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Leung, Suzannie K. Y.; Wu, Joseph; Li, Jenny Wanyi

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Children’s knowledge construction of computational thinking in a play-based classroom

Suzannie K. Y. Leung, Joseph Wu and Jenny Wanyi Li

Department of Curriculum and Instruction, Faculty of Education, the Chinese University of Hong Kong, Hong Kong, Hong Kong; Department of Social and Behavioural Sciences, City University of Hong Kong, Hong Kong, Hong Kong

ABSTRACT

This study investigated the development of computational thinking (CT) in young children within the specific context of Hong Kong. The researchers utilized an unplugged digital arts activity to explore the CT knowledge exhibited by children and document their developmental trajectories. A sample of 23 children aged 3 to 6 years participated in an animation art workshop conducted in a Hong Kong kindergarten. The video data were recorded and analyzed in terms of content. Drawing on a three-dimensional framework combining powerful ideas for teaching coding, the observations and field notes revealed that children’s CT knowledge construction aligned with the CT conceptual framework. Notably, older children demonstrated more advanced competences and more complex cognitive structures in terms of the design process, representation, algorithms, modularity, sequences, connecting, choices of conduct, and utilization of hardware/software. These findings emphasize the importance of designing age-appropriate curricula that foster children’s CT skills through the animation art.

Computational thinking (CT) refers to a cognitive approach to problem-solving that involves formulating problems, breaking them down into smaller components, and organizing and expressing solutions in a manner that is comprehensible to humans and executable by machines (Wing, 2006). The importance of CT is reflected in many twenty-first-century competences, such as creativity, critical thinking, and problem-solving (Ng & Cui, 2020). In recent years, stakeholders in K–12 education have shown a growing interest in cultivating CT to develop media literacy and problem-solving skills (Organisation for Economics and Co-operation Development [OECD], 2018). The continuous advancements in coding, coupled with the availability of engaging unplugged activities suitable for children, have led to investigations into the most effective strategies for integrating CT into K–12 education.

Since a developing child does not possess fully mature literacy, numeracy, or abstract reasoning skills (Piaget, 1971), educational initiatives relating to CT in young children must consider the progression of cognitive development. From a developmental perspective (Piaget, 1971), kindergarten children are typically in the preoperational or concrete operations stage. At that period, children tend to engage in concrete, egocentric thinking, and they are just beginning to develop knowledge of symbolic meanings and representation. A young child’s stage of development can constrain the
CT knowledge and skills that they can readily master (Goldstein & Flake, 2015). For instance, kindergarten children may have difficulty grasping if–then statements and abstract representations such as variables (Müller, Overton, & Reene, 2001). Therefore, CT frameworks designed for children’s learning must be children-friendly and developmentally appropriate.

Computational thinking framework

There is ongoing discussion regarding whether CT is a singular concept (Grover & Pea, 2013). Brennan and Resnick (2012) proposed a framework for examining and evaluating the development of CT in young learners. This framework comprises three essential dimensions: (1) computational concepts, (2) computational practices, and (3) computational perspectives. Shute, Sun, and Asbell-Clarke (2017) conducted an analysis of various CT concepts and classified CT skills into six main aspects: decomposition, abstraction, algorithm design, debugging, iteration, and generalization. Zhang and Nouri (2019) identified three types of definitions of CT found in the published literature: generic definitions that emphasize universal problem-solving skills, operational definitions that provide terminology and identify specific sub-domains of CT, and educational definitions that offer concepts and competences related to CT. Tang, Yin, Lin, Hadad, and Zhai (2020) later differentiated CT definitions that are programming-oriented from those that pertain to general problem-solving abilities.

In terms of CT frameworks in early childhood education (ECE), Bers (2018) proposed a framework for teaching coding and other CT concepts that is developmentally appropriate for children aged 4–9 years. This framework involves seven powerful ideas, which are child-friendly concepts relating to the following domains: design process, representation, control structures, debugging, algorithms, modularization, and hardware/software. More recently, Zeng, Yang, and Bautista (2023a) redeveloped the three-dimensional framework of Brennan and Resnick (2012) through a systematic review of 42 studies. Adapting to the ECE context, Zeng et al.’s (2023a) new CT curriculum framework includes CT concepts (i.e. control flow/structures, representation, and hardware/software), CT practices (i.e. algorithmic design, pattern recognition, abstraction, debugging, decomposition, iteration, and generalizing), and CT perspectives (i.e. expressing and creating, connecting, perseverance, and choices of conduct). It is worth noting that the core elements of the three-dimensional CT framework are similar to the seven powerful ideas, with the exception of the additional part on CT perspectives, which makes the CT knowledge framework more comprehensive and logical. We adopt the CT frameworks of Bers (2018) and Zeng et al. (2023a) because of their relevance to the CT learning of the age group involved in this study.

Children’s self-directed learning from the perspective of cultural construction

The concept of self-directed learning (SDL) was discussed in popular scholarly works during the 1960s and 1970s (Knowles, 1970, 1975; Rogers, 1969; Tough, 1971). SDL is a process whereby people individually regulate and execute their learning objectives to achieve lifelong goals and plans. The ability to perform SDL successfully has become a fundamental competence enabling adults to handle and adapt to the rapidly changing world (Morris, 2019). Therefore, in addition to its use for personal and informal experiences, SDL should be fostered in various formal education settings. Historically, learning theories are grounded in behaviourism (Murtonen, Gruber, & Lehtinen, 2017). However, children are no longer regarded as passive learners in a teacher-directed learning process (Morris, 2019). To prepare learners for adult life and empower them to respond to complex contextual changes in their societies, SDL underpinned by constructivism is crucial (Boyer, Edmondson, Artis, & Fleming, 2014; Jossberger, Brand-Gruwel, Boshuizen, & van de Wiel, 2010; Morris, 2019).

As discussed by Beckers, Dolmans, and Van Merriënboer (2016), SDL encompasses various dimensions. For instance, Sawatsky, Ratelle, Bonnes, Egginton, and Beckman (2017) emphasized
three dimensions of SDL: (1) the management of learning tasks, (2) the learner’s personal characteristics, and (3) contextual factors that influence a learner’s inclination toward SDL. Additionally, some scholars have emphasized a cognitive dimension of SDL. Morris (2019) explored the concept of SDL based on humanistic philosophy, pragmatic philosophy, and constructivist epistemology, which respectively describe a learning process that is individualistic, purposeful, and developmental. From a pragmatic perspective, self-directed learners tackle real-life problems (Jonassen, 1999) and view learning as a means for personal growth (Groen & Kawaiilik, 2014).

Meanwhile, Vygotsky’s (1997) cultural–historical theory acknowledges the dynamic and evolving features of children’s knowledge construction. It is thus able to capture and investigate the development process of young learners. As suggested by Fleer’s (2021) discussion of engineering education, children’s CT learning in play-based classrooms is a dynamic and evolving process of knowledge construction that involves children’s changing thoughts and behaviours in the development process. According to Fleer (2021), play-based environments have the potential to facilitate children’s holistic development. By studying children’s changing relationships within the same play environment, it is possible to observe their CT learning in a classroom that emphasizes play.

Vygotsky (1994) argued that a cultural–historical approach should consider the child’s evolving relationship with the social and material environment as a whole. From this perspective, a unique and innovative methodology can capture the influence of the environment on the child and how the child’s thoughts and reactions change within that environment (Fleer, 2021). For example, in this study, when a child acquired new CT concepts, they could utilize the same CT resources in novel ways and develop different perspectives on creating animations.

Vygotsky (1994) also introduced the notion of the relationship between the ideal/final and real/rudimentary forms of development, positing the following:

> An ideal or final form is present in the environment, and it interacts with the rudimentary form found in children, and what results is a certain form of activity which then becomes a child’s internal asset, his [sic] property and a function of his personality. (p. 353)

The dynamic interactions between the child’s real/rudimentary developmental stage (e.g. combining geometric figures to create objects) and their ideal form of development (e.g. applying CT principles to generate a series of animated artworks) are significant aspects for investigating children’s CT learning over time. Therefore, Vygotsky’s set of relational concepts was essential for comprehending how children’s CT knowledge evolved within the play-based classroom setting of this study.

**The current study**

Children’s CT also relates to the theory of constructionism, which conceptualizes learning as actively building knowledge structures through authentic experiences of making a shareable artifact (i.e. learning by making; Papert, 1980). Papert’s (1980) constructionist framework states that children can learn deeply when they build their own projects that are personally meaningful to them and reflect thoughtfully on the learning process. Papert expanded on this framework to consider how internal constructions are supported by constructions in the external environment, including the use of digital devices and technologies. Papert (1980), later followed by Clements and Meredith (1992) and Bers, Flannery, Kazakoff, and Sullivan (2014), explained that well-designed constructivist activities incorporate powerful ideas and key concepts from specific domains that have both epistemological and personal value. These powerful ideas are linked to other subjects and are based on intuitive knowledge that children have absorbed over time (Bers et al., 2014; Papert, 1980).

The animation-making activities described in this study were composed of powerful ideas from the domain of digital arts.
We know that it is important to teach CT outside the area of computer science (CS) from as early as kindergarten (Sullivan & Bers, 2015). Moreover, previous literature has argued that coding-free instruments can be applied, as CT skills can be exercised without programming through the use of unplugged activities (Zapata-Cáceres, Martin-Barroso, & Roman-Gonzalez, 2020). Unplugged activities consist of materials (e.g. pens, cards, games, and puzzles) and physical exercise that draw on CS concepts without requiring explicit knowledge of coding or computers (Otterborn, Schönborn, & Hultén, 2020). Leaving computer programming behind, the kinesthetic senses and a constructivist approach are the key principles of unplugged activities (Bell & Varenhold, 2018).

In Hong Kong, CT-related learning and teaching for young children are not addressed in local kindergarten curriculum guides (Curriculum Development Council, 2017). Therefore, we applied animation arts as a kind of unplugged activity (by manipulating geometric paperboards) to examine how children constructed their CT knowledge in a play-based classroom in Hong Kong. Although we used camera equipment at the end of the activity, the study involved a simulation of the animation art process through an unplugged approach using unplugged materials. The study aimed to address the following research questions:

1. How did kindergarten children construct CT knowledge through SDL processes?
2. How did kindergarten children at different levels perform SDL through a series of CT activities?

**Methods**

**Research design and participants**

To explore the research questions, a design-based research (DBR) approach was employed. DBR aims to generate new theories, artifacts, and practices that both explain and potentially influence learning and teaching in authentic settings (Barab & Squire, 2004, p. 2). In this DBR study, the design component involved a series of animation-making tasks conducted as part of the research. The study recruited 23 children (K1: five girls and three boys; K2: four girls and three boys; K3: five girls and three boys) in a local kindergarten in the Kowloon district of Hong Kong. All of them live in the same district and have similar level of socio-economic status.

This group of kindergarten participants served as a case study for the study. According to Parnafes and Disessa (2013), case studies enable in-depth analysis of learning, reflecting ‘the need for extended, open, and careful consideration of data’ (p. 7). Suitable for investigations such as ours, case studies can be used to provide information about real-world, sociocultural behaviours (e.g. classroom learning) that are too diverse and uncontrolled for the methods used in laboratory studies. It was expected that the empirical results of this study would inform current debates about the effective use of scaffolding pedagogy in problem-solving and animation-making activities (Godhe, Lilja, & Selwyn, 2019).

**Procedures and design-based animation-making tasks**

The context of the study was an enrichment workshop in a local kindergarten. Entitled Animation Art for Young Children, the workshop aimed to facilitate children’s development of problem-solving skills and CT through engagement with a series of algorithm design tasks to create animation art through stop-motion techniques. Stop motion is an approach to creating animated films in which objects are manipulated in small increments between each photographed frame. This creates the illusion of independent movement or change when the frames are played back in sequence. When stop motion is applied to flat materials (e.g. paper, fabrics, and photographs), it is commonly referred to as cutout animation.
In this study, children from three class levels were divided into six groups. Each group created a piece of animation work. The 95-minute workshop was designed and taught by an instructor, and two teaching assistants helped the children design their storyboards. All the teachers in this workshop were registered kindergarten teachers holding bachelor's degrees in ECE. The workshop was designed based on a set of problem-solving skills and computer-based techniques for developing children's CT, including logical reasoning, decomposition, algorithm design, and debugging. For example, the application of storyboard writing involved algorithm design, enabling us to investigate how the children created a sequence of instructions to complete the animation work. The different tasks were as follows:

1. The activity started with a given problem. The children needed to think of solutions to solve the problem. They were invited to form a group with their peers and develop ideas on worksheets.
2. The process involved symbolic pattern recognition. The children used different polygons to build the designated objects (e.g. using a triangle to represent the meaning of a rooftop). The process revealed their understandings of shapes and gave meanings to symbols.
3. The children needed to select useful materials (e.g. blocks) to build the designated objects. They had to determine which units should be moved and kept in place. Blocks and other related materials were provided to the children for testing and preparing before the final product emerged.
4. The children put forward ideas for which objects they wanted to create. For example, if a child planned to build a house, they might decompose it into two triangles, three rectangles, and one circle. The child then wrote down the components on the worksheet.
5. The children completed the storyboards by drawing or colouring the content in a logical order, which showed the sequences of actions for the video making.
6. The video involved creating the designated subject through stop-motion video. The children broke down the designated objects into different photo slides.
7. The children followed the series that they created in the storyboards and built models for taking photos of the sequences. They had to understand the operating concepts of a stop-motion video and the functions of a camera and the images captured. For example, how should the image (as code) be placed so that the camera could receive the instructions correctly?

The children at different age levels then had to follow the series that they had created in their storyboards and build models for their sequences that would be photographed using stop-motion techniques (Table 1 and Figures 1–2).

**Data collection and methods of analysis**

Altogether, six groups of children were observed during three sets of 30-minute animation art activities. A total of 540 min of video data was recorded. Qualitative research can be described as involving ‘naturally occurring, ordinary events in natural settings’ (Miles & Huberman, 1994, p. 10), and this investigation used observation to explain how the children performed their CT through animation art-making activities. A digital camera was provided for the children's animation-making processes in the classroom. In addition, two cameras were used for data collection: One was static, and the other was handheld by a research assistant. The research assistant circulated the classroom and videotaped the children's activities to ensure naturalistic observation with minimal intervention in the workshop. The researcher played the role of an observer in the classroom and took field notes of the children's dialogues and CT behaviours.

In response to the research questions, the video data were viewed and transcribed, and episodes were selected on the basis that they were representative of the children's CT development.
The representative episodes with respect to each kindergarten grade level were categorized into a number of CT concepts according to the proposed analytical framework (Bers, 2018; Zeng et al., 2023a). Meanwhile, the teaching team for this workshop (i.e. the instructor and two teaching assistants) were invited to write reflective journals to collect their views on how the children at different levels performed their CT concepts during the entire process. The data collection included the children’s artifacts (i.e. worksheets and final products) and their videotaped working processes with animation art to facilitate data triangulation through cross-examining the data sources. By examining the children’s CT development, this study makes a contribution toward understanding how CT concepts can be explicated in young children’s unplugged activities, especially in animation art contexts.

**Table 1.** Activity design of this study.

<table>
<thead>
<tr>
<th>Sessions / Class levels</th>
<th>K1 (aged 3–4)</th>
<th>K2 (aged 4–5)</th>
<th>K3 (aged 5–6)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Storytelling 5 min</strong></td>
<td>Teacher tells a story about an old woman and her magic seeds.</td>
<td>Teacher tells a story about Olaf’s adventure.</td>
<td>Teacher tells a story about the three little pigs.</td>
</tr>
<tr>
<td><strong>Discussing the problem 10 min</strong></td>
<td>The grandmother has given a magical seed to her grandson, but her grandson has no idea how to plant it.</td>
<td>Olaf needs a snowman friend to travel the world with so that he will not be lonely. What should his buddy look like?</td>
<td>One of the pigs is asking for the children’s help because a wolf has destroyed their house.</td>
</tr>
<tr>
<td><strong>Brainstorming 20 min</strong></td>
<td>Children observe and discuss a picture of a tree with fruit and break this down into a number of smaller visual components.</td>
<td>Children observe and discuss a picture of a snowman and break this down into a number of smaller visual components.</td>
<td>Children observe and discuss a picture of a house and break this down into a number of smaller visual components.</td>
</tr>
<tr>
<td><strong>Storyboard planning 30 min</strong></td>
<td>Children plan and draft a storyboard to generate a sequence showing how a tree is growing with fruit.</td>
<td>Children plan and draft a storyboard to generate a sequence showing how a snowman is made.</td>
<td>Children plan and draft a storyboard to generate a sequence showing how a house is built.</td>
</tr>
<tr>
<td><strong>Photo taking 20 min</strong></td>
<td>Children take a series of photos that show how fruit is growing on the tree.</td>
<td>Children take a series of photos that show how the snowman is made.</td>
<td>Children take a series of photos that show how the house is built.</td>
</tr>
<tr>
<td><strong>Individual sharing 10 min</strong></td>
<td>Children share the trees that they create and their ideas for making them.</td>
<td>Children share the snowman buddies for Olaf that they create and their ideas for designing them.</td>
<td>Children share the houses that they create for the three little pigs and their ideas/rationales for making them.</td>
</tr>
</tbody>
</table>

The representative episodes with respect to each kindergarten grade level were categorized into a number of CT concepts according to the proposed analytical framework (Bers, 2018; Zeng et al., 2023a). Meanwhile, the teaching team for this workshop (i.e. the instructor and two teaching assistants) were invited to write reflective journals to collect their views on how the children at different levels performed their CT concepts during the entire process. The data collection included the children’s artifacts (i.e. worksheets and final products) and their videotaped working processes with animation art to facilitate data triangulation through cross-examining the data sources. By examining the children’s CT development, this study makes a contribution toward understanding how CT concepts can be explicated in young children’s unplugged activities, especially in animation art contexts.

**Figure 1.** The classroom setting of this study.
Findings

A problem-solving situation was created for each respective class level to engage the children in CT through animation making.

Child E, class K1 (Aged 3–4): tomato bread tree

The K1-class design activity was about inviting the children to help the grandson plant a tree and then return the grown tree as a gift to his grandmother. (Figure 3)

Teacher: Grandma has some seeds that have a magical power. When we grow them, they can be an apple tree or even a cake tree. These seeds can make wishes come true for people.
Child A: How about if we grow an orange tree?
Teacher: Of course. We could grow the seed as a mixed-fruit tree too!
Child B: I want to have a grape tree.
Teacher: What is needed to grow a tree?
Child C: It needs sunshine and water.
Teacher: Anything else?
Child D: It needs wind.
Teacher: I see. A tree can get air from the wind.
Teacher: Grandma gave a seed to her grandson. However, Grandma’s little grandson has no idea how to grow a tree. What can we do for him?
Child E: We can grow a tree for him.

The teacher said, ‘Grandma would love to give a seed to you too. What will you plant, and who will you plant it for?’ In response, Child E wished to grow a tomato bread tree for her mother. She said that the red circles stood for tomatoes, while the squares were the bread. Child E then counted the total number of various shapes and took a basket to collect the paper blocks from the materials table. (Figure 4)

Teacher: How many tomatoes are you going to plant for your mother?
Child E: Two.
Teacher: What are these squares?
Child E: Sliced bread … my mother likes purple.
Teacher: So … let’s count how many circles we have?
Child E: One, two.
Teacher: And this one also … three! This is such a big circle. … And how about the triangle?
Child E: One.

Child E then completed a storyboard for growing a tomato bread tree by colouring the areas that would be shown in that particular frame. The first frame started from a seed. A tree stem (the orange triangle)
replaced the seed in the second frame. The tree grew with leaves (the purple areas) in the third frame. The blue circles and squares were the tomatoes and bread grown on the tree. (Figures 5–7)

Teacher: What kind of tree did you plant just now?
Child E: Tomato bread tree.
Teacher: What are these circles?
Child E: Tomatoes.
Teacher: And what about the square?
Child E: Sliced bread.
Teacher: How do you eat them? Is it by putting one slice of tomato and one slice of bread together?
Child E: Yes.
Teacher: Who will you give this tree to?
Child E: Give it to mother.
Teacher: Your mother would definitely love it.

Child F, class K2 (Aged 4–5): the little pink

The K2-class design activity came from the popular Disney movie Frozen. A snowman named Olaf needs a snowman friend to travel the world with. (Figure 8)

Teacher: Will you make friends at school?
Child F: Yes, of course!
Teacher: Now, Olaf has to travel around the world alone. Do you think he needs a friend too?
Child G: Yes, I guess so.
Teacher: We have magic power to make a friend for Olaf. What does Olaf’s friend look like?
Child H: Looks like Olaf!
Teacher: Then he will be a snowman too! What are his characteristics?
Child I: He is strong, so he can help Olaf carry the luggage.
Teacher: Anything else?
Child J: He will be very quiet.
Teacher: Why?
Child J: Coz he has to listen to Olaf all the time.
The teacher asked another child to give the name and appearance of Olaf’s friend. In response, Child F wished to create a classmate for Olaf who would stay with him at school and knew how to do homework and count one, two, and three. Child F counted the total number of various shapes and placed the paper blocks on the table for her visual reference. She then wrote the details and numbers on the sheet by herself. (Figures 9–10)

**Teacher:** What’s the name of this friend of Olaf?

**Child F:** The Little Pink!

**Teacher:** Why does Little Pink need to do homework?

**Child F:** Because she will be his classmate.

**Teacher:** Other than doing homework, what will she do with Olaf as a friend?

**Child F:** She will walk and run with Olaf.

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**Figure 5.** Child E’s storyboard with drawings of a sequence that is captured in four frames.

**Figure 6.** Child E’s final four frames as a sequence of stop-motion animation through taking photos.
Child F then completed a storyboard for creating the snowman (the Little Pink) by drawing the figures that would be captured in the particular frames. The first frame started with the head and a pair of eyes (three circles). A body with a triangle tie and a rectangle scarf were drawn in the second frame. Child F added two buttons to the body in the third frame. The legs (trapezoids) were added in the last frame. (Figure 11)

Figure 7. Child E shares the tree that she creates and the ideas for making it in the sharing session.

Figure 8. The teacher discusses with the children the appearance and character of Olaf's friend.
Child F then shared the snowman (Olaf’s friend) that she had created and her ideas for making it in the sharing session. (Figure 12)

Teacher: Are these legs?
Child F: One of them can run.
Teacher: Which one can run?
Child F: The pink one.
Teacher: Oh, the pink one can run. And how about the brown one? What can the brown one do?
Child F: Walk slowly!
Teacher: So, she walks on this brown leg when she walks. And when she runs, she uses her pink leg.
Child F: Yes.

Figure 9. Child F plans how to use different shapes to create a snowman by building a model of the snowman.

Figure 10. Child F’s worksheet for planning how to use different shapes to create a snowman (the little pink).
Teacher: Can she walk and run on one leg only?
Child F: Right!

Child O, class K3 (Aged 5–6): A sturdy house

The K3-class design activity started with the classic story *The Three Little Pigs*. The children were asked for help from a pig, as a wolf had destroyed the pigs’ house. *(Figure 13)*

Teacher: What did Little Pig ask us for help with?
Child K: Build a bigger house.
Child L: Build a sturdy house.
Teacher: Let’s design a house for the three little pigs. As you said, Little Pig asked for a bigger house. How big do you think is big enough? How big is your home?
Child M: My house has three rooms.
Child N: I have one room.
Teacher: So, you must design a house big enough for the pigs. What other requirements did Little Pig have for the new house?

*Figure 11.* Child F’s storyboard with drawings of a sequence that is captured in four frames.

*Figure 12.* Child F’s final four frames as a sequence of stop-motion animation through taking photos.
Child O: Sturdy.
Teacher: How can we make a house sturdy? Will it be strong enough if we use some thin branches to build the house?
Child P: A house should have pillars.
Child Q: And use wood, so it won’t be easy to collapse.
Teacher: Right. Anything else?
Child K: We need walls to prevent the wolf from getting to the pigs!
Teacher: And? What if there is a big hole in the ceiling?
Child M: Roof!
Child Q: But no chimney, please!
Teacher: Why?

Figure 13. The teacher uses different shapes to represent the creative design of the houses.
Child Q: So the wolf cannot come down through the chimney.

Teacher: Right! We have many ideas already. Now we can start to build a house for the pigs!

The teacher initiated a group discussion on the architect who created these houses and how they look graphically. (Figures 14–15)
Teacher: The design of a house can be unique and different. Let’s have a look at houses all around the world. Look at these houses! If I wanted to build a house like that, can you tell me what shape this house is made of? What shape would I need?

Child R: I can see it’s like a triangle lying down.

Teacher: Yes, we can call this a trapezoid, which is not exactly a triangle. And you can see that we have more than one way to build it. You can use five small trapezoids or put one at the back and cover it with other shapes. This means you can design your own house with our different polygons [clicks to the next PowerPoint slide].

Child S: Wow! The house is upside down!

Teacher: Yes, wouldn’t you think this house could keep the little pigs away from the wolf? You might think about it! And would you tell me what shape this house is made of?

Child T: A window in a square shape.

Teacher: Yes, you are right. This house is made of a bunch of different shapes. Let’s see what we could use for the different parts of the house. We could also use a bigger square for the body part, a triangle for the roof, and a rectangle for the chimney. You can see that by combining our different polygons, we can build houses in all the shapes you can imagine. You can design a very special house for the three little pigs.

Child O then completed a storyboard for creating a sturdy house for the pigs by drawing figures that would be captured in six frames. The first frame started from the base of the house. A machine bar and the entrance were built in the second frame. In the third frame, the second level of the house was built above the ground floor. On top of these, the third and fourth floors were drawn in the fourth frame. The fifth floor was drawn in the fifth frame. The rooftop was built in the last frame. (Figure 16)

Child O then shared the sturdy house that he had created and his ideas for making it in the sharing session. (Figures 17–18)

Child O: Here is a door, and there is a door too. Would it be too easy for the big wolf to get inside when there are too many doors?

Teacher: Um … if the door is easy to open, it would be very dangerous.

Child O: I have an idea. Let’s lock the door.

Teacher: Great! You know how to do it.

Child O: When the big wolf comes, one of the pigs closes the door. Bing bang! The big wolf smashes down the door.

Teacher: That door is incredible! How can we stop the big wolf from going inside our house? How can we protect ourselves?

Child O: Build a machine here. It can push the big wolf away.

Teacher: Good! What shape is this machine?

Child O: Push the wolf away.

Teacher: So, when the big wolf comes nearby, the machine pushes it away! ‘Don’t come here!’ That’s why you chose a very long rectangle to build the machine. When the big wolf is still far away, the machine can detect it and push it away. It doesn’t allow the big wolf to come close.

Child O: Yah! Push it away. This part can throw flames onto the tail of the big wolf.
Discussion

In our study, three grades of kindergarten children participated in unplugged animation-making activities and constructed CT knowledge through SDL processes, such as self-design and hands-on manipulation. The findings from the data analysis of the observation videos, the children’s artifacts, and the research team’s reflective journals answered the two research questions from a qualitative perspective.

Children’s CT knowledge construction through SDL processes

By carrying out a series of animation-making tasks in a play-based classroom, the children constructed CT knowledge through SDL processes, the key point of which was to take responsibility for planning and making (Morris, 2019). Regarding humanistic philosophical assumptions (Morris, 2019), learners are autonomous and capable of making wise decisions. Humanistic learners have a sense of responsibility to themselves and possess an urge toward self-actualization. They have their own unique potential to develop their own self-concept and personal understanding of the world (Elias & Merriam, 1995; Leach, 2018). Grounded in the theory of constructivism, CT places importance on learning by doing in children’s knowledge-building processes (Papert, 1980), which aligns with SDL. The study showed that unplugged activities (without the use of programming tools) can be effective in facilitating young children’s acquisition of CT knowledge, further validating the points raised by existing studies (Li & Yang, 2023; Zapata-Cáceres et al., 2020) and providing strong empirical data on children’s CT unplugged activities. In addition, the study showed that animation art activities (by manipulating geometric paperboards) are well suited for use as a vehicle for
unplugged activities, and the combination of CT and digital art has provided new perspectives for children’s CT research.

Furthermore, guided by the cultural–historical theory of Vygotsky (1994) and Fleer (2021), we showed that a rich play environment can meet the needs of children’s dynamic knowledge absorption. This is particularly relevant for kindergartens with rich environments in which kindergarten teachers are eager to conduct play-based teaching to scaffold children’s learning in formal education settings and provide meaningful learning experiences for young children (Fleer, 2021). Fleer (2021) further explained that Vygotsky’s study of children’s learning is able to capture ‘in motion the process of children’s development’ (p. 1360). Specifically, children can better understand CT knowledge by continuously identifying and figuring out problems in play (e.g. through design-based animation-making activities).

According to Bers et al. (2014), a constructionist teaching approach allows children to freely explore their own interests through technologies while investigating domain-specific learning content and exercising metacognitive, problem-solving, and reasoning skills. In this series of activities, the teacher acted as a facilitator and supporter, and the children, as the main problem solvers, tried to solve the problems themselves. The CT knowledge that the children in this study gained through the animation art-making activities is outlined in Table 2. Previous empirical studies have shown the applicability of both Bers’s (2018) powerful ideas of CT and Zeng et al.’s (2023a) CT framework to the kindergarten curriculum, as well as their usefulness in guiding teachers’ pedagogy (Yang, Luo, & Su, 2022; Zeng, Yang, & Bautista, 2023b). In our study, the first five components of CT knowledge (i.e. design process, representation, algorithms, modularity, and hardware/software) were consistent with Bers’s (2018) powerful ideas, while the last three were in line with the CT concepts (i.e. sequences) and CT perspectives (i.e. connecting and choices of conduct) in the CT framework of Zeng et al. (2023a).

**Children’s SDL performance in relation to their developmental trajectories**

According to Nor and Saeednia (2009), SDL has two main dimensions: internal motivation and learning ability. The SDL process is not about a child’s individual learning without any dependence on others; rather, it is about ensuring that they are on the right path and learn independently under a certain degree of guidance from a teacher (Beckers et al., 2016). Based on Piaget’s (1971) cognitive development theory, children’s developmental considerations must be observed when designing CT educational programmes for young children. In this study, the children at K1, K2, and K3 age levels had different performances based on their learning abilities during the learning process.

First, the support provided by the teachers decreased with age. The teachers taught basic knowledge and conducted questioning dialogues to guide the children in engaging with the CT activities.
Table 2. Children’s CT knowledge in the process of animation art-making activities.

<table>
<thead>
<tr>
<th>CT knowledge</th>
<th>Definitions</th>
<th>Specific ideas</th>
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<tbody>
<tr>
<td>Design process</td>
<td>The design process is open-ended, consisting of the following stages: ask, imagine, plan, create, test, improve, and share (Bers, 2018).</td>
<td>Throughout the unplugged animation process, children were engaged in problem-solving thinking based on the story’s context. This was accompanied by storyboard planning and was followed by the creation of a product (using geometric paperboards). The process concluded with a sharing session. In our study, children were encouraged to select and combine different geometric shapes to perform their imaginative ideas. For example, children in the unplugged activities used circles to represent apples, trapezoids to represent the legs of a snowman, and triangles to represent the roof of a house.</td>
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<tr>
<td>Representation</td>
<td>Representation occurs when a programming language uses symbols to represent instructions (Bers, 2018).</td>
<td>Throughout the entire animation-making activities, children began by giving birth to ideas. They manipulated the tasks step by step and ended up with the creation of a final product. In addition, algorithms were also used in the animation part, which was manifested in how children captured the production process of the final work sequentially through each photo to complete the video making. For example, Child E divided the storyboard creation of growing a bread tree into four mini modules (i.e. planting the seed, growing the trunk, growing the leaves, and bearing the fruit).</td>
</tr>
<tr>
<td>Algorithms</td>
<td>Algorithms refer to a series of sequential steps in problem-solving or task processing (Bers, 2018).</td>
<td>For example, Child E divided the storyboard creation of growing a bread tree into four mini modules (i.e. planting the seed, growing the trunk, growing the leaves, and bearing the fruit).</td>
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<td>Modularity</td>
<td>Modularity means the process of breaking down big and difficult tasks into more easy and manageable units (Bers, 2018).</td>
<td>The camera used in the activities was the hardware, providing an opportunity for children to learn how to use digital devices. Software concepts were also involved, as the animations were created by using stop-motion apps.</td>
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<td>Hardware/Software</td>
<td>The computing system operation involves both hardware and software. The hardware executes the instructions given by the software; thus, they accomplish the task together (Bers, 2018).</td>
<td>The storyboard drawing and animation-making process involved sequence-related concepts.</td>
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<tr>
<td>Sequences</td>
<td>A sequence refers to a set of task-specific instructions or steps that can be implemented by a human being or a computer (Brennan &amp; Resnick, 2012).</td>
<td>During the activities, children obeyed the classroom rules and conducted their activities in an orderly manner. For example, they did not go from Zone A to Zone C in the classroom without permission, use cameras violently, or vandalize other people’s artworks.</td>
</tr>
<tr>
<td>Choices of conduct</td>
<td>Choices of conduct involve the capacity to consciously make decisions about one’s actions, such as performing respectful behaviours to others (Pugnali, Sullivan, &amp; Bers, 2017; Sullivan &amp; Bers, 2018).</td>
<td>During the activities, children obeyed the classroom rules and conducted their activities in an orderly manner. For example, they did not go from Zone A to Zone C in the classroom without permission, use cameras violently, or vandalize other people’s artworks.</td>
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<tr>
<td>Connecting</td>
<td>Connecting is embodied in two aspects: creating with others and creating for others. It focuses on communication, collaboration, and sharing (Brennan &amp; Resnick, 2012).</td>
<td>Connections with peers, teachers, and parents could be seen in the three selected children’s episodes, as evidenced by children creating artworks for their mothers, discussing and communicating details with their teachers, and sharing ideas and artworks with their peers.</td>
</tr>
</tbody>
</table>

For example, the teacher helped the K1 children count the number of shapes together, but the K2 and K3 children could do this task on their own. In addition, the K3 children were able to draw their storyboards in a direct sequence, while the K1 children needed the teacher’s guidance to complete their storyboards with different colours.

Second, the difficulty of the activity increased with age. We designed three themed activities for K1, K2, and K3 children depending on their interests, experience, and abilities. Specifically, the tasks became more challenging in the upper grades, as the children were required to use more complex materials and take more steps to create their animation art products. For example, the K3 children were provided with trapezoids and parallelograms, whereas the K1 children had only four basic shapes and the K2 children had five. Moreover, the K3 children used six frames to produce more complicated artworks than the K1 and K2 children.

Third, the depth and breadth of thinking increase with age. Children develop more ideas in CT activities as the mind matures, which is especially apparent during dialogue interactions with a teacher. For instance, when talking with K1 children, the teachers often asked questions such as ‘What’s this?’ to help the children express their ideas. However, with the K2 and K3 children, the
questions were more expanding and thought-provoking, such as ‘What are his characteristics?’ ‘Why?’ and ‘How can we make a house sturdy?’ Moreover, the K3 children were encouraged to share the rationales of their artwork creations and to engage in further problem discussions. For example, the teacher and Child O discussed how to prevent the Big Wolf from getting into the house.

**Conclusion**

Undoubtedly, CT is a necessary competence for individuals, and more and more education scholars and policymakers have emphasized its essential role in early childhood. Moreover, SDL has been mainly used in adult learning and not so much in formal educational settings in kindergartens. Our study explored how children constructed CT knowledge based on SDL theory in a play-based classroom by providing an animation art workshop for kindergarten children to engage in a series of unplugged CT activities. The study provided qualitative empirical data for CT research in the field of ECE, highlighting the necessity and importance of unplugged activities in children’s CT study. Although CT is not included in the curriculum of Hong Kong kindergartens at present, there are arts education activities that can be well integrated with CT activities, and the experience of this study can be used as a reference for kindergartens to promote children’s CT skills more effectively. In conclusion, CT is a new research hotspot in the field of ECE. By examining the integration of CT with digital art and SDL, this study has enriched CT research in terms of both diversity and novelty.

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**Notes on contributors**

**Suzannie Kit-ying Leung**, Ph.D. Dr. Suzannie Leung is an Assistant Professor in the Department of Curriculum and Instruction, the Chinese University of Hong Kong. She is an experienced practitioner in early childhood education. With her interdisciplinary background in media arts, psychology and education, she has been engaged in kindergarten teacher education, curriculum development, program design for gifted and talented children, and curatorial work for early childhood art exhibitions for many years.

**Joseph Wu**, Ph.D. Dr. Joseph Wu is currently an associate professor and also the program leader of the Master of Social Sciences (Psychology in Education) at the Department of Social and Behavioural Sciences, City University of Hong Kong. He is a registered teacher. He is an experienced teacher educator and has substantial knowledge in Hong Kong education system.

**Jenny Wan-yi Li** Ms. Jenny Wan-yi Li obtained a Master of Education degree in early childhood education from the Education University of Hong Kong. She now works as a research assistant in the Department of Curriculum and Instruction at the Chinese University of Hong Kong. Her research interests include the parent–child relationship, STEAM creativity in early childhood education, and teacher education.

**ORCID**

Suzannie K. Y. Leung http://orcid.org/0000-0002-9300-4830
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