (Feldman 2004) and are frequently used in the research of early childhood CT education (e.g., Armoni 2012; Bers et al. 2014; Kazakoff and Bers 2012). Therefore, in this study we draw on his work as a theoretical foundation. Figure 1 shows the key characteristics of Piaget's four stages of cognitive development (summarized from Sigelman and Rider 2012, p. 49).

In Hong Kong, the age of kindergarten students (i.e., preschoolers) ranges from 3 to 6 (K1 = 3 to 4; K2 = 4 to 5; K3 = 5 to 6). In other words, they are in the preoperational stage of Piaget. In this stage, children exhibit an increase in language and symbolic thinking ability. As Sigelman and Rider (2012) described, they "can use words as symbols to talk about a problem and can mentally imagine doing something before actually doing it" (p. 49). Despite their capacity for symbolic thought, they lack the tools of logical thought. As a result, they have to rely on their perceptions which, however, are easily deceived by appearances. To facilitate student learning in the preoperational stage, Armoni (2012) and Ojose (2008) suggested tangible materials, such as blocks, be incorporated with learning tasks. Ojose (2008) further highlighted the importance of teacher–student conversation (e.g., questioning) and observation during lessons. Based on students' voices and

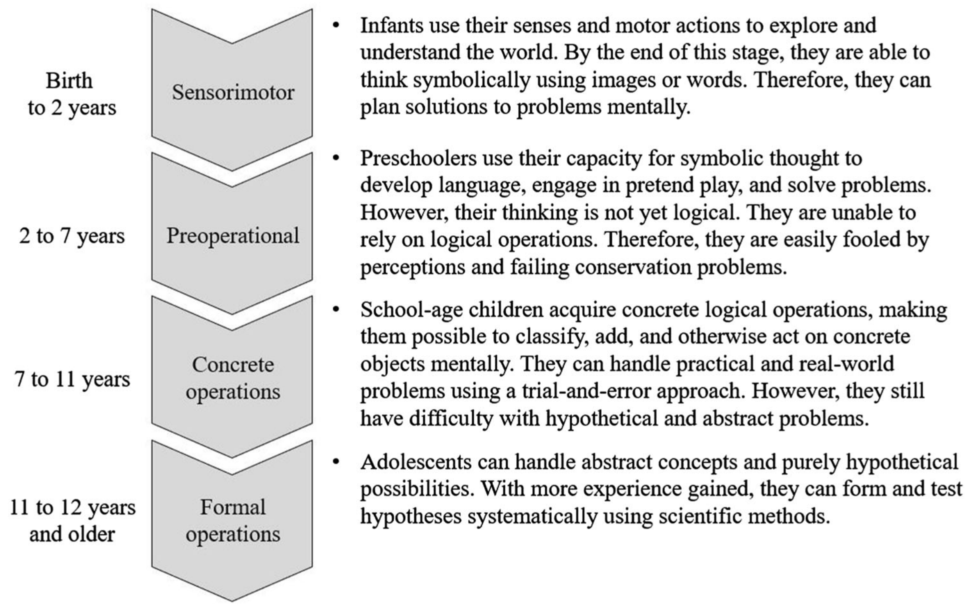

Fig. 1 Piaget's four stages of cognitive development

acts on problem-solving, teachers can infer their mechanisms of thinking and offer proper aid or feedback to facilitate students' CT learning (Bers et al. 2014; Hsu et al. 2018; Ojose 2008).

Computational Thinking

A highly cited paper by Wing (2006) laid the foundation for subsequent discussions on CT education. A very first description of CT, as she outlined, is a process of "solving problems, designing systems, and understanding human behavior, by drawing on the concepts fundamental to computer science" (p. 33). Since then, CT has become popular and appealing to the academic community (Grover and Pea 2013; Lye and Koh 2014; Shute et al. 2017). Compared to the time of Wing (2006), multiple elements have been added explicitly to the body of CT literature. For example, Angeli et al. (2016) propose a five-element conceptual framework for CT (i.e., abstraction, generalization, decomposition, algorithms, and debugging). A recent review by Hsu et al. (2018) further identifies 19 thinking steps of CT across studies including pattern recognition, algorithm design, and simulation, among others.

Through the lens of Piaget's Theory of Cognitive Development, *pattern recognition* and *algorithm design* are two possible CT skills that can be introduced to preschoolers. Pattern recognition involves an observation of patterns, trends, and regularities in data or other objects (Hsu et al. 2018). For algorithm design, Buitrago Flórez et al. (2017) defined it as "a way of obtaining a solution through a series of steps" (p. 836). Angeli et al. (2016) and Shute et al. (2017) added that *sequencing* is an essential CT concept for algorithm design. Shute et al. (2017) shared an example of algorithm design activities in which students have to find the shortest path in a maze that fulfills some specific criteria. For example, students are required to insert a sequence of directional arrows to guide "a leprechaun" (a character of a story) to "a pot of gold" (a targeted position to be reached) without hitting obstacles. Recall that children in the preoperational stage are able to use symbols (e.g., images and words) to represent objects and events (Sigelman and Rider 2012). In theory, after appropriate training, they can (1) recognize patterns that involve symbols and (2) use symbols or simple words to present sequences and algorithm designs.

However, children in the preoperational stage rely on their perceptions to solve problems (Sigelman and Rider 2012). Therefore, tangible materials should be used to cultivate their CT. One possible strategy is to offer unplugged (without devices) CT activities prior to their plugged (with devices) counterpart (Looi et al. 2018). CS Unplugged (https://csunplugged.org/), for example, provides various activities that cultivate CT through tangible materials, such as puzzles and cards, without using digital devices (Angeli et al. 2016). Having more concrete experiences of CT in unplugged activities can help preschoolers have a better foundation for cultivating CT in plugged contexts.

Language in Computational Thinking

In addition to CT skills, Bers et al. (2014) pointed out that "children must understand in general that people use symbolic language to communicate with computers, and they must select specific instructions to accurately represent their intended outcome" (p. 150). Although children in the preoperational stage can use symbols and language (Sigelman and Rider 2012), CT activities (e.g., program a robot) may involve some specific computer-related language that they are not familiar with. Therefore, students should first be introduced with the necessary vocabularies and instructions prior to CT activities.

From the Piagetian perspective of language and education, educators should provide younger children with opportunities for interactions with the physical environment (Sigelman and Rider 2012). In a similar manner, Asher (1977) emphasized the essence of learning language through physical actions. His Total Physical Response is a widely used language learning strategy in early childhood education, suggesting that "understanding should be developed through movements of the student's body" (p. 4). The premise of Asher's Total Physical Response theoretical perspective is consistent with the embodied cognition view (Choi and Kim 2015). According to the embodied cognition theory, motor movements or gestures can activate images in working memory and help facilitate encoding (Richardson et al. 2003). In other words, meaningful gestures with speech have a positive influence on verbal information memory and thus support young children's cognitive development (Macedonia et al. 2011).

Bui (2018) continues to add that pre-class preparations and classroom teaching are two important stages of implementing Asher's Total Physical Response. Before the lesson, teachers should set achievable objectives with reference to students' language ability. Relevant visual and audio materials can be prepared accordingly. During the lesson, teachers can demonstrate an action and give its corresponding commands. To strengthen students' association between the action and commands, vocabulary drills are the major activities in which meaning can be clarified via physical movements (Bui 2018). In early childhood education, Er (2013) states that Total Physical Response is most effective when the learning activities are reinforced with games, songs, and stories. This kind of activities can also create an enjoyable, fun, and interesting environment to engage preschoolers in the learning process (Er 2013).

Designing CT Activities for Preschoolers

In this study, the plugged CT activity that we chose was Bee-Bot (https://www.bee-bot.us/). Bee-Bot is a programmable robot with a mat (Fig. 2) which is suitable for the children in the preoperational stage (Angeli et al. 2016). The device (i.e., Bee-Bot) can be controlled by several buttons, such as backward/forward and rotation to the left/right buttons. Users can enter their programmed sequence for executing a series of commands. The goal of the Bee-Bot activity is to guide using commands of the Bee-Bot to a targeted position, such as a treasure as printed on the mat, without hitting obstacles (e.g., waterfall and forest). Referring to Shute et al. (2017), the minimal CT skills involved in the Bee-Bot activity are *sequencing* and *algorithm design*. To establish a foundation for learning CT, an introduction to *pattern recognition* can serve as a starter to cultivate students' sense of order (e.g., an array of symbols). As discussed in the previous section, children in the preoperational stage are able to learn these three CT skills. They, however, largely rely on their perceptions (Sigelman and Rider 2012). Therefore, teaching in an unplugged environment using tangible materials can provide them with more concrete experiences to cultivate their CT (Looi et al. 2018).

The first set of our unplugged activities includes LEGO pattern and sequencing stories (Fig. 3). LEGO pattern is a hands-on pattern building activity for students to learn pattern recognition. Starting with some simple color patterns of LEGO bricks (e.g., orange–blue–orange–blue), the sense of patterns can be cultivated. Teachers can further ask their students to continue the pattern using suitable LEGO bricks. When students are able to recognize those simple patterns, teachers can stretch their ability using more complicated patterns (i.e., with both colors and shapes varied). For sequencing stories, the main CT focus is sequencing. Students are required to arrange several pictures of story scenes in a correct sequence. Taking "Everyday events" as an example, there are six pictures of daily routine. Students should arrange the pictures in the order of (1) wash and brush teeth, (2) breakfast, (3) school, (4) lunch, (5) playtime, and (6) go home. With the ability of pattern recognition and sequencing, students are better prepared to design a path with its corresponding sequence of commands in the Bee-Bot activity.

The second set of our unplugged activities includes Vocabulary building songs, Direction game through cards, and Tic-Tac-Toe (Fig. 4). This set of activities leverages the language learning strategy of Total Physical Response (Asher 1977; Bui 2018; Er 2013), aiming to visually and verbally introduce students with necessary language to

Fig. 2 A Bee-Bot (lower right corner) with a Bee-Bot mat

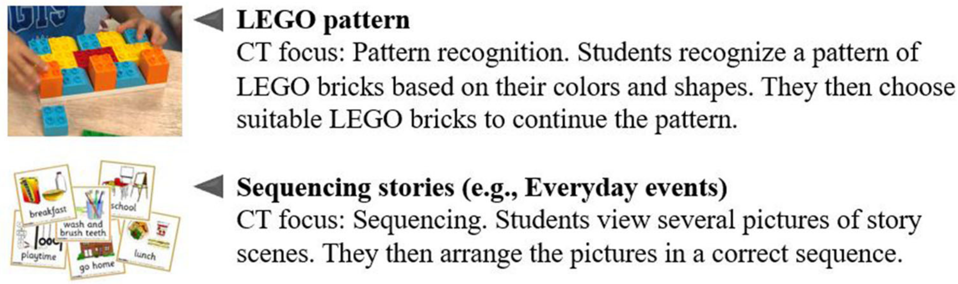

Fig. 3 Major unplugged activities to cultivate CT

express and apply their CT in the Bee-Bot activity. Therefore, physical movements are incorporated in this set of activities. Taking "Tic-Tac-Toe" as an example, it is a game in which a student acts as a robot and a teacher (or another student) gives verbal commands. These commands are some positional and directional language, such as "turn around" and "six steps forward." Following these commands, the student moves from one position to another. According to Asher (1977), students can better acquire the language through this kind of physical actions.

With the CT skills and necessary language acquired in the above unplugged activities, teachers can introduce algorithm design in the Bee-Bot activity (i.e., Direction game with Bee-Bot). As a transition to this plugged activity, teachers can first conduct the unplugged Direction game using the Bee-Bot mat (Fig. 5). Arrow cards are used when designing algorithms to guide the Bee-Bot. In the words of Armoni (2012), "The goal is that this concrete knowledge will in due time evolve or transfer to more general and abstract contexts" (p. 19). Meanwhile, students can get used to the setting and rules of the Bee-Bot activity. Upon the completion of the unplugged Bee-Bot activity, students can start their algorithm design and input their commands into the Bee-Bot. To stretch their ability of algorithm design, teachers can alter the difficulty levels of the direction game, such as defining additional treasures/obstacles and bringing the Bee-Bot back to the starting position.

Method

Research Design and the CT Course

Figure 6 summarizes the procedures for implementing our study. In the first stage, we designed several unplugged and plugged activities as mentioned in the "Designing CT Activities for Preschoolers" section. With reference to prior research in early childhood education (e.g., Hsu et al. 2018; Israel et al. 2015), we expected that not all kindergarten teachers were familiar with CT education. They might get frustrated by new instructional practice. In fact, the lack of computer skills and pedagogical knowledge are also some major teacher perceptions about teaching CT in other contexts, such as primary and secondary schools (e.g., Ling et al. 2017; Wu et al. 2018).

To address the possible challenges to new instructional practice, we drew on a highly cited framework for professional development and teacher learning by Borko (2004). His framework is based on the situated learning theoretical perspective. In the words of Adler (2000), situated theorists view teacher learning as "a process of

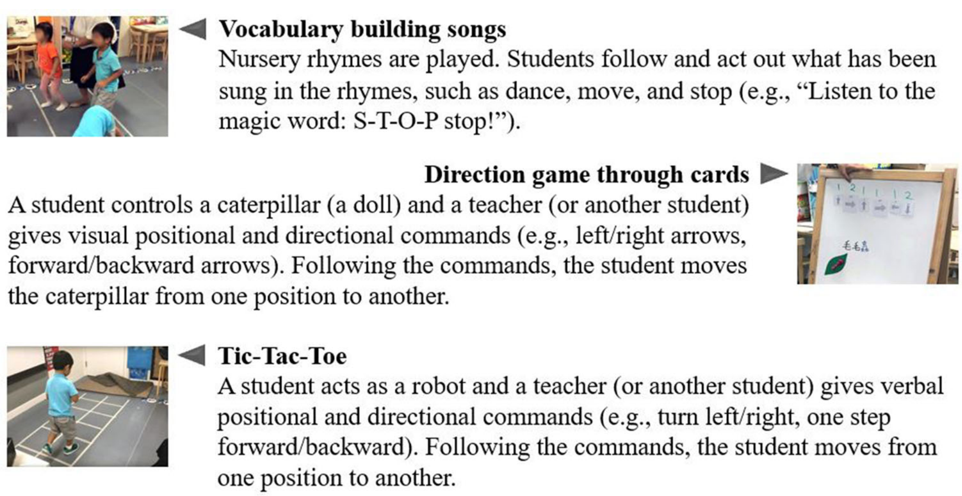

Fig. 4 Major unplugged activities to acquire language for the Bee-Bot activity

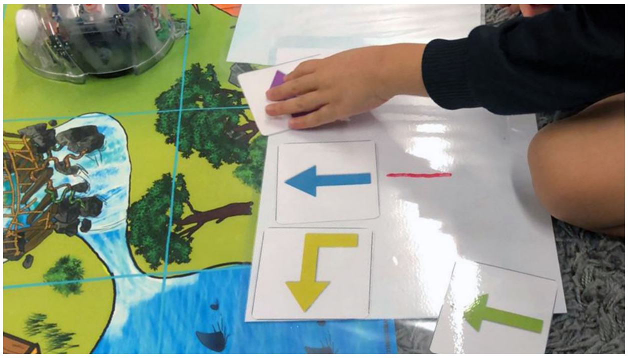

Fig. 5 Direction game through arrow cards with a Bee-Bot mat

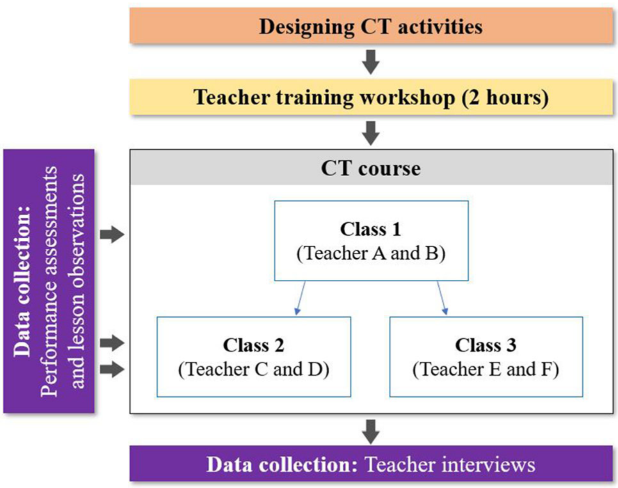

Fig. 6 Procedures for implementing the study

increasing participation in the practice of teaching, and through this participation, a process of becoming knowledgeable in and about teaching" (p. 37). From the situative perspective, what people learn is grounded in the contexts and activities in which they learn (Greeno et al. 1996). Borko (2004) thus summarized that teacher learning occurs in multiple aspects, involving facilitators, teachers, professional development programs, and contexts (Fig. 7).

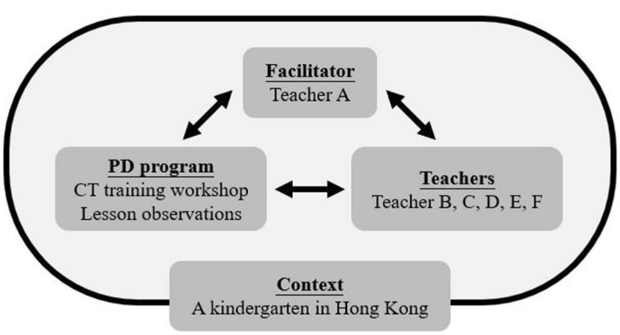

Fig. 7 Framework for the professional development (PD) system

In Borko's (2004) framework, teachers must first understand the central facts about the subject they teach. It is therefore important that professional development programs, led by experienced facilitators, focus explicitly on the specific subject matter. The facilitators must understand the goal of the program well. Borko (2004) further argued that the use of the teachers' authentic classrooms provides essential contexts for facilitating teacher learning because they can fully relate and apply what they have learned into actual practice.

In this study, the first author (the facilitator) offered a 2-h training workshop as a professional development program for five kindergarten teachers, during which the concepts and instructional strategies of CT were introduced. The facilitator is an experienced CT teacher who had received doctoral level training in conducting CT activities. In addition to the workshop, the teachers learned how to conduct the CT activities by observing the CT lessons of the facilitator (Teacher A).

In the next stage, we administered our CT course in a kindergarten in Hong Kong. Three individual classes were run, involving three groups of preschoolers (an average of 3 to 4 students each). The CT course was 1 week in duration, consisting of five 2-h lessons (i.e., a total of 10 h). We delivered five CT activities in each lesson. Each activity lasted for 20 to 30 min. Although some activities were rerun throughout the course in difference lessons, the difficulty level increased progressively. For example, the first activity of each lesson was LEGO pattern. During the first few lessons, students were required to describe some simple LEGO patterns (i.e., with different colors only) and continue the patterns using LEGO bricks. Toward the end of the course, more complicated patterns (i.e., with both colors and shapes varied) were presented. A detailed course rundown is provided in Appendix 1.

Research Context and Participants

As mentioned above, this study was conducted in a kindergarten. In Hong Kong, pair teaching is a common practice in preschool settings. Such a practice not only facilitates student learning but also enhances classroom management. Therefore, each class was taught by two teachers; of the three classes, a total of six teachers participated in the study (Table 1). Their teaching experience ranged from 3 to more than 15 years. All the teacher participants were novice CT educators, except for Teacher A who had received doctoral level training in CT instructions.

Our CT course was offered as an enrichment course during summer. Student participation was entirely voluntary. All K1 (aged 3 to 4), K2 (aged 4 to 5), and K3 (aged 5 to 6) students in the kindergarten could enroll in the course. We successfully obtained a parental consent for study from

Table 1 Information on the teacher participants

Class	Teacher	Teaching experience	Experience of CT instructions
Class 1	A (the first author)	Over 15 years	Received doctoral level training in CT instructions
	B	7 years	Novice
Class 2	C	6 years	Novice
	D	3 years	Novice
Class 3	E	13 years	Strong interest in teaching CT and coding
	F	6 years	Novice

11 student participants ($N_{K1} = 3$; $N_{K2} = 6$; $N_{K3} = 2$). Despite the small number of student participants, this study lays some important groundwork for us to examine and test our unplugged and plugged CT activities in early childhood education. It can provide insights for other researchers to scale-up our study in other preschool contexts.

Data Collection and Analysis

Our research questions were addressed using three major sources of data, including performance assessments, lesson observations, and teacher interviews. Figure 8 provides an overview of the data sources and their corresponding purposes.

To assess students' CT learning, we adopted the 6-point Likert scale (ranged from 0 to 5) rubric of performance assessments by Bers et al. (2014). As they defined, a score of 4 or above is "the target level of achievement" (p. 149). Their assessment rubric was developed in the context of early childhood CT education, and thus suitable for our study (see Appendix 2). Three assessments were conducted toward the end of the CT course, including LEGO pattern (pattern recognition), Sequencing stories (sequencing), and Direction game with Bee-Bot (algorithm design). To enhance the reliability, student performance was rated by two researchers. Inter-rater reliability was high (91%). In the event of disagreements, the two researchers would review the lesson recordings together to come to a consensus.

Lesson observations had been done throughout the course as children's verbalization and actions on CT materials reflect their thought processes (Ojose 2008). Similar to Israel et al. (2015), we took detailed field notes of student performance and interactions as well as teachers' instructional practices during the CT activities. Lessons were video-recorded and transcribed in order to detect excerpts that could provide information to address the research questions (Fessakis et al. 2013). To protect students' privacy, we had ensured that their faces were outside the camera view or having their images blurred in any forms of public disseminations. All field notes were typed and shared among researchers for analysis (Israel et al. 2015).

Finally, all the six teacher participants were interviewed to understand, from their perspectives, students' CT learning and their implementations of the CT activities. We adopted a semi-structured interview approach, and the interview protocol was developed based on Israel et al. (2015). For example, "Have you faced any challenges in implementing [the CT activities]? Probe for additional information and examples" (p. 278). We first transcribed the interview data, and then performed a series of qualitative data analysis procedures proposed by Creswell (2012). The interview data were thematically analyzed and organized into categories by the second and third authors. To enhance the consistency of coding, exemplary quotes were identified to illustrate each constructed category/subcategory. Any disagreements between the two coders were resolved through discussion to come to a consensus.

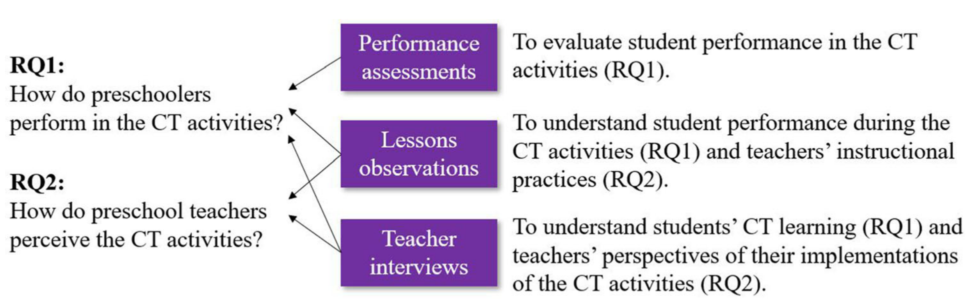

Fig. 8 Overview of the data sources

Findings

The findings are presented in two subsections according to the sequence of the research questions.

RQ1: How do Preschoolers Perform in the CT Activities?

Figure 9 shows that almost all students were able to reach the level of complete achievement or mostly complete achievement in the assessments of pattern recognition (LEGO pattern) and sequencing (Sequencing stories). For algorithm design (Direction game with Bee-Bot), however, only 7 out of 11 students could be rated as reaching the target level of achievement. Those students who had got partially complete achievement were from K1 (n = 3) and K2 (n = 1).

From the teacher interviews, further qualitative evidence could be identified to support the above quantitative results of student performance. Teachers' comments included

- Pattern recognition: *After the LEGO activity, they (the students) learned patterns and shapes.* (Teacher F)
- Sequencing: *In the unplugged sequencing activities, children were able to give the correct sequence of story cards.* (Teacher A)
- Algorithm design: *Children could follow the instruction and design a path to move the robot on the mat.* (Teacher B)

Regarding the K1 students' failure to reach the target level of achievement, some teacher participants offered the following explanations:

- *I would say directional understanding of K1 students was challenging.* (Teacher F)
- *K1 children faced difficulty in saying or linking directional vocabularies to the directions.* (Teacher A)

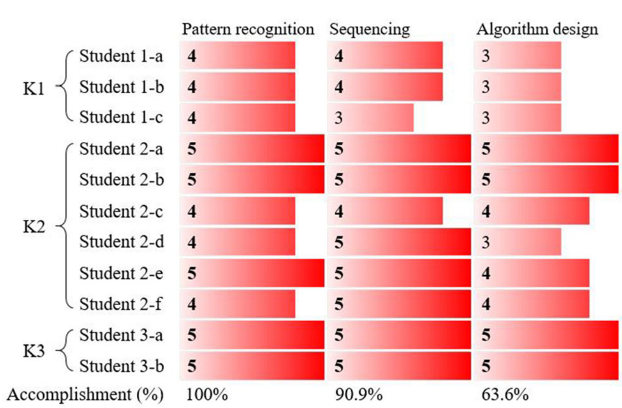

Fig. 9 Student performance of each CT skill (Note: a score of 4 or above is the target level of achievement)

RQ2: How do Preschool Teachers Perceive the CT Activities?

Overall, the teacher participants reported positive sentiments about the use of our CT activities with their students. First, some teachers (n = 3) found teaching CT to be fun and interesting. As they expressed during the interviews,

> *Teaching them [the students] sequencing and directional games was fun, and they learned a lot through those unplugged activities.* (Teacher B)

Second, all teachers (n = 6) confirmed that the unplugged activities could provide their students with concrete experiences to cultivate CT:

- *It was good to start from concrete to abstract learning.* (Teacher F)
- *Visual orientation and visual cards activities were done. Tangible cards helped them to plan the path.* (Teacher E)

Third, several teachers (n = 4) explicitly mentioned that they found the use of the unplugged activities to be useful. More specifically, these activities helped the students *apply* the CT skills to the plugged activity (i.e., the Bee-Bot activity). Their views are extracted as follows:

- *In my class, children learned more about patterns and applied it in coding through arrow cards and eventually the Bee-Bot.* (Teacher F)
- *Taking some concepts through unplugged activities that they already have some experiences with and using these to apply with the technology helped them to respond quickly and understand better.* (Teacher E)

Despite the positive sentiments, three major practical challenges of our CT intervention were identified. First, most of our teacher participants (n = 5) lacked the knowledge of CT instructions. As they expressed during the interviews,

- *I went to the bookfair and I got exposed to this term [computational thinking]. I don't know much but it looks like high-tech things.* (Teacher B)

Regarding the training (i.e., workshop and class observation) that we provided, the teacher participants (n = 5) found that class observation was an effective way for them to equip the instructional strategies of CT education. As one teacher mentioned,

- *I have got learning and teaching strategies from [Teacher A]. Observations help when I don't have experience of how to teach CT.* (Teacher C)

The second challenge was about learner diversity in class. The teachers (n = 4) from two classes specifically pointed out that the K1 students got confused with the direction while the others did not:

- *Mixed ability kids—K2 knows direction but K1 students were not able to follow direction. So, it was challenging.* (Teacher C)
- *It was hard as it was mixed age group. … Most of the K2 and K3 students were good but I think the K1 students were struggling a bit with the activities.* (Teacher F)
- *When they need to send the Bee-Bot to a specific location on the map, some children got confused. They had difficulty in visualizing multiple steps of the Bee-Bot.* (Teacher E)

Several teachers ($n = 3$) therefore suggested (1) strengthening the teaching of directional language and (2) dividing students into different classes by age:

- *Direction from Nursery rhymes was a great idea if it is done for longer.* (Teacher F)
- *Next time, please use separate age group to learn as their abilities are different.* (Teacher C)

Besides the above challenges and their suggestions, a few teachers ($n = 3$) foresaw that the current resources were only enough for a week and suggested more resources be developed:

- *The CT course materials for this lesson planning were good enough. But for longer coding class, we should have more resources.* (Teacher F)

However, the design and production of both plugged and their corresponding unplugged activities were time consuming. In the words of one teacher participant, "*At first I was a bit overwhelmed*" (Teacher F). Especially, designing appropriate unplugged activities and their corresponding materials to cultivate preschoolers' CT required significant intelligent input (Teacher A).

Discussion

The findings pertaining to each research question are discussed in two subsections: (1) student attainment and lessons learned about the activity design, and (2) practical challenges and possible solutions. After that, we acknowledge several limitations of this study and provide recommendations for future research.

Student Attainment and Lessons Learned about the Activity Design

CT is a basic skill that everyone, even preschoolers, should equip (Chen et al. 2017; Grover and Pea 2013). In order to cultivate their CT, we first provided them with some hands-on learning experiences using the unplugged activities (e.g., LEGO pattern). The theoretical foundation of such a practice is based on Piaget's Theory of Cognitive Development. In early childhood education, the theory suggests the use of tangible materials which can provide preschoolers with more concrete experiences to cultivate CT (Armoni 2012; Ojose 2008). We found that almost all of our students could accomplish the tasks of pattern recognition and sequencing. Extending previous research on early childhood CT education (e.g., Bers et al. 2014; Fessakis et al. 2013; Kazakoff and Bers 2012), this study provides more concrete evidence that children in the pre-operational stage could acquire these two CT skills in unplugged environments.

Besides the unplugged activities for cultivating CT, we designed several unplugged activities to equip our students with the necessary language for the subsequent plugged activity (i.e., the Bee-Bot activity). The importance of these activities can be reflected in their possible confusion about directional language. More specifically, even though we had gone through this set of activities with our K1 students (aged 3 to 4), they did not fully comprehend those vocabularies/instructions (e.g., turn left/right) used in the Bee-Bot activity. By contrast, Bers et al. (2014) did not report such a problem when relevant language and instructions were introduced. However, it is important to notice that their student participants were 5 to 6 years old while our study involved some younger students in K1 (aged 3 to 4) and K2 (aged 4 to 5). The findings of our study indicate that more training on directional language is needed especially for K1 students (aged 3 to 4) to establish a solid foundation for subsequent CT activities.

In the plugged activity, most K2 and K3 students could apply the concepts learned in the pattern recognition and sequencing activities. The students could design a correct path to guide the Bee-Bot even in some complicated problems (e.g., having multiple treasures/obstacles defined and bringing back the Bee-Bot). This finding echoed with the existing literature that children at age 5 could start to program (Bers et al. 2014; Fessakis et al. 2013; Kazakoff and Bers 2012). Most importantly, our study provides preliminary evidence that the use of the unplugged activities could foster most students' accomplishment in the plugged CT activity.

However, not all students could demonstrate their mastery of algorithm design. We found that the K1 and a few K2 students had difficulty in using directional language during the Bee-Bot activity. Also, our teacher participants pointed out that they "had difficulty in visualizing multiple steps of the Bee-Bot" (Teacher E). Besides strengthening their training on CT language, we can allow these students to use arrows (as a temporary substitute of verbal commands) to represent their algorithm design. Furthermore, differentiated instruction is another possible strategy to cater to learner diversity in CT education. While more advanced problems (e.g., up to 5 to 7 steps) can be given to the more capable students, teachers can first offer some problems that consist of 2 to 4 steps for the younger or less capable ones. In other words, achievable goals should be set according to students' CT and CT language ability, even though they are in the same age group or stage of cognitive development.

Practical Challenges and Possible Solutions

Apart from learner diversity in the CT course, two practical challenges were identified. First, our teacher participants doubted their competence of CT instructions. Consistent with Hsu et al. (2018) and Israel et al. (2015), there is a need to provide professional training especially for those teachers with no or limited CT knowledge. In addition to CT workshops, another possible strategy that we used was lesson demonstration. As our teacher participants expressed, they could learn a lot (e.g., executing lesson plans and CT activities) from observing authentic CT lessons. This finding confirms Borko's (2004) framework for professional development and teacher learning. More specifically, the facilitator had guided the teacher participants to construct new knowledge and practices of CT instructions.

Second, although our teacher participants suggested creating more CT resources for future practice, the design and production of instructional materials required a considerable investment of teacher effort. Especially, the connection between unplugged and plugged CT activities should be carefully established, making the preparation work overwhelming for some teachers. However, Glass et al. (1981) point out that the practical importance of an intervention relies on its costs and benefits. Despite the significant amount of start-up effort, the CT instructional materials can be reused when rerunning the courses. Resonated with Looi et al. (2018), such effort could facilitate students' CT learning. The production of learning resources is therefore cost-effective in the long run. In future practice, teachers can produce and accumulate CT resources progressively so that the preparation workload is manageable.

Limitations and Recommendations for Future Research

Although this study provides evidence that the unplugged and plugged activities could cultivate preschoolers' CT, our findings should not be over-generalized due to two limitations. First, our CT activities mainly focused on pattern recognition, sequencing, and algorithm design. Further research is required to examine whether our CT activity design is applicable to cultivate other CT skills (e.g., decomposition and debugging) in early childhood education.

Second, although we presented both quantitative and qualitative evidence of student performance in different grades (i.e., K1, K2, and K3), the generalizability of our findings was limited by the small number of student participants. We therefore suggest future studies be scaled up by involving more student participants with different ages in the preoperational stage. Researchers may also consider testing the feasibility of cultivating CT in pre-kindergarten contexts.

Conclusion

This study tested the feasibility of cultivating CT in early childhood education and has laid a useful preliminary groundwork for the implementation of CT education in preschool settings in Hong Kong. Based on Piaget's Theory of Cognitive Development, we focused on cultivating three CT skills (i.e., pattern recognition, sequencing, and algorithm design) and developed several unplugged and plugged CT activities for kindergarten students. Using tangible materials, our unplugged activities aimed to provide students with more concrete experience of CT. Leveraging Asher's Total Physical Response, another set of unplugged activities was designed to acquire students with the necessary language for subsequent CT learning. Students could thus have a better foundation for the plugged CT activity that involved a digital device (i.e., the Bee-Bot). We found that the K2 (aged 4 to 5) and K3 (aged 5 to 6) students could generally demonstrate their ability of pattern recognition, sequencing, and algorithm design. By contrast, the K1 students failed to design a correct algorithm in some complicated problems. However, one should exercise caution when viewing our findings because of the small sample size. In future research, we suggest scaling up this study by introducing more CT skills and involving more student participants with different ages in preschool settings.

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Appendix 1

See Table 2.

Table 2 Activity plan of the CT course

Time	Day 1	Day 2	Day 3	Day 4	Day 5
20 min	LEGO pattern	LEGO pattern	LEGO pattern	LEGO pattern	LEGO pattern
20 min	Story telling	Sequencing stories	Direction game with cards	Direction game with cards	Direction game with cards
30 min	Sequencing stories	Direction game using a Bee-Bot mat	Direction game with Bee-Bot	Direction game with Bee-Bot	Direction game with Bee-Bot
30 min	Vocabulary building songs	Vocabulary building songs	Vocabulary building songs	Vocabulary building songs	Vocabulary building songs
20 min	Direction game with cards	Direction game with cards	Tic-Tac-Toe	Tic-Tac-Toe	Tic-Tac-Toe

Appendix 2

See Table 3.

Table 3 The rubric of performance assessments for CT activities (Bers et al. 2014, p. 149)

Score	Description
5	Complete achievement of the goal, task, or understanding
4	Mostly complete achievement of the goal, task, or understanding
3	Partially complete achievement of the goal, task, or understanding
2	Very incomplete achievement of the goal, task, or understanding
1	Did not complete the goal, task, or understanding
0	Did not attempt/Other

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