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Computational thinking in early childhood is underpinned by sequencing ability and self-regulation: a cross-sectional study

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Abstract
Computational thinking (CT) is a new literacy of 21st century that can be transferred to and applied in different real-world situations, although being derived from the discipline of computer science. Tangible robots or child-friendly digital apps are used to implement coding education with the goal of promoting young children's CT. However, there are still controversies on the validity and applicability of CT in early childhood, mainly due to the vagueness of the learning mechanism underlying young children's CT. This cross-sectional study examined the associations among sequencing ability, self-regulation and CT among Chinses preschoolers (N=101, M_{age} = 5.25 years, SD=0.73). Results showed that sequencing ability and self-regulation have positive and significant associations with CT, and the relationship between sequencing ability and CT was fully mediated by self-regulation, even after controlling for child gender, age, and family socioeconomic status (SES). This implies CT in early childhood as a combination of sequencing ability and self-regulation. Findings of this study have implications for early childhood CT education programs, suggesting the need to assist children in learning sequencing and how to self-regulate in coding (both plugged and unplugged) and STEM activities.

Keywords Computational thinking · Sequencing ability · Self-regulation · Preschool children · Early childhood education

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Described as a new literacy of the 21st century, computational thinking (CT) is broadly defined as systematic analysis, exploration, and testing of solutions to open-ended and often complex problems based on the analytical process rooted in the discipline of computer science (Lu & Fletcher, 2009; Wing, 2006). In recent years, CT in early childhood is also emerging as a field (Bers, 2018; Manches & Plowman, 2017; Wang et al., 2021). Tangible robots or child-friendly digital apps are used to implement coding education with the goal of promoting young children's CT (Bers, 2018). However, there are still some controversies on the validity and applicability of CT in early childhood, mainly due to the vagueness of the learning mechanism underlying children's CT.

Some existing research (e.g., Gerosa et al., 2021; Roman-Gonzalez et al., 2017; Wing 2011) in developmental psychology has defined several relevant cognitive skills involved in children's learning processes which might overlap or correlate to CT skills, including self-regulation and sequencing ability. Myers (2021) highlights the importance of exploring the intersection of self-regulation and CT, sharing findings from a 2014 study and supporting the idea of teaching CT skills within an integrated early childhood curriculum to develop well-prepared citizens for the 21st century. More recent definitions of CT from the field of computer science education, support the claim, reinforcing the notion that it is important to promote the cognitive processes underlying CT education (Gerosa et al., 2021; Shell & Soh, 2013) showed that students with higher levels of self-regulation retained CT skills at a significantly higher rate compared to other students. Liu et al. (2021) also found that personal traits such as self-regulation could affect one's CT skills. However, there is far little direct evidence to reveal the associations between these cognitive abilities (e.g., self-regulation) and CT. Moreover, little is known as to the potential mechanism linking these cognitive abilities, particularly at an early age. Since sequencing ability and self-regulation are two fundamental cognitive abilities in early childhood, we conducted this cross-sectional study to understand if sequencing ability and self-regulation is related to CT, and to explore the possible mediation effect of self-regulation between sequencing ability and CT. The focus on cognitive issues related to learning CT in early childhood will inform the design of curricula for CT education, as well as teacher professional development in this field.

1 Literature review

1.1 Computational thinking, sequencing ability, and self-regulation

1.1.1 Computational thinking (CT)

According to Sands et al. (2018), computational thinking (CT) is a problem-solving approach influenced by computer science practices. It encompasses various analytical skills such as system design, problem decomposition, and algorithmic thinking, as well as the use of different levels of abstraction to solve problems, as described by Lu and Fletcher (2009). Additionally, CT is a set of mental skills and computer science concepts that can impact different fields, as noted by Wing (2011). Brennan and Resnick (2012) proposed a more comprehensive framework that emphasizes the importance of CT for computational practices and perspectives beyond programming and hardware. Bers (2018) focused on CT in early childhood and defined it as a way for children to freely express their ideas using computers or other programming tools. Bers (2018) identified seven powerful ideas of computer science as the key components of CT: algorithms, modularity, control structures, representations, hardware/software, design processes, and debugging. However, these definitions are criticized for being more defined by computer scientists than by cognitive psychologists.

Viewed as the 21st century's new literacy, researchers and educators have worked to integrate CT into multiple subjects in K-12 (Sands et al., 2018; Sun et al., 2021). CT is not only crucial for problem-solving, engineering design, and being ready for computer science and related occupations, but also has broad implications for discipline learning, such as reading, writing and mathematics (Wing, 2006, 2011). For instance, some educational robotics programs were found to be able to help children learn number, size, and shape, as well as representation, spatial concepts, and measurement, which are key concepts and skills of mathematics (Highfield, 2000; Resnick et al., 1998; Wang et al., 2021). However, there is sparse research on the definition and promotion of CT in early childhood, thus our research will focus on young children's CT and its relationship with other cognitive abilities.

1.1.2 Sequencing ability

Sequencing ability is a traditional area of focus in early childhood education. Sequencing is a common component of early math and reading activities, which involves the action of putting objects or events in the correct order (Zelazo et al., 1997). Sequencing ability is thus the ability applicable to multiple domains-mathematics, reading and even basic life tasks (Kazakoff et al., 2013). For example, children learn to retell a story by using the ability of logical sequencing. Sometimes they need to order numbers according to teachers' requirements, and follow the sequence of daily activities in early childhood classrooms. In both literacy and mathematics, sequencing is essential for putting words and numbers in the appropriate order (Neuman & Dickinson, 2002).

As noted by Sarama and Clements (1987), sequencing, along with sorting, measurement, and pattern recognition, forms the foundation of young children's mathematical learning. These basic skills enable children to think mathematically about the world. Piaget (1969) argued that sequencing is a skill that children begin to develop at the age of three, and it is a critical component of mathematics learning that is closely linked to children's reversible thinking and simple to complex logical thinking. Research has shown that sequencing ability is a key predictor of children's higher-level thinking skills. According to Kazakoff et al. (2013), computer programming involves a process similar to story sequencing, where symbolic commands are arranged in a sequence to create algorithms that instruct a computer or robot. This same process of sequencing commands is used by children when they retell stories in a logical order. To create successful programs, children must use procedural thinking, such as "next," "before," and "until," and understand the correct order of commands, as noted by Pea and Kurland (1984).

Since sequencing is an important component of early literacy learning, research on children's sequencing measured by picture story assessment is common in early childhood education (Kazakoff et al., 2013). Picture story assessment requires narrative thinking and understanding of sequences by recognizing features represented in each picture (Paris & Paris, 2003). A picture sequencing assessment was chosen to evaluate children's sequencing ability after their participation in robot programming activities, mainly because of the similarities between programming a robot and telling a story that involves ordered steps (Kazakoff & Bers, 2014 a, b).

1.1.3 Self-regulation

The ability of self-regulation is derived from the executive function of the brain and is a cognitive element that integrate the executive functions of attention, working memory and inhibition (Bodrova & Leong, 2006). Self-regulation begins with goal setting, and the motivation and executive functions share roles in the cognitive processes underlying self-regulation. The act of choosing a goal involves choosing among different tasks to pursue or the level of performance to aspire to within a task (Zimmerman, 2001). To achieve the defined goals, self-regulation is underpinned by executive functions, which are the cognitive processes enabling control over thinking and behaviors (McClelland & Cameron, 2012; Hamilton el al., 2011). Self-regulation plays an important role in the enhancement of autonomy, self-control, and self-efficacy (McClelland et al., 2007). It influences children' academic skills, social adjustment, and school readiness (Eisenberg el al., 2010; McClelland et al., 2007). A study conducted by Schmitt et al. (2014) showed that children's behavioral self-regulation measured by the Head-Toes-Knees-Shoulders task (HTKS; Cameron et al., 2009) had a strongly positive relationship with early math and literacy skills. An extensive body of studies in Europe, North America, and China use HTKS to investigate preschool children's self-regulation and demonstrate that it predicts children's school readiness, and even the long-term academic performance (Ahmed et al., 2019; Gestsdottir et al., 2014).

1.1.4 Associations among CT, sequencing ability and self-regulation

In recent years, a few studies have focused on exploring the associations among CT and other cognitive abilities (Ambrosio et al., 2014; Gerosa et al., 2021; Román-González, 2017). In terms of sequencing ability, the extant results indicated that CT and sequencing ability maybe interconnected. In the definitions of CT, sequencing/order in algorithms for defining and solving open-ended complex problem that is foundational to CT (Arfé et al., 2019; Brennan & Resnick, 2012). In Fedorenko et al.'s (2019) study, young children's engagement in computer programming is similar to the process of natural language comprehension and production, which requires the equipment of sequencing ability. Gerosa et al. (2021) found that children's temporal sequencing ability is a significant predictor of CT. Kazakoff and Bers (2012) conducted a small-scale intervention study and revealed that children's participation in developmentally appropriate coding activities would lead to an increase in sequencing ability. As CT is the primary goal of engaging children in computer programming, it could be the case that CT is related to sequencing ability among young children. It is thus possible that, from a cognitive perspective, CT and sequencing ability are interconnected.

Previous studies have demonstrated a distinct relation between self-regulation and math achievement (Brock et al., 2009; Bull & Scerif, 2001; Espy et al., 2004). Research found that executive functions at early childhood was related to children's concurrently and subsequently math performance (Ahmed et al., 2019; Mazzocco & Kover, 2007), suggesting executive function is a stable predictor of children's math learning. In terms of sequencing, sequencing is a complex cognitive process that needs the involvement of self-regulation and executive functions, such as working memory, inhibitory control and mental flexibility. For example, Elkin et al. (2016) found that children performed better on sequencing a correct program that required them to manipulate less programming instructions, suggesting that younger children may not have enough working memory to hold more instructions simultaneously in their minds (Shonkoff et al., 2011).

Although there have been sparse research studies performed to help understand the relationship between self-regulation and CT, some previous studies demonstrated that self-regulation plays an important role in CT learning. For example, Gerosa et al. (2021) reported that children's CT performance was significantly and positively correlated with executive functions such as planning and working memory. Robertson et al. (2020) assessed the CT and executive functions of children aged 11–12 years and found that there are positive associations between children's behavioral, emotional, and cognitive regulations and CT. Shell et al. (2013) found that self-regulation could improve students' performance in computer science courses by increasing students' memory involvement in learning. Peters-Burton et al. (2015) claimed that CT can be viewed as self-regulated learning process. Kazakoff (2014) examined the bidirectional relationship between self-regulation and learning to code in two kindergarten classrooms utilizing ScratchJr.

Based on the existing studies, self-regulation can be linked to children's CT and sequencing ability, CT maybe have intersection with sequencing ability and self-regulation, however, the existing studies lack direct evidence in early childhood, so it is necessary to further explore the relationship between sequencing ability, self-regulation and CT among young children.

1.2 The possible mediating role of self-regulation in early childhood development

Some extant studies have found that self-regulation often plays a mediating role in early childhood development. Gözüm and Aktulun (2021) found that self-regulation has a partial mediating effect between receptive language and early academic skills, indicating that it is critical to support children's self-regulation skills in the early years. Lucas-Nihei (2020) found that preschooler's self-regulation mediates the relation of parent-child attachment quality and preschooler's peer acceptance. In Padilla-Walker et al.'s (2010) study, self-regulation played a partial mediating role in the relationship between sibling relationship and children's positive and negative behaviors, suggesting that a positive sibling relationship could act as the training ground for self-regulation, and thus triggered children's prosocial behaviors. Ganesalingam et al.'s (2007) evidence indicated that self-regulation acted as a significant mediator between childhood traumatic brain injury and social and behavioral functions. After brain injury, young children's self-regulation ability decreased, resulting in poor social and behavioral functions. These findings suggested that self-regulation plays a key role in relationships between different variables in a specific development area, such as cognition, behavior, and social-emotional development of children.

Previous research explained the mediating mechanism of self-regulation in the relationship between different variables. The ability of self-regulation is derived from the executive function of the brain (Bodrova & Leong, 2006), and this executive function is accompanied by a mechanism of control and regulation. The regulation mechanism can adjust children's emotion and behavior to make them conform to the targeted behavior (Catalsakal, 2016; Zimmerman, 2001). Some studies found that making long-term plans, preparing for possible events, task persistence in the face of failure, goal setting, goal attainment strategies, and time management all require self-regulation skills (Baumeister et al., 2003). Accordingly, self-regulation is similar to a psychological device (Morosanova, 2013) and is associated with positive outcomes (Eiden et al., 2007), which can adjust the relationship between two related variables to point to a positive outcome.

Based on the extant studies, sequencing ability affects children's CT, while self-regulation is regarded as an important factor of CT learning (Erin et al., 2015). In this sense, self-regulation may mediate how sequencing ability is linked to CT. Therefore, we examined the mediating effect of self-regulation between sequencing ability and CT in preschoolers.

1.3 The Present Study

Due to the importance of CT, there is a proliferation of early coding curricula and technologies designed for young children to promote their CT. However, there is rare empirical evidence to understand and promote the cognitive process underlying CT among young children. Therefore, it is important to reveal the mechanism that influences children's CT. Based on the preliminary evidence about the links among sequencing ability, self-regulation, and CT, we conducted a cross-sectional study to provide direct evidence for the associations between these targeted variables among Chinese young children. The main purpose of this study was not only to prove whether sequencing ability and self-regulation positively correlate with children's CT, but also to investigate the mediating effect of self-regulation between sequencing ability and CT.

This study was guided by the following two research questions:

RQ1: Are sequencing ability and self-regulation associated with CT among the Chinese preschoolers?

RQ2: Does self-regulation mediate the relationship between sequencing ability and CT among the Chinese preschoolers?

This study was guided by the following research hypothesis:

Hypothesis 1 Sequencing ability is positively associated with CT among young children.

Hypothesis 2 Self-regulation is positively associated with CT among young children.

Hypothesis 3 Sequencing ability is positively associated with self-regulation among young children.

Hypothesis 4 Self-regulation mediates the relationship between sequencing ability and CT among young children.

2 Method

This study used a quantitative methodology with a cross-sectional research design to assess the CT, self-regulation, and sequencing skills of Chinese preschoolers. Demographic data was collected from parents/caregivers through a survey. The child assessments were administered in children's native language (Mandarin) by six assessors.

2.1 Participants

Table 1 shows the demographic data for participants. A total of 101 Chinese children ($N_{boys} = 49$; $N_{girls} = 52$; overall mean age=5.25 years, SD=0.73) who were enrolled in a public preschool serving children aged 4–6 years in Beijing, China participated in this study. Convenience sampling was implemented. Informed consent forms were obtained from the child participants' parents/caregivers before assessing the children's CT and sequencing skills. Letters describing the research project and consent forms were given to parents/guardians through the teachers. Parents/caregivers were also asked to complete a survey that collects information about their highest levels of education, occupation, family income, and their child's date of birth and gender. All the child assessments were administered in children's native language (i.e., Mandarin), in a quiet, open room in the preschool, and by six assessors who were an Assistant Professor (N=1) and postgraduate students in Early Childhood Education (N=5). The study has obtained ethical approval from the relevant institutional review board prior to the commencement of data collection.

2.2 Measures

TechCheck The CT assessment implemented in this study was translated from Relkin and colleagues' TechCheck (Relkin et al., 2020). TechCheck has a total of 15 items and assesses six domains of CT that are developmentally appropriate for young children, including algorithms, modularity, control structures, representation, hardware/software, and debugging (Bers, 2018). Each question is presented in a force-selection multiple-choice format with four options, each correct response is awarded

Table 1 Demographic Data for Participants

Demographic characteristics	
Child age (M ± *SD*)	5.25 ± 0.73
Child gender	
Boy	49 (48.5)
Girl	52 (51.5)
Father education	
High school and below	9 (8.9)
Associated degree	24 (23.8)
Bachelor degree	52 (51.5)
Master degree and above	16 (15.8)
Mother education	
High school and below	5 (5)
Associated degree	30 (29.7)
Bachelor degree	50 (49.5)
Master degree and above	16 (15.8)
Father vocation	
Semi-technical and technical worker	23 (22.7)
Semi-professional and public servant	28 (27.7)
Professional and officer	45 (44.6)
High-level professional and administrator	5 (5)
Mother vocation	
Semi-technical and technical worker	28 (27.7)
Semi-professional and public servant	26 (25.7)
Professional and officer	45 (44.6)
High-level professional and administrator	2 (2)
Household income	
< 5000 RMB per month	3 (3)
> = 5000 and < 7999 RMB per month	7 (6.9)
> = 8000 and < 9999 RMB per month	6 (5.9)
> = 10,000 and < 11,999 RMB per month	9 (8.9)
> = 12,000 and < 14,999 RMB per month	14 (13.9)
> = 15,000 and < 19,999 RMB per month	9(8.9)
> = 20,000 RMB per month	53(52.5)

with one point, with a maximum score of 15 points. TechCheck was shown to have good psychometric properties (The observed $\alpha = 0.68$; criterion validity at $r = .53$) in a previous validation study (Relkin et al., 2020). The assessment computerized version was released on Wenjuanxing, the largest online survey platform in China. Since the young children are pre-literate, the assessors read each question out loud to the children twice and give them up to one minute to answer each question. It normally takes 12 min to administer the TechCheck with young children (Relkin et al., 2020).

The head-toes-knees-shoulders task In this study, the Head-Toes-Knees-Shoulders (HTKS) task was used to measure children's behavioral self-regulation. The HTKS task was developed by Claire Cameron and Megan McClelland. Previous studies have showed this measure is a valid and reliable measure of self-regulation in young children that has been translated into over 20 languages and is being used worldwide (McClelland et al., 2014, Schmitt et al., 2014). The HTKS task consists of 30 items and measures three aspects of functioning, including cognitive flexibility, working memory, and inhibitory control. In the HTKS task, children were asked to respond to assessor's specific commands. Children were given 0 points for wrong responses, 1 point for self-corrected responds and 2 points for correct responses (Cameron Ponitz et al., 2009). The total score of this measure ranges from 0 to 60.

Picture sequencing task Children were administered the direct assessment of Picture Sequencing Task (PST, Kazakoff & Bers 2014 a, b) to assess their sequencing ability in this study. Picture story sequencing assessments are common for assessing sequencing in early childhood. For example, children were tasked with organizing four picture sequences that denote temporal events in PST (Brown, 1975). Five picture stories were used in the present study. Each picture story contains four picture cards and the children are asked to put them in order to make a correct story. During each picture sequencing task, the child participants were shown and interpreted according to a standardized procedure. After the child participant finished each sequencing task, the assessor then recorded the order that the child places the cards in. The child participant was awarded a score of 2, 1, or 0 for a correct sequence, a sequence with the correct beginning and ending cards, and a completely incorrect sequence, accordingly. The maximum score is 10 points for the picture sequencing task.

2.3 Statistical analyses

All these statistical analyses were conducted using the 26th version of SPSS Statistics software. First, we computed the descriptive statistics, i.e., mean and standard deviation, for each variable. Then, we conducted preliminary analyses, such as using independent sample t-tests across gender to test for differences in mean levels. Second, we evaluated the correlation between variables using the Pearson correlation analysis. The magnitude of the correlation coefficient was interpreted according to the criteria recommended by Gignac and Szodorai (2016) when reporting effect sizes in correlational studies. In addition, to investigate the mediating effect of self-regulation between sequencing ability and CT, mediation analysis was assessed using Hayes' PROCESS macros (Hayes, 2012) in SPSS.

The PROCESS approach combines regression and bootstrap methods and is used to check for mediation by interpreting results based on beta coefficients and bootstrapping confidence intervals. In the current study, a simple mediator model was used and Fig. 1 illustrates this model, as proposed by Preacher and Hayes (2004). In Panel A of the model, the unstandardized path coefficient c represents the total effect of the independent variable (X) on the dependent variable (Y). In Panel B, the direct effect of X on Y (path c') and the indirect effect of X on Y through the mediator (M) are represented. The total effect of X on Y (path c) is the sum of the direct and indirect effects. The model parameters were estimated using a bootstrapping approach, which avoids assumptions about sampling distributions by empirically estimating the sampling distribution of a statistic from the available data and using it to establish confidence intervals and calculate p-values. Hypotheses can be tested and confi-

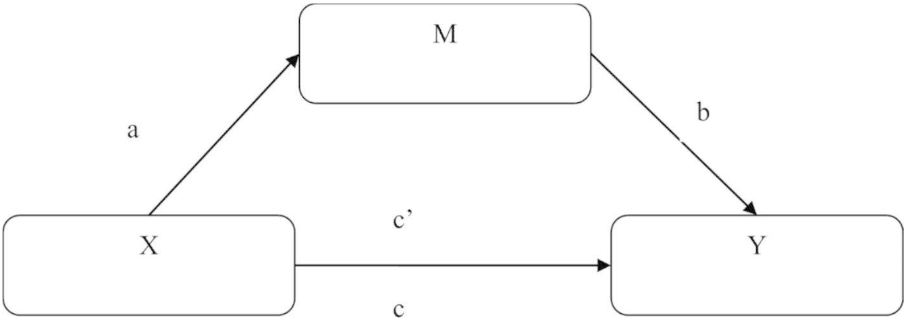

Fig. 1 Simple Mediator Model

dence intervals constructed using the bootstrap sampling distribution. Ordinary least squares were used to estimate all model paths.

3 Findings

3.1 Descriptive and correlational analyses

Table 2 showed the results of descriptive statistical and correlational analyses. Findings demonstrated that the mean scores of children's CT, sequencing ability and self-regulation are 7.42 (SD=2.89), 4.49 (SD=2.74) and 41.63 (SD=13.91), respectively.

The result of correlational analyses showed that a positive relationship exists between CT, sequencing ability and self-regulation. Children's sequencing ability was positively correlated with CT ($r=.36$, $p<.001$). Self-regulation was positively correlated with CT ($r=.54$, $p<.001$), and sequencing ability correlated positively and significantly with self-regulation ($r=.40$, $p<.001$). The magnitude of the relationship between sequencing ability and CT, between self-regulation and CT and between sequencing ability and self-regulation were large, according to the standards for evaluating the magnitude of correlational coefficients (Gignac & Szodorai, 2016). Therefore, the Hypothesis 1, Hypothesis 2 and Hypothesis 3 were confirmed.

Table 2 Mean, Standard Deviation, and Correlation Coefficients among the Variables

Variable	M	SD	1	2	3	4	5	6
1. gender	1.51	0.50	--	0.11	-0.05	0.04	0.07	-0.07
2. age	5.25	0.73		--	0.13	0.34**	0.36***	0.44***
3. Family SES	21.39	4.29			--	0.02	0.30**	0.11
4. sequencing ability	4.49	2.74				--	0.40***	0.36***
5. self-regulation	41.63	13.91					--	0.54***
6. CT	7.42	2.89						--

Notes. ** Correlation is significant at the 0.01 level (2-tailed); SES=socioeconomic status; CT=computational thinking

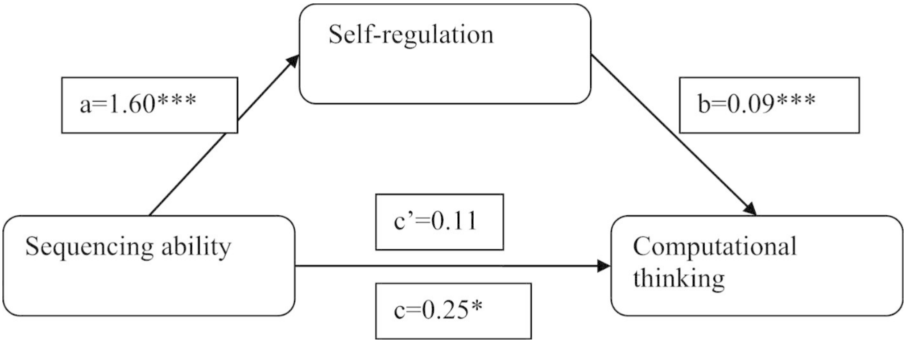

Fig. 2 The Regression-Based Path Coefficients of the Mediation Analysis of Self-Regulation in the Relationship Between Sequencing Ability and CT

We also explored whether there were differences in the sequencing ability, self-regulation and CT across gender, age and family SES. Results demonstrated there were no significant gender differences in sequencing ability, self-regulation and CT. Result of correlation analyses demonstrated significant correlations between age and sequencing ability, self-regulation and CT, with effect sizes ranging from 0.34 to 0.44, and family SES was significantly correlated with self-regulation($r=.30$).Because the results showed that age, SES had correlation with children's CT, sequencing ability and self-regulation, we controlled for the potential effect of these variables in the following mediation analysis.

3.2 Mediation analysis

The correlation results confirmed that sequencing ability, self-regulation and CT were positively correlated. Therefore, we additionally verified self-regulation as a mediator among sequencing ability and CT by using PROCESS macro in SPSS.

Table 3 shows the bias corrected and accelerated bootstrap confidence intervals results. The results of mediation analysis as per regression-based approach can be seen in Fig. 2. After controlling the effect of gender, age and family SES, our results revealed that when self-regulation was not added as a mediator variable, the total effect of sequencing ability on CT came out to be significant ($\beta=0.25$, $t=2.54$, $p<.05$). When self-regulation was added as a mediator variable, the sequencing ability was not able to predict CT directly ($\beta=0.11$, $t=1.12$, $p>0.05$). the results also suggest that sequencing ability was significant predict self-regulation ($\beta=1.60$,

Table 3 Bootstrapping Results for Regression Model Parameters

	Unstandardized for coefficient		Bootstrapping 95% CI	
	Coefficient	Std. error	Lower CI	Upper CI
Total effect	0.25	0.10	0.05	0.44
Direct effect	0.11	0.10	-0.08	0.30
Indirect effect	0.14	0.06	0.05	0.26

Table 4 Mediation Analysis of Self-Regulation in the Relationship Between Sequencing Ability and CT

Predictor variable	Dependent variable	β	*t*	R^2	*F*
sequencing ability	CT	0.25	2.54*	0.26	8.55***
sequencing ability	Self-regulation	1.60	3.45***	0.29	9.72***
sequencing ability	CT	0.11	1.12	0.39	12.36***
self-regulation		0.09	4.54***		

Notes. *** $p<.001$, ** $p<.01$, * $p<.05$; CT = computational thinking

t = 3.45, p < .001), and the effect of self-regulation on CT came out to be significant (β = 0.09, t = 4.54, p < .001) in the mediator model. Overall, from the results of regression-based approach, it can be seen that self-regulation had fully mediation effect between sequencing ability and CT. Therefore, the Hypothesis 4 was confirmed. Table 4 shows the results of mediating effect analysis.

Current analyses utilized 5000 bootstrap resamples to generate 95% confidence intervals. The indirect and total effects in the model are tested using bootstrap samples. Table 3 represents the bias corrected and accelerated bootstrap confidence intervals results as per the PROCESS macro in SPSS. The result indicated that the indirect effect of sequencing ability on CT via self-regulation came out to be significant as it does not include zero in the 95% bias corrected and accelerated bootstrap confidence interval (indirect effect = 0.14, SE = 0.06; 95% CI unstandardized = 0.05 to 0.26). From the results of indirect effect, it can be inferred that although sequencing ability provide a baseline of computational thinking, it is through self-regulation in those children regulate their cognition, emotions and behaviors are able to perform better in CT. Hence, the findings of this paper provides novel viewpoints which will contribute to the existing literature and provide direction for further empirical developments.

4 Discussion

We conducted this cross-sectional study to investigate the relationship among sequencing ability, self-regulation, and CT among Chinese preschool children. It contributes to the international literature by exploring CT in early childhood and its relationships with other cognitive abilities with direct measures.

4.1 CT in early childhood = sequencing ability + self-regulation

First, the results showed that sequencing ability had a significant positive correlation with children's CT. This result was consistent with the findings of Gerosa et al.'s (2021) study, which found that sequencing ability positively predicts CT of children aged 5. This finding suggests that the development of sequencing ability may can serve to prepare young children for better using CT to formulating problems and their solutions. In previous research, the development of sequencing has been found to play a vital role in creating sequenced commands to give instructions to a computer or a robot (Kazakoff et al., 2013). Children's engagement in coding is similar to the process of retelling a story in a logical sequence or ordering numbers in the correct sequence (Fedorenko el al., 2019; Kazakoff et al., 2013). It indicates that sequencing is one of the basic computational concepts and skills in CT framework (Brennan & Resnick, 2012). To some extent, our study supports the study of Kazakoff and Bers (2012), who offered preliminary evidence of the positive effect of programming education on young children's development of sequencing ability. As explained by Fedorenko et al. (2019), young children's engagement in coding is similar to the process of natural language comprehension and production, which requires the equipment of sequencing ability. Coding is highlighted as a process of creating sequenced commands to give instructions to a computer or a robot (Kazakoff & Bers, 2014a, b). Our study provides evidence to further support that children's sequencing ability could be one of the specific cognitive processes supporting CT. Given that sequencing ability is critical not only to mathematics and language learning but also to everyday activities such as getting dressed and brushing teeth, early childhood educators should focus on providing children with ample opportunities for sequencing practice in math, language, and daily life activities. Such practice can have a positive impact on the CT development among young children.

Second, our findings demonstrated that self-regulation is significantly correlated with CT. This aligns with previous evidence, indicating that young children's working memory (Gerosa et al., 2021), inhibitory control (Arfe et al., 2019) and executive functions (Arfe et al., 2020) are associated with CT. Since executive functions, including planning, visuo-spatial working memory and inhibition skills, are often used to regulate children's thinking and behaviors when children participated in coding activities (Di Lieto et al., 2017), children with a higher level of self-regulation tend to perform better in CT tasks. It is likely that self-regulation may serve as a valuable cognitive tool, which can boost CT of young children.

Third, the unique evidence of this study revealed that self-regulation fully mediated the association between sequencing ability and CT among Chinese young children, indicating that if young children possess a higher level of sequencing ability and self-regulation, they will perform better in CT tasks. Our evidence supports previous studies on the positive associations between self-regulation and children's sequencing ability. In terms of the development of sequencing ability among young children, more working memory must be involved in hard sequencing process (Elkin et al., 2016). Sullivan and Bers (2014) also found that preschool children encounter more difficulties on a hard-sequencing Solve-It programming task (ordering five programming blocks) than an easy-sequencing Solve-It task (ordering four programming blocks). A possible explanation is that younger children do not have enough working memory to hold more than five instructions simultaneously in their minds until they are several years older (Shonkoff et al., 2011). In our study, children's sequencing ability was assessed by ordering the four pictures of a story correctly in given time, the children's success on the sequencing task maybe due to their working memory and the capacity to simultaneously remember and process all the parts of the story. Therefore, it is likely that with the higher level of sequencing ability, young children's self-regulation, including working memory, attention span, and ability to plan will increase, thus leading to better performance on CT tasks (Shonkoff et al., 2011).

4.2 Contributions of the study

As noted in a review by Hsu et al. (2018), previous research on CT has largely focused on high-grade primary students, adolescents, and adults. This study contributes to the limited literature on CT in early childhood by examining the associations between CT and other cognitive factors, particularly the mediating role of self-regulation between sequencing ability and CT in Chinese young children. The results indicate that sequencing ability and self-regulation are significantly positively associated with young children's CT, and self-regulation robustly mediates the link between sequencing ability and CT. Although there is a lack of knowledge about the cultural variance of CT, it is important to note that cultural experiences may influence children's cognitive abilities, as suggested by Richland et al. (2010). The Chinese traditional culture, which emphasizes respect, humility, classroom discipline, and self-control (Yang, 2018; Yang & Li, 2020), may impact children's abilities to self-regulate and self-monitor their learning and increase their awareness of their behavior in any learning activities. Therefore, while Chinese culture may have some influence on our findings, globalization may limit this impact, highlighting the need for further cross-cultural research in this field.

4.3 Implications for CT education

The findings provide several implications. Our study confirmed that sequencing ability and self-regulation play an important role in young children's CT development, thus shedding light on future research on effective learning programs tailored for young children in terms of promoting their CT.

The results imply that high level of sequencing ability tends to result in better CT. Since sequencing is an important component of both early mathematics and early literacy learning and it is a common theme in early childhood classroom, our finding suggest that sequencing skills may be one of the specific cognitive processes that supporting CT among young children. That is, story sequencing skills, number sequencing skills are not only the foundational skills of mathematics and literacy learning, but also serve as the cognitive tool to boost children's CT. Therefore, it may be worthwhile when introducing young children to computational related concepts and practices to focus on increasing their basic sequencing ability (Elkin et al.,2016). In addition, since sequencing is a basic skill in children's multi-domain learning, this study provides solid evidence and support for the integration of CT into discipline teaching, such as STEM and language, in early childhood classrooms. It is necessary to support early childhood teachers to make greater efforts to appreciate the need for interdisciplinary teaching approaches in CT related teaching. Furthermore, computer programming can be seen a version of story sequencing, since previous research showed that sequencing abilities increased after an intensive robotics workshop for a sample of preschool children (Kazakoff et al., 2014, 2013). Moreover, our findings demonstrate the urgent need to integrate effective programming education into early childhood classrooms, to not just cultivate children's sequencing abilities, but also hold considerable promise to achieve CT development for children.

The results also imply that self-regulation is also a key to develop CT. Self-regulation robustly mediated the relationship between sequencing ability and CT among young children. Therefore, teachers should pay more attention to increase children's self-regulation skills during learning activities, including children's inhibitory control, attentional flexibility and working memory, which are important for the development of young children's CT. Previous research has defined self-regulation as the self-directive process through which individuals transform their cognitive functioning into task performance (Zimmerman, 2001). With the ability of self-regulation, children are able to recognize their own learning and take control of their thoughts and behaviors in learning process, which means that children can continuously monitor the progress toward their learning goal, checking outcomes, and redirecting unsuccessful efforts (Berk, 2003). Children who developed better self-regulation skills are better to integrate multiple components of skills, attention, working memory, and inhibitory control in their learning (Corno & Mandinach, 1983). Since self-regulation skills develops significantly during early childhood (Wanless et al., 2016), self-regulation should be emphasized in early childhood (Erin et al., 2015). Therefore, children's learning behaviors like setting goals, planning, monitoring, directing, and regulating actions towards learning goals should be concerned by teachers.

4.4 Limitations and future research directions

This study has several limitations, the most important of which is the small size and scope of sample. To address this limitation, future research should consist of a larger group of samples, which could provide a better understanding. Moreover, we only used direct assessments for assessing children's sequencing ability and computational thinking, which may need the supplement of more evidence generated with other types of measurement tools such as teacher report and observer report. Lastly, since this study only investigated sequencing ability, self-regulation, and CT among Chinese young children, a generalization of these results s to other cultural contexts should be taken cautiously. Researchers can consider using a cross-cultural approach to explore the associations between CT and other cognitive abilities in early childhood in the future.

Data availability statement The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.a

Declarations

Competing interests The authors have no conflicts of interest to disclose.

References

Ahmed, S. F., Tang, S., Waters, N. E., & Davis-Kean, P. (2019). Executive function and academic achievement: Longitudinal relations from early childhood to adolescence. *Journal of Educational Psychology*, *111*(3), 446–458. https://doi.org/10.1037/edu0000296.

Ambrosio, A. P., Xavier, C., & Georges, F. (2014). Digital ink for cognitive assessment of computational thinking. In *2014 IEEE Frontiers in Education Conference* (pp. 1520–1526). https://doi.org/10.1109/FIE.2014.7044237

Arfé, B., Vardanega, T., Montuori, C., & Lavanga, M. (2019). Coding in primary grades boosts children's executive functions. *Frontiers in Psychology*, *10*, 2713. https://doi.org/10.3389/fpsyg.2019.02713.

Arfé, B., Vardanega, T., & Ronconi, L. (2020). The effects of coding on children's planning and inhibition skills. *Computers & Education*, *148*, 103807. https://doi.org/10.1016/j.compedu.2020.103807.

Baumeister, R. F., & Vohs, K. D. (2003). Self-regulation and the executive function of the self. *Handbook of Self and Identity*, *1*, 197–217.

Berk, L. E. (2003). *Child Development* Allyn and Bacon.

Bers, M. U. (2018). *Coding as a playground: Programming and computational thinking in the early childhood classroom*. Routledge.

Bers, M. U., Flannery, L., Kazakoff, E. R., & Sullivan, A. (2014). Computational thinking and tinkering: Exploration of an early childhood robotics curriculum. *Computers & Education*, *72*, 145–157. https://doi.org/10.1016/j.compedu.2013.10.020.

Bodrova, E., & Leong, D. J. (2006). Self-regulation as a key to school readiness: How early childhood teachers can promote this critical competency. In M. Zaslow, & I. Martinez-Beck (Eds.), *Critical issues in early childhood professional development* (pp. 203–224). Paul H Brookes Publishing.

Brennan, K., & Resnick, M. (2012, April). New frameworks for studying and assessing the development of computational thinking. In *Proceedings of the 2012 annual meeting of the American Educational Research Association, Vancouver, Canada* (Vol. 1, p. 25).

Brock, L. L., Rimm-Kaufman, S. E., Nathanson, L., & Grimm, K. J. (2009). The contributions of "hot" and "cool" executive function to children's academic achievement, learning-related behaviors, and engagement in kindergarten. *Early Childhood Research Quarterly*, *24*(3), 337–349. https://doi.org/10.1016/j.ecresq.2009.06.001.

Brown, A. L. (1975). Recognition, reconstruction, and recall of narrative sequences by preoperational children. *Child Development, 46*(1), 156–166. https://doi.org/1128844

Bull, R., & Scerif, G. (2001). Executive function as a predictor of children's mathematics ability: Inhibition, switching, and working memory. *Developmental Neuropsychology*, *19*, 273–293. https://doi.org/10.1207/S15326942DN1903_3.

Cameron Ponitz, C., McClelland, M. M., Matthews, J. S., & Morrison, F. J. (2009). A structured observation of behavioral self-regulation and its contribution to kindergarten outcomes. *Developmental Psychology*, *45*(3), 605–619. https://doi.org/10.1037/a0015365.

Catalsakal, S. (2016). *How trait mindfulness is related to job performance and job satisfaction: self-regulation as a potential mediator*. Master's thesis, Middle East Technical University.

Clements, D. H. (1987). Longitudinal study of the effects of Logo programming on cognitive abilities and achievement. *Journal of Educational Computing Research*, *3*(1), 73–94. https://doi.org/10.2190%2FRCNV-2HYF-60CM-K7K7.

Corno, L., & Mandinach, E. B. (1983). The role of cognitive engagement in classroom learning and motivation. *Educational Psychologist*, *18*, 88–108. https://doi.org/10.1080/00461528309529266.

Di Lieto, M. C., Inguaggiato, E., Castro, E., Cecchi, F., Cioni, G., Dell'Omo, M., & Dario, P. (2017). Educational robotics intervention on executive functions in preschool children: A pilot study. *Computers in Human Behavior*, *71*, 16–23. https://doi.org/10.1016/j.chb.2017.01.018.

Eiden, R. D., Edwards, E. P., & Leonard, K. E. (2007). A conceptual model for the development of externalizing behavior problems among kindergarten children of alcoholic families: Role of parenting and children's self-regulation. *Developmental Psychology*, *43*(5), 1187–1201.

Eisenberg, N., Valiente, C., & Eggum, N. D. (2010). Self-regulation and school readiness. *Early Education and Development*, *21*(5), 681–698. https://doi.org/10.1080/10409289.2010.497451.

Elkin, M., Sullivan, A., & Bers, M. U. (2016). Programming with the KIBO robotics kit in preschool classrooms. *Computers in the Schools*, *33*(3), 169–186. https://doi.org/10.1080/07380569.2016.1216251.

Espy, K., McDiarmid, M., Kwik, M., Stalets, M., Hamby, A., & Senn, T. (2004). The contribution of executive functions to emergent mathematics skills in preschool children. *Developmental Neuroscience*, *26*, 465–486. https://doi.org/10.1207/s15326942dn26016.

Fedorenko, E., Ivanova, A., Dhamala, R., & Bers, M. U. (2019). The language of programming: A cognitive perspective. *Trends in Cognitive Sciences*, *23*(7), 525–528. https://doi.org/10.1016/j.tics.2019.04.010.

Ganesalingam, K., Sanson, A., Anderson, V., & Yeates, K. (2007). Self-regulation as a mediator of the effects of childhood traumatic brain injury on social and behavioral functioning. *Journal of the International Neuropsychological Society*, *13*(2), 298–311. https://doi.org/10.1017/S1355617707070324.

Gerosa, A., Koleszar, V., Tejera, G., Gómez-Sena, L., & Carboni, A. (2021). Cognitive abilities and computational thinking at age 5: Evidence for associations to sequencing and symbolic number comparison. *Computers and Education Open*, *2*, 100043. https://doi.org/10.1016/j.caeo.2021.100043.

Gestsdottir, S., von Suchodoletz, A., Wanless, S. B., Hubert, B., Guimard, P., Birgisdottir, F., & McClelland, M. (2014). Early behavioral self-regulation, academic achievement, and gender: Longitudinal findings from France, Germany, and Iceland. *Applied Developmental Science*, *18*(2), 90–109. https://doi.org/10.1080/10888691.2014.894870.

Gignac, G. E., & Szodorai, E. T. (2016). Effect size guidelines for individual differences researchers. *Personality and Individual Differences*, *102*, 74–78. https://doi.org/10.1016/j.paid.2016.06.069.

Gözüm, A. İ. C., & Aktulun, Ö. U. (2021). Relationship between Pre-Schoolers' self-regulation, language, and early academic skills: The mediating role of self-regulation and moderating role of gender. *Current Psychology*, *40*(10), 4718–4740. https://doi.org/10.1007/s12144-021-01699-3.

Hamilton, R., Vohs, K. D., Sellier, A. L., & Meyvis, T. (2011). Being of two minds: Switching mindsets exhausts self-regulatory resources. *Organizational Behavior and Human Decision Processes*, *115*(1), 13–24. https://doi.org/10.1016/j.obhdp.2010.11.005.

Hayes, A. F. (2012). PROCESS: A versatile computational tool for observed variable mediation, moderation, and conditional process modeling. http://www.afhayes.com/public/process2012.pdf

Highfield, K. (2000). Robotic toys as a catalyst for mathematical problem solving. *Australian Primary Mathematics Classroom*, *15*(2), 22–27.

Hsu, T. C., Chang, S. C., & Hung, Y. T. (2018). How to learn and how to teach computational thinking: Suggestions based on a review of the literature. *Computers & Education*, *126*, 296–310. https://doi.org/10.1016/j.compedu.2018.07.004.

Kazakoff, E. (2014). Cats in Space, Pigs that Race: Does self-regulation play a role when kindergartners learn to code? Unpublished doctoral dissertation, Tufts University.

Kazakoff, E., & Bers, M. (2012). Programming in a robotics context in the kindergarten classroom: The impact on sequencing skills. *Journal of Educational Multimedia and Hypermedia*, *21*(4), 371–391.

Kazakoff, E. R., & Bers, M. U. (2014a). Put your robot in, put your robot out: Sequencing through programming robots in early childhood. Journal of Educational Computing Research, 50(4), 553–573. https://doi.org/10.2190%2FEC.50.4.f.

Kazakoff, E. R., & Bers, M. U. (2014b). Put your robot in, put your robot out: Sequencing through programming robots in early childhood. Journal of Educational Computing Research, 50(4), 553–573. https://doi.org/10.2190%2FEC.50.4.f.

Kazakoff, E. R., Sullivan, A., & Bers, M. U. (2013). The effect of a classroom-based intensive robotics and programming workshop on sequencing ability in early childhood. *Early Childhood Education Journal*, *41*(4), 245–255. https://doi.org/10.1007/s10643-012-0554-5.

Liu, Y. C., Huang, T. H., & Sung, C. L. (2021). The determinants of impact of personal traits on computational thinking with programming instruction.Interactive Learning Environments,1–15.

Lu, J. J., & Fletcher, G. H. (2009). Thinking about computational thinking. *Proceedings of the 40th ACM Technical Symposium on Computer Science Education*, 260–264. https://doi.org/10.1145/1508865.1508959

Lucas-Nihei, J. N. (2020). *Mediating the Relation Between Parent-Child Attachment Relationships and Peer Acceptance with Preschoolers' Self-Regulation* Doctoral dissertation, Illinois State University.

Manches, A., & Plowman, L. (2017). Computing education in children's early years: A call for debate. *British Journal of Educational Technology*, *48*(1), 191–201. https://doi.org/10.1111/bjet.12355.

Mazzocco, M. M. M., & Kover, S. T. (2007). A longitudinal assessment of executive function skills and their association with math performance. *Child Neuropsychology*, *13*, 18–45. https://doi.org/10.1080/09297040600611346.

McClelland, M. M., & Cameron, C. E. (2012). Self-regulation in early childhood: Improving conceptual clarity and developing ecologically valid measures. *Child Development Perspectives*, *6*(2), 136–142. https://doi.org/10.1111/j.1750-8606.2011.00191.x.

McClelland, M. M., Cameron, C. E., Connor, C. M., Farris, C. L., Jewkes, A. M., & Morrison, F. J. (2007). Links between behavioral regulation and preschoolers' literacy, vocabulary, and math skills. *Developmental Psychology*, *43*(4), 947. https://doi.org/10.1037/0012-1649.43.4.947.

McClelland, M. M., Cameron, C. E., Duncan, R., Bowles, R. P., Acock, A. C., Miao, A., & Pratt, M. E. (2014). Predictors of early growth in academic achievement: The head-toes-knees-shoulders task. *Frontiers in Psychology*, *5*, 599. https://doi.org/10.3389/fpsyg.2014.00599.

Morosanova, V. I. (2013). Self-regulation and personality. *Procedia-Social and Behavioral Sciences*, *86*, 452–457. https://doi.org/10.1016/j.sbspro.2013.08.596.

Myers, E. K. (2021). The role of executive function and self-regulation in the development of computational thinking. In M. Bers (Ed.), *Teaching computational thinking and coding to young children* (pp. 64–83). IGI Global.

Neuman, S. B., & Dickinson, D. K. (Eds.). (2002). *Handbook of early literacy research*. Guilford Press.

Padilla-Walker, L. M., Harper, J. M., & Jensen, A. C. (2010). Self-regulation as a mediator between sibling relationship quality and early adolescents' positive and negative outcomes. *Journal of family Psychology*, *24*(4), 419. https://doi.org/10.1037/a0020387.

Paris, A. H., & Paris, S. G. (2003). Assessing narrative comprehension in young children. *Reading Research Quarterly*, *38*(1), 36–76. https://doi.org/10.1598/RRQ.38.1.3.

Pea, R. D., & Kurland, D. M. (1984). On the cognitive effects of learning computer programming. *New Ideas in Psychology*, *2*, 137–168. https://doi.org/10.1016/0732-118X(84)90018-7.

Peters-Burton, E. E., Cleary, T. J., & Kitsantas, A. (2015). The Development of Computational Thinking in the Context of Science and Engineering Practices: A Self-Regulated Learning Approach. *International Association for Development of the Information Society*, 257–261.

Piaget, J. (1969). *The child's conception of time*. Routledge & Kegan Paul.

Preacher, K. J., & Hayes, A. F. (2004). SPSS and SAS procedures for estimating indirect effects in simple mediation models. *Behavior research methods, instruments, & computers*, *36*, 717–731.

Relkin, E., de Ruiter, L., & Bers, M. U. (2020). TechCheck: Development and validation of an unplugged assessment of computational thinking in early childhood education. *Journal of Science Education and Technology*, *29*, 482–498. https://doi.org/10.1007/s10956-020-09831-x.

Resnick, M., Martin, F., Berg, R., Borovoy, R., Colella, V., Kramer, K., & Silverman, B. (1998, January). Digital manipulatives: new toys to think with. In *Proceedings of the SIGCHI conference on Human factors in computing systems* (pp. 281–287).

Richland, L. E., Chan, T. K., Morrison, R. G., & Au, T. K. F. (2010). Young children's analogical reasoning across cultures: Similarities and differences. *Journal of Experimental Child Psychology*, *105*(1–2), 146–153. https://doi.org/10.1016/j.jecp.2009.08.003.

Robertson, J., Gray, S., Toye, M., & Booth, J. (2020). The relationship between executive functions and computational thinking. *International Journal of Computer Science Education in Schools*, *3*(4), 35–49. https://doi.org/10.21585/ijcses.v3i4.76.

Román-González, M., Pérez-González, J. C., & Jiménez-Fernández, C. (2017). Which cognitive abilities underlie computational thinking? Criterion validity of the computational thinking test. *Computers in Human Behavior*, *72*, 678–691. https://doi.org/10.1016/j.chb.2016.08.047.

Sands, P., Yadav, A., & Good, J. (2018). Computational thinking in K-12: In-service teacher perceptions of computational thinking. In M. Khine (Ed.), *Computational thinking in the STEM disciplines*. Springer. https://doi.org/10.1007/978-3-319-93566-98.

Schmitt, S. A., Pratt, M. E., & McClelland, M. M. (2014). Examining the validity of behavioral self-regulation tools in predicting preschoolers' academic achievement. *Early Education and Development*, *25*(5), 641–660. https://doi.org/10.1080/10409289.2014.850397.

Shell, D. F., & Soh, L. K. (2013). Profiles of motivated self-regulation in college computer science courses: Differences in major versus required non-major courses. *Journal of Science Education and Technology*, *22*, 899–913.

Shell, D. F., Hazley, M. P., Soh, L. K., Ingraham, E., & Ramsay, S. (2013, October). Associations of students' creativity, motivation, and self-regulation with learning and achievement in college computer science courses. *In 2013 IEEE Frontiers in Education Conference (FIE)* (pp. 1637–1643). https://doi.org/10.1109/FIE.2013.6685116

Shonkoff, J. P., Duncan, G. J., Fisher, P. A., Magnuson, K., & Raver, C. (2011). *Building the brain's "air traffic control" system: How early experiences shape the development of executive function* (Working Paper No. 11). http://www.developingchild.harvard.edu

Sun, L., Hu, L., Yang, W., Zhou, D., & Wang, X. (2021). STEM learning attitude predicts computational thinking skills among primary school students. *Journal of Computer Assisted Learning*, *37*(2), 346–358. https://doi.org/10.1111/jcal.12493.

Wang, X. C., Choi, Y., Benson, K., Eggleston, C., & Weber, D. (2021). Teacher's role in fostering preschoolers' computational thinking: An exploratory case study. *Early Education and Development*, *32*(1), 26–48. https://doi.org/10.1080/10409289.2020.1759012.

Wanless, S. B., Kim, K. H., Zhang, C., Degol, J. L., Chen, J. L., & Chen, F. M. (2016). Trajectories of behavioral regulation for taiwanese children from 3.5 to 6 years and relations to math and vocabulary outcomes. *Early Childhood Research Quarterly*, *34*, 104–114. https://doi.org/10.1016/j.ecresq.2015.10.001.

Wing, J. (2006). Computational thinking. *Communications of the ACM, 49*(3), 33–35. https://dl.acm.org/doi/fullHtml/10.1145/1118178.1118215

Wing, J. (2011). Research notebook: Computational thinking—what and why. *The Link Magazine*, *6*, 20–23. https://www.cs.cmu.edu/link/research-notebook-computational-thinking-what-and-why.

Yang, W. (2018). *Early childhood curriculum as cultural practice: A comparative study of school-based curriculum development in Hong Kong and Shenzhen* PhD thesis. The University of Hong Kong.

Yang, W., & Li, H. (2020). The role of culture in early childhood curriculum development: A case study of curriculum innovations in Hong Kong kindergartens. *Contemporary Issues in Early Childhood*https://doi.org/10.1177%2F1463949119900359.

Zelazo, P. D., Carter, A., Reznick, J. S., & Frye, D. (1997). Early development of executive function: A problem-solving framework. *Review of General Psychology*, *1*(2), 198–226. https://doi.org/10.1037%2F1089-2680.1.2.198.

Zimmerman, B. J. (2001). Theories of self-regulated learning and academic achievement: An overview and analysis. In B. J. Zimmerman, & D. H. Schunk (Eds.), *Self-regulated learning and academic achievement: Theoretical perspectives* (pp. 1–65). Lawrence Erlbaum.

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