






Early artificial intelligence education: Effects of cooperative play and direct instruction on kindergarteners' computational thinking, sequencing, self-regulation and theory of mind skills

Jiahong Su¹  | Weipeng Yang²  | Iris Heung Yue Yim³  | Hui Li²  |
Xiao Hu¹ 

¹Faculty of Education, The University of Hong Kong, Hong Kong, China

²Department of Early Childhood Education, The Education University of Hong Kong, Hong Kong, China

³Faculty of Education, University of Cambridge, Cambridge, UK

Correspondence

Jiahong Su, Faculty of Education, The University of Hong Kong, Hong Kong SAR, China.

Email: maggiesu@connect.hku.hk

Abstract

Background: While the integration of robot-based learning in early childhood education has gained increasing attention in recent years, there is still a lack of evidence regarding the impact of AI robots on young children's learning.

Objectives: The study explored the effectiveness of two AI education approaches in advancing kindergarteners' computational thinking, sequencing, self-regulation and theory of mind skills.

Methods: An experiment was conducted with 90 kindergarteners (ages 5–6) randomly assigned to either a direct instruction (DI), cooperative play (CP) or control group.

Results: Results show that (1) children in all three groups had significant improvements on computational thinking, sequencing and self-regulation; (2) both early AI education approaches (CP and DI) significantly enhance young children's computational thinking, sequencing, self-regulation and theory of mind skills; (3) the DI group had significant higher improvement than the CP group on computational thinking; (4) the CP group exhibited greater enhancements in theory of mind skills than the DI group.

Conclusion: These findings jointly demonstrate that each AI educational approach has unique strengths, underscoring the significance of designing new pedagogies to expand children's skills.

KEYWORDS

AI education, computational thinking; sequencing, early childhood education, self-regulation; theory of mind skills

1 | INTRODUCTION

In recent years, the integration of robot-based learning in early childhood education has been a burgeoning area of interest (e.g., Su

et al., 2022; Yang et al., 2022). Nevertheless, the scholarly community still grapples with the dearth of concrete evidence regarding the influence of artificial intelligence (AI) robots on the learning evolution of young children (Su et al., 2023). This particular informational lacuna is

This is an open access article under the terms of the [Creative Commons Attribution-NonCommercial-NoDerivs](https://creativecommons.org/licenses/by-nc-nd/4.0/) License, which permits use and distribution in any medium, provided the original work is properly cited, the use is non-commercial and no modifications or adaptations are made.

© 2024 The Author(s). *Journal of Computer Assisted Learning* published by John Wiley & Sons Ltd.

noteworthy, given the considerable benefits early introduction to robotics-based education could hold, as corroborated by previous research (Su et al., 2022; Toh et al., 2016). Moreover, determining the optimal method of curriculum implementation in early education remains a contested topic. Some research advocates for the superiority of direct instruction (DI) over cooperative play (CP) or inquiry (Jenkins et al., 2018), while countering studies suggest otherwise (Lerkanen et al., 2016). DI employs a rigorously structured, teacher-centered pedagogy, with the educator delivering a comprehensive lesson plan to steer students through their learning journey (Li et al., 2020; Yin et al., 2020). Conversely, the philosophy of CP or inquiry centres on active child involvement during activities, peer interaction, as well as personal agency and idea ownership (Pyle & Danniels, 2017; Zippert et al., 2019). To fill the gaps, this study aimed to compare the effectiveness of two pedagogical approaches of early AI education in kindergartens.

1.1 | Robot play and child learning outcomes

Robotics presents a compelling means to cultivate critical 21st-century competencies, such as creativity, collaboration and digital literacy (Sullivan & Bers, 2016). Therefore, the rapidly growing field of robotics—integrating facets of computer science, engineering, and technology—has found renewed relevance in the sphere of education, eliciting increasing interest among scholars and practitioners alike (Alam, 2022; Zhong & Xia, 2020). The burgeoning research on the integration and influences of robot play on child outcomes suggests promising implications for early childhood education. Existing evidence indicates that integrating robotics into early learning contexts fortifies a variety of fundamental skills among young children. These include enhanced problem-solving aptitude (Ali et al., 2022; Hashimoto et al., 2013), advanced cognitive development (Yang et al., 2022; Yang et al., 2023), and improved social capacities (Telisheva et al., 2022). This section will review and synthesize the extant evidence to address the impact of robot play on computational thinking, self-regulation, sequencing ability and theory of mind, respectively.

Wing (2006) defines computational thinking as a problem-solving process in which problems are systematically structured, data is rationally arranged and representation through abstraction is utilized. Research indicates that the incorporation of robotics within early childhood education can bolster the development of computational thinking abilities, such as algorithmic reasoning, debugging and iterative design (Bers et al., 2014; Kazakoff et al., 2013). Evidently, Bers et al. (2014) discovered that children engaging in a robotics-centric and programming curriculum significantly excelled in their computational thinking skills when juxtaposed with a contrasting group.

Self-regulation embodies the capacity to oversee and control personal behaviour, emotions, and thoughts (Yang et al., 2023; Zimmerman, 2000). It has been established that robot-supported education can foster self-regulation through fostering task persistence, goal-oriented behaviours, and self-monitoring (Encarnação et al., 2014). As emphasized in Chang et al.'s (2010) research, lower primary school

attendees participating in a robot-aided learning module demonstrated considerable enhancements in self-regulation and executive function skills when compared against a control group. The learning enhancements were attributed to the tangible, interactive aspect of robotics, which spurs physical movement, interaction and problem-solving. However, Yang et al. (2022) recently provided inconclusive evidence regarding whether involvement in robot play substantially improved a child's self-regulation capabilities.

Sequencing ability, or the aptitude to comprehend and manipulate the sequence of events or actions (Yang et al., 2023), forms a foundational skill set associated with numeracy prowess (McKeveatt et al., 2023) and reading comprehension abilities (Gouldthorp et al., 2018). Robotics education can foster such capabilities by encouraging children to conceptualize and implement algorithms—systematic step-by-step processes to accomplish a task (Sullivan & Bers, 2016). Reflecting this assertion, a study by Kazakoff et al. (2013) found that participation in a robotics and programming curriculum resulted in considerable improvements in sequencing ability, mirrored in Yang et al.'s (2022) recent findings regarding the impact of coding play with robots in early childhood environments.

Theory of mind, the capability to ascribe mental states such as beliefs, desires and intentions to oneself and others (Premack & Woodruff, 1978), has been minimally explored in the context of robot play. Nonetheless, some studies suggest a correlation between robotics and socioemotional skill development, including empathy, perspective-taking and social problem-solving (Mubin et al., 2013). Children's perspective-taking, for example, refers to one's ability to relate to others, which is interconnected with theory of mind (Barnes-Holmes et al., 2004). Tanaka et al. (2014) cite improvements in empathy, communicative abilities and emotional understanding in children interacting with socially assistive robots. In an exploratory study by Di Dio et al. (2020) involving preschool and school-age children's interactions with both humans and humanoid robots, no substantial differences were found in the trust levels developed towards their play partners. Children seemed to employ similar psychological processes in developing trust, irrespective of whether the interacting party was a human or a robot (Di Dio et al., 2020).

1.2 | Cooperative play versus direct instruction in early childhood education

Two distinctive pedagogical approaches are widely observed in early childhood classrooms: child-led CP versus teacher-dominating direct instruction (Yin et al., 2020). In particular, CP is characterized by the emphasis it places on child-initiated activities and active collaboration, alongside peer interaction (Wood, 2019). Conversely, DI method primarily incorporates teacher-led lessons, explicit instruction and structured activities (Wood, 2019). The effectiveness of these two approaches has been the subject of much debate. Some studies found that CP might foster the growth of social and emotional skills more effectively (Lillard et al., 2013). Contrarily, numerous studies have exhibited that DI might yield larger improvements in academic skills (Duncan et al., 2007; Jenkins et al., 2018).

Recently, Skene et al. (2022) conducted a meta-analysis and revealed that guided play, a synthesis of the two approaches, had a more significant impact on augmenting children's early math skills, shape knowledge, and task-switching abilities, as compared to DI and free play. However, it did not map equal success across all outcomes. Moreover, no empirical evidence has been reported to compare the different effectiveness of CP and DI in early AI education, demonstrating a remarkable knowledge gap. Therefore, exploring whether child-led CP or teacher-led DI proves more fruitful in fostering computational thinking, self-regulation, sequencing and theory of mind in kindergarten-aged children becomes a crucial research question. Accordingly, this study is dedicated to investigating the relative efficacy of these pedagogical strategies within early childhood context.

1.3 | The present study

Su and Yang's (2022) scoping review reveals that AI robots can be used to enhance children's learning in early childhood education settings. The present study aims to contribute to our understanding of the impact of AI robots on young children's learning, as well as the most effective way to implement robotics-based learning in kindergarten classrooms. Specifically, this study aims to address the following research questions

1. What is the impact of early AI education on young children's computational thinking, sequencing, self-regulation and theory of mind skills?
2. Between cooperative robot play and DI, which AI educational approach is more effective in promoting young children's computational thinking, sequencing, self-regulation and theory of mind skills?

Accordingly, this study endeavours to examine the following hypotheses:

Hypothesis 1. Early AI education significantly enhances young children's computational thinking, sequencing, self-regulation and theory of mind skills.

Hypothesis 2. Cooperative robot play and DI have different effectiveness in promoting young children's computational thinking, sequencing, self-regulation and theory of mind skills.

2 | METHODS

2.1 | Participants

The sample consisted of 90 kindergarten children aged 5–6 (M: 5.82 years old; SD: 0.382); 54 were boys (60%) and 36 were girls (40%) in the same kindergarten in south China. A total of three classes participated in the study. Participants were randomly assigned to

TABLE 1 Overview of the curricular content for the two intervention groups.

Direct instruction group/cooperative play group	
Week 1	Introduction to AI robots (i.e., the functions of two AI robots)
Week 2	Interacting with the AI robot
Week 3	Gesture recognition and dancing using AI robots
Week 4	Coding using AI robot
Week 5	Coding using AI robot
Week 6	Playing math knowledge games using the AI robot
Week 7	Listening to the stories created by AI robot
Week 8	Role-play (Using the story from the previous lesson)

Abbreviation: AI, artificial intelligence.

one of three groups each of which comprised 30 children: DI group, cooperative playgroup and control group. The DI group and CP group attended eight sessions of AI learning (see Table 1 for more information). The control group attended the standard kindergarten program.

2.2 | AI robots

The AI robots include UBTECH robots (Figure 1) and AI dogs (Figure 2) which are compact AI robots specifically designed for young children. UBTECH robots and AI dogs are well-suited for kindergarten children because they provide engaging interactive and educational experiences, aiming to help children develop their social skills and problem-solving abilities. The UBTECH robot offers a wide range of functions, including education, entertainment and companionship. The UBTECH robot can interact with children, dance, teach programming knowledge and tell stories. The AI robotic dog is capable of singing, dancing, performing entertaining actions, responding to gestures, engaging in intelligent programming, interacting through touch and mathematical question-and-answer games.

2.3 | Research interventions: Direct instruction group and cooperative play group

This experiment study was conducted to compare the effectiveness of two different AI educational approaches in terms of computational thinking (CT), sequencing, self-regulation and theory of mind skills. DI group and CP group AI robot-based intervention programs were conducted during eight weekly half-hour sessions in which the children learned the functions of AI robots. In the first class, the functions of two AI robots are introduced. Children can interact with the AI robots in the second class. The third class focuses on learning how to use the robots for gesture recognition and dance together with them. Children can learn basic programming knowledge using AI robots in the fourth and fifth sessions. In the sixth class, children have the opportunity to play math knowledge games using the AI robots. Furthermore,



FIGURE 1 UBTECH robot.



FIGURE 2 AI dog.

children can listen to stories told by AI robots in the seventh class. Lastly, children have the opportunity to play role-play activities with the robots in the last class (Table 1).

There are 15 robots in the DI group and 15 in the CP group, a total of 30 robots across these two groups. In these groups, two children use a robot. In the DI group, teachers and researchers provide teaching and guidance. In the CP group, the two children collaborate to discuss how to program the robot and accomplish tasks, without receiving guidance from the teacher and researcher.

2.4 | Procedures

First and foremost, we prepared and distributed consent forms describing our project to the kindergarten principal and obtained

informed consent from him/her. After that, we obtained informed consent from the three class teachers who were assigned by the principal to participate in our study. Through the contact of class teachers, we were able to obtain the informed consent forms and parent questionnaires from children's parents or guardians. We also obtained oral consent from the participating children.

With parents' consent, all the participating children were assessed immediately before the teacher training. The teachers from the kindergarten participated in a face-to-face teacher training workshop and were introduced to the AI4KG curriculum, including learning aims, teaching content and teaching methods.

After a total of 8 weeks of intervention, children were assessed with the same instruments immediately. All the tests were administered to all children individually and in a quiet room. Each child takes 30–40 min to complete the assessment.

2.5 | Instruments

All three groups were assessed pre- and post-intervention on CT, sequencing, self-regulation and theory of mind skills.

2.5.1 | Computational thinking

TechCheck, developed by Relkin et al. (2020), is an assessment tool designed to evaluate children's computational thinking. TechCheck-K is an unplugged CT assessment that consists of 15 items categorized into six dimensions: algorithm design, modularity/decomposition, control structures/pattern recognition, representation/abstraction, hardware/software and debugging (Relkin & Bers, 2021). TechCheck has been used in several studies to evaluate the CT abilities of preschool children in the Chinese context (e.g., Li & Yang, 2023; Yang et al., 2023). The criterion validity of TechCheck-K demonstrates good results, with $r = 0.76$ (Relkin & Bers, 2021).

2.5.2 | Sequencing

In order to assess children's early coding skills, we employed the Picture Sequencing Task (PST) to determine whether children were capable of physically manipulating cards to visualize the sequence of stories. The PST was adapted from Baron-Cohen et al. (1986)'s picture sequencing cards specifically designed for preschool and kindergarten children. Each picture story in the PST consists of four picture cards and children were instructed to arrange them in the correct order to form a coherent story. Researchers followed a standardized procedure to present and explain the cards to the children for the sequencing tasks. Following each task, the researchers assigned a score of 2, 1 or 0 based on the participants' performance, indicating a correct sequence, a sequence with the correct beginning and ending cards or a completely incorrect sequence, respectively. The pre-test and post-test each utilized five different picture stories, resulting in a total

score ranging from 0 to 10 points for the PST for each child participant. The picture story categories used in the pre-test and post-test were carefully matched to ensure equal difficulty for both tests.

2.5.3 | Self-regulation

We used Head-Toes-Knees-Shoulders (HTKS) task to evaluate children's self-regulation skills (Ponitz et al., 2009). The HTKS task comprises 30 items, with a scoring range of 0–60. Researchers assigned a score of 0 for incorrect responses, 1 for self-corrected responses and 2 for correct responses to each participant's performance. Previous studies have demonstrated that this measure exhibits high interrater reliability and validity in assessing the self-regulation of children from diverse cultures, such as pre-schoolers from USA (McClelland et al., 2014), Hong Kong region (Liu et al., 2018) and China (Ren et al., 2018).

2.5.4 | Theory of mind skills

The study assessed theory of mind skills based on Wellman and Liu's (2004) research, which encompassed diverse desires, diverse beliefs, knowledge access, content false belief and apparent emotion. Kindergarten children were presented with questions and accompanying photographs and they provided answers to each question. For each theory of mind skills task, researchers assigned a score of 1 for a correct answer and 0 for an incorrect answer. The pre-test and post-test included five pictures, respectively. As a result, participants received a total score ranging from 0 to 10 points for theory of mind skills in both the pre-test and post-test.

TABLE 2 Pre- and post- means and standard deviations.

	Pre-test		Post-test		F	p
	M	SD	M	SD		
Computational thinking						
DI group	7.7	1.54	9.6	1.67	0.079	< 0.001***
CP group	7.6	2.03	9.13	2.35	0.724	0.009**
Control group	7.47	2.19	8.87	2.432	0.496	0.023*
Sequencing						
DI group	4.9	0.85	6.63	1.25	6.318	< 0.001***
CP group	4.87	0.973	6.67	1.37	2.328	< 0.001***
Control group	4.9	0.845	5.77	1.040	1.105	< 0.001***
Self-regulation						
DI group	45.83	2.23	52.63	3.85	9.750	< 0.001***
CP group	45.70	2.04	51.77	2.79	2.736	< 0.001***
Control group	45.73	4.362	51.30	4.706	0.233	< 0.001***
Theory of mind skills						
DI group	2.60	0.68	3.4	0.77	0.640	< 0.001***
CP group	2.7	0.651	3.77	0.68	0.004	< 0.001***
Control group	2.53	0.681	2.93	1.015	3.697	0.078

Abbreviations: CP, cooperative play; DI, direct instruction.

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

2.6 | Statistical methods

All the statistical analyses were performed using SPSS version 27 software. To answer research question 1 and test hypothesis 1, we conducted a t-test comparing the means of pre-test and post-test scores within each pedagogical condition. To answer research question 2 and test hypothesis 2, we first employed the one-way analysis of variance (ANOVA) to benchmark if the three groups differed at the beginning (pre-test). Second, we use ANOVA to compare the improvement of scores (post-pre) across the three conditions. Third, if ANOVA on score improvement on CT, sequencing, self-regulation or theory of mind show significant differences across three groups, we conducted post hoc pairwise tests, to compare DI versus CP, CP versus control, DI versus control, revealing the relative advantages of these pedagogical approaches in cultivating children's CT, sequencing, self-regulation and theory of mind skills.

3 | RESULTS

Table 2 shows the descriptive statistics of scores in pre- and post-test on each of the four constructs and across three groups. It also reported the results of t-test comparing the means of pre- and post-test on each of the four constructs and within each group. From the results, we can see that in all the four aspects, all pedagogical approaches improved the test scores. This answer our first research question, that both early AI education approaches (CP and DI) significantly enhance young children's CT, self-regulation, sequencing and theory of mind skills.

Results of the one-way ANOVA on pre-test scores revealed no significant differences among the three groups on computational thinking

($F = 0.109$, $p = 0.897$), sequencing ability ($F = 0.014$, $p = 0.986$), self-regulation ($F = 0.015$, $p = 0.985$), or theory of mind skills ($F = 0.471$, $p = 0.626$). In other words, at the beginning of this study, all three groups of children were comparable in these four aspects.

3.1 | Computational thinking

Results of the one-way ANOVA on score improvement (post-test–pre-test) of computational thinking across the three groups showed a significant difference ($F = 5.958$, $p = 0.004$). Post-hoc pairwise comparisons revealed that the DI group had significantly higher score improvement than the CP group and the control group, where there were no statistically significant differences between CP and the control groups, as shown in Table 3.

3.2 | Sequencing ability

Results of the one-way ANOVA on score improvement (post-test–pre-test) of sequencing ability across the three groups showed a significant difference ($F = 20.730$, $p < 0.001$). Post-hoc pairwise comparisons revealed that both DI and CP groups had significantly higher score improvement than the control group while CP group had a higher score improvement than the DI group (Table 4).

3.3 | Self-regulation

Results of the one-way ANOVA on score improvement (post-test–pre-test) of self-regulation across the three groups showed a

TABLE 3 Pairwise comparisons between groups on computational thinking.

(I) group	(J) group	Mean difference (I–J)	<i>p</i>
DI	CP	0.36667*	0.050
DI	Control group	0.50000**	0.004
CP	Control group	0.13333	1.000

Abbreviations: CP, cooperative play; DI, direct instruction.

*The mean difference is significant at the 0.05 level.

**The mean difference is significant at the 0.01 level.

TABLE 4 Pairwise comparisons between groups on sequencing ability.

(I) group	(J) group	Mean difference (I–J)	<i>p</i>
DI	CP	–0.06667	0.976
DI	Control group	0.86667***	< 0.001
CP	Control group	0.93333***	< 0.001

Abbreviations: CP, cooperative play; DI, direct instruction.

***The mean difference is significant at the 0.001 level.

marginally significant difference at the $p = 0.1$ level ($F = 2.744$, $p = 0.07$). Post-hoc pairwise comparisons revealed that the DI group had a marginally higher improvement than the CP and control group while there were no statistically significant differences between the DI and CP groups or between the CP and control groups as shown in Table 5.

3.4 | Theory of mind skills

Results of the one-way ANOVA on score improvement (post-test–pre-test) of Theory of Mind Skills showed a significant difference ($F = 13.439$, $p < 0.001$). Post-hoc pairwise comparisons revealed that the DI and CP groups had significantly higher improvement than the control group. However, the score improvement of the CP group was higher than that of the DI group, as shown in Table 6.

4 | DISCUSSION

This study revolved around exploring the potential enhancement of computational thinking, sequencing, self-regulation and theory of mind skills in Chinese kindergarteners through the use of two different AI educational approaches. The findings indicate positive and nuanced effects and have important implications for early AI education in early childhood settings.

4.1 | Early AI education has positive impacts

This promising study found increase in four key areas from pre-test to post-test in the three groups (Table 2), optimistically indicating the

TABLE 5 Pairwise comparisons between groups on self-regulation.

(I) group	(J) group	Mean difference (I–J)	<i>p</i>
DI	CP	0.73333	0.519
DI	Control group	1.23333	0.087
CP	Control group	0.50000	0.584

Abbreviations: CP, cooperative play; DI, direct instruction.

TABLE 6 Pairwise comparisons between groups on theory of mind skills.

(I) group	(J) group	Mean difference (I–J)	<i>p</i>
DI	CP	–0.26667	0.090
DI	Control Group	0.40000**	0.008
CP	Control Group	0.66667***	< 0.001

Abbreviations: CP, cooperative play; DI, direct instruction.

**The mean difference is significant at the 0.01 level;

***The mean difference is significant at the 0.001 level.

positive influence of AI robot-based interventions on early education. The enhancements noted in computational thinking, sequencing ability, theory of mind skills and self-regulation suggest that the AI robots meaningfully enriched the children's learning experience beyond what was observed in the control group (Tables 3–6). Echoing the encouraging findings of Yang et al.'s (2022) research, which showcased improvements in computational thinking, sequencing ability, and self-regulation among children engaged in robot programming and block play, this study reaffirms the potential of AI in early education.

While we must acknowledge that some of the rise in test scores could connect to the children's normal growth and development as per Deoni et al. (2016), an inspiring highlight from the results is clear. The children involved in the intervention groups registered more significant advancements in all four evaluations compared to their peers in the control group (Tables 3–6). This gratifying outcome strengthens the idea that AI robot programs can serve as effective educational methods, accordingly promising to bolster a range of skills in kindergarten children. These findings shed light on the promising future AI has in revolutionizing early stage education in a positive and impactful manner.

4.2 | Cooperative play versus direct instruction: Which is more effective?

Notwithstanding the use of identical content in both intervention methods, superior results were observed in computational thinking (Table 3) and self-regulation (Table 5) tests among children who received DI when compared to their counterparts in the CP group. A range of theoretical perspectives and ast research findings can elucidate this outcome. According to the Cognitive Load Theory by Sweller (1988), direct teaching methods decrease extraneous cognitive load while fostering intrinsic one, hence proving more adept at managing cognitive overburden compared to CP. Expounding on this, Vygotsky's (1978) zone of proximal development presents the idea that DI—a process where teachers offer targeted guidance and support—assists learners in navigating the trajectory between their current abilities and intended learning targets. A crucial instructional strategy in this domain is scaffolding, entailing the provision of transitory support by a more knowledgeable individual, frequently incorporated in DI, to shepherd students throughout their learning journey. The effectiveness of DI over CP is corroborated by existing research investigations, such as those of Kirschner et al. (2006), Hattie (2009) and Alfieri et al. (2011), demonstrating higher efficacy in improving students' achievements. Consequently, the evidence suggests that DI, through better cognitive load management, enhanced guidance and strong support structures, can effectively cultivate self-regulation skills among learners, thereby assisting them in achieving their educational objectives.

The study's findings also indicated that kindergarteners in the CP group showed greater improvements in theory of mind skills compared to those in the DI group. This observation is remarkable as it underscores the potential advantages of incorporating CP into early childhood education. The observed superior enhancements in the CP group could be due to the interactive and collaborative nature of

CP (Jarvis et al., 2014). This type of play offers children opportunities to negotiate roles, collectively solve problems, and understand differing perspectives (Krych-Appelbaum et al., 2007), thereby fostering their theory of mind skills. While DI can effectively impart specific skills or knowledge, it may not provide children with sufficient opportunities to explore, experiment and interact with their peers in a manner that promotes theory of mind. These findings emphasize the importance of integrating CP into early childhood education programs. However, additional research is required to investigate the long-term impacts of these approaches and to ascertain the optimal balance between CP and DI for enhancing cognitive and social skills among kindergarteners.

4.3 | Contributions of the study

This study stands as a pioneering investigation into the effects of AI educational approaches on early childhood development, specifically elucidating its impact on computational thinking, sequencing, self-regulations and theory of mind skills among kindergarten children. This ground-breaking contribution fills a gap in the research literature, as there have been no such comparative studies conducted in early childhood classrooms. Advancing the international research trajectory in child-robot interaction, this study enhances our scientific exploration by integrating multi-group experimental designs and implementing diverse measures to assess child learning outcomes, thereby significantly enriching our understanding of early AI education. Furthermore, its findings construct a novel foundation for future similar studies, extending beyond the scope of previous studies that have mainly focused on assessing the effects of educational robotics on children's computational thinking (Funk et al., 2021).

4.4 | Limitations and implications for future research

This study's limitations must be acknowledged to contextualize its findings. Firstly, the immediate effects of interventions lasting only 8 weeks were evaluated; no extended outcomes were assessed. Future research, therefore, should investigate the potential enduring impacts of early childhood interventions. Second, the limited sample size for each intervention group in this study may impact the generalizability of the findings. This limitation signals the need for broader verification through a large-scale randomized controlled trial encompassing multiple and diverse early childhood settings.

Nevertheless, this research has some implications for future exploration within the field. First, it underscores the profound potential of AI robot programs as effective tools in fostering essential skills like computational thinking, sequencing, self-regulation and theory of mind among young children. The pronounced improvement observed in these areas in comparison to the control group invites educators and researchers to consider the transformative potential of AI robot programs in bolstering vital competency development in early education.

Next, the project's findings illuminate the compelling argument favouring DI over CP for skill mastery, notably in managing cognitive load and enhancing self-regulation skills. This vital insight indicates the necessity for education professionals to contemplate adopting DI methodologies when imparting critical skills to young learners. By providing clear guidance and learning support, DI can significantly optimize the learning process, reducing the need for children to hunt for relevant information or strategies, thereby effectively managing cognitive load compared to CP.

In contrast, the CP approach displayed more robust improvements in theory of mind skills. These nuanced results advocate for a blended instructional paradigm, incorporating varied activities and approaches for the holistic skill development of young children.

Lastly, the study paves the way for future research to delve into the enduring impacts of AI robot programs on the progression of critical skills among young children. The present study showcases promising progress in all four assessments across the three groups from pre-test to post-test. However, additional, extensive research is warranted to decipher how AI robot programs can continuously nurture and enhance these critical skills over an extended timeline.

5 | CONCLUSIONS

This research offers empirical evidence of the efficacy of AI education in fostering the development of computational thinking, sequencing, self-regulation and theory of mind skills among kindergarteners. The results ascertained improvements across all four skill areas in both instruction modes—DI and CP. This indicates the merits of both structured instructional and play-based learning in conducting early AI education. However, the two approaches exhibited more pronounced enhancements in different areas. The conclusions drawn from this research carry weighty implications, encouraging educators and research scholars to traverse new pathways for cultivating crucial competencies in young children, leveraging the power of early AI education.

AUTHOR CONTRIBUTIONS

Jiahong Su: Conceptualization; methodology; data curation; formal analysis; visualization; investigation; writing – original draft; writing – review and editing. **Weipeng Yang:** Writing – original draft; writing – review and editing. **Iris Heung Yue Yim:** Writing – review and editing. **Hui Li:** Writing – review and editing. **Xiao Hu:** Writing – review and editing.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ORCID

Jiahong Su  <https://orcid.org/0000-0002-9681-7677>

Weipeng Yang  <https://orcid.org/0000-0002-8057-2863>

Iris Heung Yue Yim  <https://orcid.org/0000-0002-5392-0092>

Hui Li  <https://orcid.org/0000-0001-9355-1116>

Xiao Hu  <https://orcid.org/0000-0003-3994-0385>

REFERENCES

- Alam, A. (2022). Social robots in education for long-term human-robot interaction: Socially supportive behaviour of robotic tutor for creating robot-tangible learning environment in a guided discovery learning interaction. *ECS Transactions*, 107(1), 12389–12403.
- Alfieri, L., Brooks, P. J., Aldrich, N. J., & Tenenbaum, H. R. (2011). Does discovery-based instruction enhance learning? *Journal of Educational Psychology*, 103(1), 1–18.
- Ali, S., Devasia, N. E., & Breazeal, C. (2022). Escape! bot: Social robots as creative problem-solving partners. In *Proceedings of the 14th Conference on Creativity and Cognition* (pp. 275–283). ACM.
- Barnes-Holmes, Y., McHugh, L., & Barnes-Holmes, D. (2004). Perspective-taking and theory of mind: A relational frame account. *The Behavior Analyst Today*, 5(1), 15–25. <https://doi.org/10.1037/h0100133>
- Baron-Cohen, S., Leslie, A. M., & Frith, U. (1986). Mechanical, behavioural and intentional understanding of picture stories in autistic children. *British Journal of Developmental Psychology*, 4, 113–125. <https://doi.org/10.1111/j.2044-835X.1986.tb01003.x>
- 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.
- Chang, C.-W., Lee, J.-H., Chao, P.-Y., Wang, C.-Y., & Chen, G.-D. (2010). Exploring the possibility of using humanoid robots as instructional tools for teaching a second language in primary school. *Educational Technology & Society*, 13(2), 13–24.
- Deoni, S. C., O'Muircheartaigh, J., Elison, J. T., Walker, L., Doernberg, E., Waskiewicz, N., ... Jumbe, N. L. (2016). White matter maturation profiles through early childhood predict general cognitive ability. *Brain Structure and Function*, 221, 1189–1203.
- Di Dio, C., Manzi, F., Peretti, G., Cangelosi, A., Harris, P. L., Massaro, D., & Marchetti, A. (2020). Shall I trust you? From child-robot interaction to trusting relationships. *Frontiers in Psychology*, 11, 469.
- Duncan, G. J., Dowsett, C. J., Claessens, A., Magnuson, K., Huston, A. C., Klebanov, P., Pagani, L. S., Feinstein, L., Engel, M., Brooks-Gunn, J., Sexton, H., Duckworth, K., & Japel, C. (2007). School readiness and later achievement. *Developmental Psychology*, 43(6), 1428–1446.
- Encarnação, P., Alvarez, L., Rios, A., Maya, C., Adams, K., & Cook, A. (2014). Using virtual robot-mediated play activities to assess cognitive skills. *Disability and Rehabilitation: Assistive Technology*, 9(3), 231–241.
- Funk, M. G., Cascalho, J. M., Santos, A. I., & Mendes, A. B. (2021). Educational robotics and tangible devices for promoting computational thinking. *Frontiers in Robotics and AI*, 8, 713416.
- Gouldthorp, B., Katsipis, L., & Mueller, C. (2018). An investigation of the role of sequencing in children's reading comprehension. *Reading Research Quarterly*, 53(1), 91–106.
- Hashimoto, T., Kobayashi, H., Polishuk, A., & Verner, I. (2013). Elementary science lesson delivered by robot. In *In 2013 8th ACM/IEEE international conference on human-robot interaction (HRI)* (pp. 133–134). IEEE.
- Hattie, J. (2009). *Visible learning: A synthesis of over 800 meta-analyses relating to achievement*. Routledge.
- Jarvis, P., Newman, S., & Swiniarski, L. (2014). On 'becoming social': The importance of collaborative free play in childhood. *International Journal of Play*, 3(1), 53–68.
- Jenkins, J. M., Duncan, G. J., Auger, A., Bitler, M., Domina, T., & Burchinal, M. (2018). Boosting school readiness: Should preschool teachers target skills or the whole child? *Economics of Education Review*, 65, 107–125.
- 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.

- Kirschner, P. A., Sweller, J., & Clark, R. E. (2006). Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. *Educational Psychologist*, 41(2), 75–86.
- Krych-Appelbaum, M., Law, J. B., Jones, D., Barnacz, A., Johnson, A., & Keenan, J. P. (2007). “I think I know what you mean”: The role of theory of mind in collaborative communication. *Interaction Studies*, 8(2), 267–280. <https://doi.org/10.1075/is.8.2.05kry>
- Lerikkanen, M. K., Kiuru, N., Pakarinen, E., Poikkeus, A. M., Rasku-Puttonen, H., Siekkinen, M., & Nurmi, J. E. (2016). Child-centered versus teacher-directed teaching practices: Associations with the development of academic skills in the first grade at school. *Early Childhood Research Quarterly*, 36, 145–156.
- Li, W., & Yang, W. (2023). Promoting children's computational thinking: A quasi-experimental study of web-mediated parent education. *Journal of Computer Assisted Learning*, 39, 1564–1575. <https://doi.org/10.1111/jcal.12818>
- Li, Z. Y., Yang, W., & Li, H. (2020). Teachers' pedagogical interactions as linked to personal beliefs and profiles: A mixed-methods study in Hong Kong kindergartens. *International Journal of Early Years Education*, 28(4), 366–381.
- Lillard, A. S., Lerner, M. D., Hopkins, E. J., Dore, R. A., Smith, E. D., & Palmquist, C. M. (2013). The impact of pretend play on children's development: A review of the evidence. *Psychological Bulletin*, 139(1), 1–34.
- Liu, Y., Sun, H., Lin, D., Li, H., Yeung, S. S. S., & Wong, T. T. Y. (2018). The unique role of executive function skills in predicting Hong Kong kindergarteners' reading comprehension. *British Journal of Educational Psychology*, 88(4), 628–644.
- 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.
- McKevett, N. M., Coddling, R. S., & Running, K. R. (2023). The effects of representational instruction and the great race on Preschoolers' early numeracy skills. *Remedial and Special Education*, 45, 18–29. <https://doi.org/10.1177/07419325231160292>
- Mubin, O., Stevens, C. J., Shahid, S., Al Mahmud, A., & Dong, J.-J. (2013). A review of the applicability of robots in education. *Journal of Technology in Education and Learning*, 1, 1–7.
- Ponitz, C. 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>
- Premack, D., & Woodruff, G. (1978). Does the chimpanzee have a theory of mind? *Behavioral and Brain Sciences*, 1(4), 515–526.
- Pyle, A., & Danniels, E. (2017). A continuum of play-based learning: The role of the teacher in play-based pedagogy and the fear of hijacking play. *Early Education and Development*, 28(3), 274–289.
- Relkin, E., & Bers, M. (2021). Techcheck-k: A measure of computational thinking for kindergarten children. In *2021 IEEE global engineering education conference (EDUCON)* (pp. 1696–1702). IEEE.
- 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(4), 482–498.
- Ren, L., Zhang, X., Yang, W., & Song, Z. (2018). Relations among parenting, child behavioral regulation and early competencies: A study on Chinese preschoolers. *Journal of Child and Family Studies*, 27, 639–652.
- Skene, K., O'Farrelly, C. M., Byrne, E. M., Kirby, N., Stevens, E. C., & Ramchandani, P. G. (2022). Can guidance during play enhance children's learning and development in educational contexts? A systematic review and meta-analysis. *Child Development*, 93(4), 1162–1180.
- Su, J., & Yang, W. (2022). Artificial intelligence in early childhood education: A scoping review. *Computers and Education: Artificial Intelligence*, 100049, 1–13.
- Su, J., Yang, W., & Zhong, Y. (2022). Influences of gender and socioeconomic status on children's use of robotics in early childhood education: A systematic review. *Early Education and Development*, 1–17.
- Su, J., Ng, D. T. K., & Chu, S. K. W. (2023). Artificial intelligence (AI) literacy in early childhood education: The challenges and opportunities. *Computers and Education: Artificial Intelligence*, 4, 100124.
- Sullivan, A., & Bers, M. U. (2016). Robotics in the early childhood classroom: Learning outcomes from an 8-week robotics curriculum in pre-kindergarten through second grade. *International Journal of Technology and Design Education*, 26(1), 3–20.
- Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive Science*, 12(2), 257–285.
- Tanaka, F., Takahashi, T., Matsuzoe, S., Tazawa, N., & Morita, M. (2014, March). Telepresence robot helps children in communicating with teachers who speak a different language. In *Proceedings of the 2014 ACM/IEEE international conference on human-robot interaction* (pp. 399–406). ACM. <https://doi.org/10.1145/2559636.2559654>
- Telisheva, Z., Amirova, A., Rakhymbayeva, N., Zhanatkyzy, A., & Sandygulova, A. (2022). The quantitative case-by-case analyses of the socio-emotional outcomes of children with ASD in robot-assisted autism therapy. *Multimodal Technologies and Interaction*, 6(6), 46.
- Toh, L. P. E., Causo, A., Tzuo, P. W., Chen, I. M., & Yeo, S. H. (2016). A review on the use of robots in education and young children. *Journal of Educational Technology & Society*, 19(2), 148–163.
- Vygotsky, L. S. (1978). *Mind in society: Development of higher psychological processes*. Harvard University Press.
- Wellman, H. M., & Liu, D. (2004). Scaling of theory-of-mind tasks. *Child Development*, 75(2), 523–541.
- Wing, J. M. (2006). Computational thinking. *Communications of the ACM*, 49(3), 33–35.
- Wood, E. (2019). Unbalanced and unbalancing acts in the early years foundation stage: A critical discourse analysis of policy-led evidence on teaching and play from the office for standards in education in England (Ofsted). *Education*, 47(7), 784–795.
- Yang, W., Gao, H., Jiang, Y., & Li, H. (2023). Beyond computing: Computational thinking is associated with sequencing ability and self-regulation among Chinese young children. *Early Childhood Research Quarterly*, 64, 324–330.
- Yang, W., Ng, D. T. K., & Gao, H. (2022). Robot programming versus block play in early childhood education: Effects on computational thinking, sequencing ability, and self-regulation. *British Journal of Educational Technology*, 53(6), 1817–1841.
- Yin, Q., Yang, W., & Li, H. (2020). Blending constructivism and instructivism: A study of classroom dialogue in Singapore kindergartens. *Journal of Research in Childhood Education*, 34(4), 583–600.
- Zhong, B., & Xia, L. (2020). A systematic review on exploring the potential of educational robotics in mathematics education. *International Journal of Science and Mathematics Education*, 18, 79–101.
- Zimmerman, B. J. (2000). Attaining self-regulation: A social cognitive perspective. In M. Boekaerts, P. R. Pintrich, & M. Zeidner (Eds.), *Handbook of self-regulation* (pp. 13–39). Academic Press.
- Zippert, E. L., Eason, S. H., Marshall, S., & Ramani, G. B. (2019). Preschool children's math exploration during play with peers. *Journal of Applied Developmental Psychology*, 65, 101072.

How to cite this article: Su, J., Yang, W., Yim, I. H. Y., Li, H., & Hu, X. (2024). Early artificial intelligence education: Effects of cooperative play and direct instruction on kindergarteners' computational thinking, sequencing, self-regulation and theory of mind skills. *Journal of Computer Assisted Learning*, 1–9. <https://doi.org/10.1111/jcal.13040>