Bringing Computational Thinking to Life Through Play

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Abstract. Digital tools and solutions are increasingly used in society, creating a need for more digital skills in the workplace and everyday life. As society becomes increasingly digital, computational thinking becomes a fundamental skill for the 21st century. This paper examines play's role in young children's CT development in early childhood education. This paper presents a narrative review and uses forward snowballing to extend the search result. Twenty-two articles met the criteria and were manually collected. The publications were categorized into five categories: programming tools, robotics, unplugged activities, making and exploring, and guided vs. free play. For CT activities to be social and communicative, concepts such as mutuality and scaffolding must be incorporated into operational pedagogical CT frameworks. As such, CT can be designed as a play-oriented activity in that children coordinate and develop themselves, with or without educators' guidance. As a co-creator, an educator can mediate CT and support the children in guiding activities forward.

Keywords: Computational play · Computational thinking · Early Childhood Education · digital artefacts

1 Introduction

The increasing use of computational tools and digital solutions in society has created an increasing need for digital skills both in terms of employment capabilities but also in relation to citizen life. The increasing digitization in society makes Computational Thinking (CT) a fundamental skill for the 21st century where people are required to become digital literate.

CT was first introduced by Seymour Papert (1980) but is more commonly linked with Jeanette Wing's (2006) definition saying that CT is *"solving problems, designing systems, and understanding human behavior, by drawing on the concepts fundamental to computer science"* She also state that CT is a fundamental skill for everyone, not just for computer scientists and that *"we should add computational thinking to every child's analytical ability"*.

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Until recently computer programming was seen as a skill for mathematicians, scientists, and engineers, and the benefits for everyone to learn how to code was not yet perceived. Henceforth, the pedagogical approaches in the field of computer science drew from the Science, Technology, Engineering, and Mathematics- (STEM) disciplines (Bers, 2019). Due to the growing technical requirement in society CT and related fields have been introduced as early as preschool or kindergarten curriculums in several countries. Consequently, new pedagogical approaches in teaching CT must be developed and the content need to be adapted to better support the children in their development and understanding of CT. This has led to many different experiments where attempts have been made to introduce children to digital technology and CT through play and play-based learning activities. Different tools and software programs have been developed to support these activities such as block-based programming software, tangible coding objects and button-based programming robots.

In the same way, this movement has also led to new ways of framing CT. Barr & Stephenson (2011) aimed at developing an operational definition of CT for K-12 education and in the process came up with several core computational thinking concepts and capabilities to teach the students including: data collection, data analysis, data representation, problem decomposition, abstraction, algorithms & procedures, automation, parallelization. They also attempted to define a classroom culture that included strategies such as: Increased use of computational vocabulary, group work with explicit use of computational processes such as decomposition, abstraction, negotiation and consensus building, and a mindset that accepted failed solution attempts. A child's computational vocabulary can be seen when they begin to employ the processes of CT, such as sorting building blocks by color to decompose or make sequencing.

Brennan and Resnick (2012) presented a framework based on the aspects learned when young people engage with digital technology and programming with three different dimensions of CT - computational concepts (the concepts designers engage with as they program), computational practices (the practices designers develop as they engage with the concepts, and computational perspectives (the perspectives designers form about the world around them and about themselves). In Brennan and Resnick (2012) children learn how to program using the block-based programming software Scratch which has been widely used as a tool for children to initially start learning about programming and CT. In a systematic review by Zhang and Nouri (2019), they examine the CT skills that can be obtained through working with Scratch in K-9. While the study concludes that it is possible for children in kindergarten to learn certain CT skills the research in this area is very limited. The authors suggest that their findings can help teachers and researchers with "what to teach" and "what can be learned" by providing them with an overview of the mental abilities of the students but they should also start exploring if other methods are better suited to teach certain CT skills that are challenging to learn for children. Murcia and Tang (2019) examine CT in early childhood based on a social constructivist view of language and representation. They propose a parallel analogy in which coding might be equivalent to computational thinking. As an outward expression of computational thinking, coding is a visible manifestation of computational thinking (e.g., writing a program). Nevertheless, CT is only possible to develop and become internalized (Vygotsky, 1986) for young children within a zone of proximal development through the interaction of coding (using symbols and other resources like tangible coding technologies) with adults and peers within a social space. Coding, like every language, consists of various representational modes, including mathematical symbols, images, gestures and physical objects. In early childhood education (ECE), CT allows children to share ideas, test their limits, and receive feedback with the help of information they capture through their senses. In these actions, imagination and creativity play an essential role in producing new knowledge (Buitrago et al., 2017). Moreover, CT skills are developed through robotics by leveraging playful characteristics of the resource and context, which represents a positive impact according to Froebel's approach to games (Resnick & Rosenbaum, 2013).

In this review, we aim to identify and interpret the different applications of CT as a starting point for discussing key areas of early childhood education with particular emphasis on play and pedagogy. In this paper, we interpret existing literature from the perspective of computational thinking and play. Through a narrative literature review, we investigate CT in early childhood. However, because of the limited literature on CT in early childhood education, we looked at how researchers cited other relevant studies using forward snowballing. Taking a broader perspective on CT was crucial to understand how CT could be applied in an ECE setting. This is further explained in section three. How we methodically approached the narrative snowballing review. This is followed by the outcome of the review divided into five thematic sections (CT tools; Robotics; Unplugged activities; Making and exploring, and Guided play vs free play). Then, we introduce a theoretical chapter based on Bruner's pedagogical theory focusing on the concept of scaffolding and progression in learning followed by a note on the relationship between play and learning. Finally, we present an analytical discussion based on the outcome of the narrative snowballing review and the theoretical framing.

2 Pedagogical Perspectives

In this chapter, we describe pedagogical perspectives as a theoretical framing and analytical tool to discuss key issues of CT in relation to its application in early childhood education specifically emphasizing play and learning. By this, the chapter is intended to frame the concluding analytical discussion, which will end this article.

Becoming CT competent requires learning CT concepts, programming, coding, etc. and working within the opportunities and limitations this offers. For children this means to find out what can be done with different kinds of CT activities by trying them out in different combinations and circumstances, which can enable children to develop competence from their experiences. This calls for sensitive educators to support children to internalize and develop their CT understanding. In this regard, Bruner (1961) argues for scaffolding, i.e., to actively support children when they start to learn new concepts. Bruner's theory of scaffolding was particularly influenced by Vygotsky's zone of proximal development theory, where a child can learn from a more knowledgeable other (Wood et al., 1976). However, for children to master such CT concepts and activities, they need to continually deepen their understanding of CT. Problem-solving skills, abstractions, and computational vocabulary are examples of some concepts covered in CT (Webb &

Rosson, 2013). Bruner (1977) termed such revisiting processes as a spiral curriculum in education, where each successive revision builds children's understanding and requires increasingly sophisticated cognitive strategies. According to Bruner (1977), CT learning hence should emerge from progressive practicing of CT through three stages, namely enactive, iconic, and symbolic (Lowe and Brophy, 2017):

- *Enactive*: children learn by engaging in active representations (i.e., through physical and manual activities).
- *Iconic*: children are confident in using an iconic mode of representation as they become more familiar with the content; they can perform tasks by imagining concrete pictures.
- *Symbolic*: As a result, children develop the ability to represent abstract, symbolic ideas without the need for physical manipulation or mental imagery.

To develop a pedagogical structure that reflects this kind of progressive learning when dealing with CT in teaching activities requires that educators have a fundamental knowledge of the field. Bruner (1977) emphasizes the necessity of clarifying the broader structure of a field of knowledge as it otherwise becomes difficult for children to generalize from what has been learnt. Here, building on children's interest and to make knowledge usable beyond the situation in which the learning has occurred. Taking departure in children's interest implies considering children's acts of learning. Depending on the children's age, this interest can have different directions. Kindergarten children tend to focus on establishing relationships between experience and action of trial-and-error character, i.e. by intuitive regulations rather than by symbolic operation. Schoolchildren, on the other hand, are more operational compared to younger children as they, for example, can transform data from the real world into the mind and from this use them selectively in solving problems (Bruner, 1977, 1990). In the context of CT activities, this would mean that young children are intuitive concrete actors being challenged in understanding basic ideas behind, for example, coding. Older children, on the other hand, can connect and transform concrete manipulation into abstract concepts and thereby grasp CT ideas of, for example, programming. Against this background, educators can be seen as limited in transmitting CT concepts to children in early childhood education, also when it comes to intuitive manners. To deal with such challenges, Bruner (1990, 1977) emphasized that meaning and processes involved in the making of meaning are central to individual's learning and development and require an active participation by the educators. One way of acknowledging these matters is through play.

Research on the topic of play describes it as an activity with its own values (Sutton-Smith, 2001), as an unpredictable process without a goal (Huizinga, 2004) or as identified rules of play such as mutuality, unity and turn-taking (Olofsson, 1987). However, in an educational context, play is often described as a resource for learning rather than an activity having its own value (Smith & Pellegrini, 2013). Describing play in terms of Sutton Smith (2001) can be described as having intrinsic values and diversity, which can raise questions about how play and learning can be seen as compatible with each other. This connection between play and learning is also acknowledged by Jonsson and Pramling Samuelsson (2017). While research argues that play as an unpredictable phenomenon cannot guarantee that adults can guide young children's learning towards a particular direction, Jonsson and Pramling Samuelsson (2017) argue that learning in fact has the same premises as play, in particular among younger children. Despite their different dimensions, play and its similarities with the premises of learning put forward creativity, joy, meaning making and children's opportunities to set their own goal as characteristics for play as well as learning (Pramling-Samuelsson & Johansson 2006). Based on this, it can be argued that teachers' scaffolding can become a basis for teaching young children. This as scaffolding can establish a relation between a child and teacher and thus direct their attention to the same object. Children's play ceases unless those involved succeed in establishing such a relationship, therefore teaching, learning and play are always of a social and communicative nature (Pramling, Doverborg, Pramling Samuelsson, 2017).

3 A Narrative Review with Snowballing

The narrative review aims to provide insight into the extant literature on CT play in early education. This type of review seeks to summarize or synthesize what has been written about a particular topic. The information presented is not intended to be generalized or to provide cumulative knowledge (Paré & Kitsiou, 2017). Green et al. (2006) argue that narrative overviews represent an excellent way to keep up with new research and to get a broader view of the field. However, the limitation of this approach concerns that it is not systematic enough to provide robust evidence such as in systematic reviews (Green et al., 2006). It is our intention to contribute to ongoing efforts in exploring CT in early childhood education. In this review, we aim to identify and interpret the different applications of CT as a starting point for discussing key areas of early childhood education with special emphasis on play and pedagogy. This will enable us to gain a deeper understanding of how CT can be embedded in research as well as how it can be introduced in early childhood education. The review question focused on: *How are CT and play utilized in early childhood education? How can computational play contribute to children's early childhood education?*

As Hart (1998) states, reviewing is the process of obtaining an overview of a diverse body of research to synthesize a unique approach to the subject matter. The literature search strategy we developed was intended to obtain an overview of the broad strands of research, not a comprehensive review of all existing literature.

3.1 Organizing the Review

The research articles we selected were selected from three main educational research sources, focusing on publications published between 2012 and 2022, both in Proquest, Education Database; Ebsco host, Academic Serch Premier and ERIC as well as SCOPUS with the phrase "computational thinking" AND "play" AND "early childhood". Table 1 below presents the inclusion and exclusion criteria that were used to determine the relevance of each research article.

The study was conducted in July 2022. In total, 23 articles were saved and classified as relevant or not for the review; 13 articles met the inclusion criteria defined in Fig. 1. Two authors decided on the inclusion status of titles and abstracts. The second screening of

Table 1. Inclusion and exclusion criteria

Inclusion	Exclusion
• Empirical investigation of CT play in early childhood education	• An empirical investigation of CT plays other than early childhood education
• The study should consider and discuss how CT play can be tangled in early childhood education	• Empirical investigation of programming excluding CT
• Peer-reviewed article	

full-text articles, again conducted by two independent research team members, ensured that the studies discussed CT play in early childhood education.

After screening the titles and abstracts of articles with potential relevance, full-text articles were obtained. Based on predetermined inclusion criteria, the full-text papers were analyzed. Our review process utilized forward snowballing to ensure that we included all relevant studies (Wohlin, 2014). The forward snowballing process is displayed in Fig. 1 as a step that identifies relevant articles based on those citing the article selected from the databases. Articles were sorted according to the same procedures as those identified using database searching. To identify each research question, we carefully read each article, considering the connection between CT and play and the relation to early childhood education. 9 articles were found during snowballing. We manually collected data from 22 articles that met the criteria. An overview of the 22 collected articles can be found in Appendix A.

All included publications were grouped into the following five categories: programming tools, robotics, unplugged activities, making and exploring, and guided vs free play.

In the following, the five categories are described.

3.2 CT Tools

Learning CT can take many forms, one of them can be through programming. Different programming languages have been developed, where children can create a program by putting together different pieces of code in sequences of commands. For example, it can take the form of blocks of code, such as in Scratch (Maloney et al., 2010) or ScratchJr (Flannery et al., 2013), or it can use other tangible representations of commands, such as icons, colors, or physical objects (Berson et al., 2019), for example, in a sequence (Wang et al., 2014) to code a program or object. In multiple studies with children, Scratch has been extensively used as a tool for teaching programming (Zhang & Nouri, 2019); however, other tools have been utilized in playful activities that engage children as early as preschool. Wang and colleagues (2021) have for example used a toy called code-a-pillar. With different joints added to the caterpillar's body, it is possible to program it to move in different directions. Using tangible coding blocks (wooden cubes), children aged 5–9 were able to build and escape mazes in an experiment based on a game-based design. Wang et al., (2014) claim that they in this way cultivated children's computational

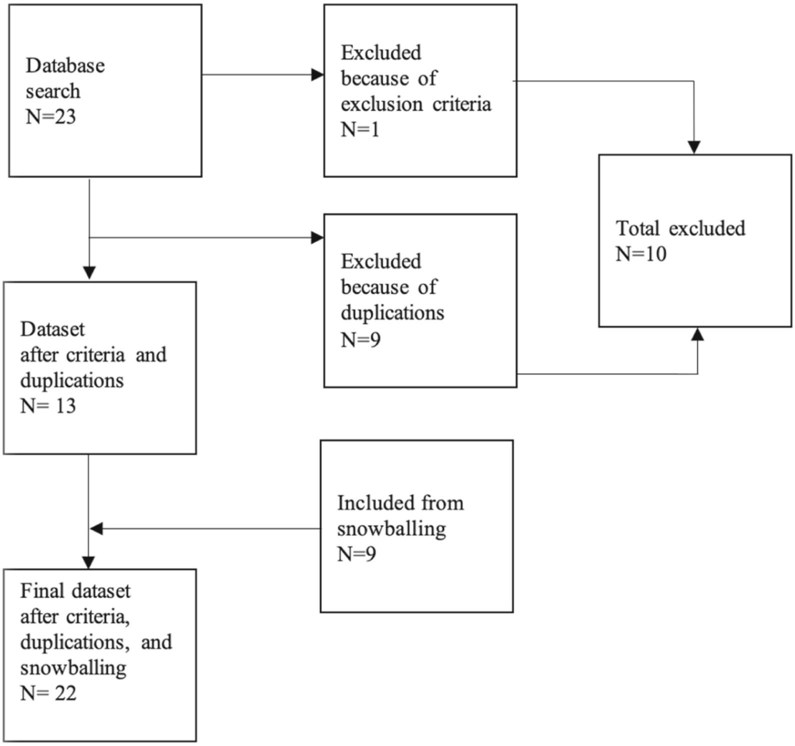

Fig. 1. Review process

thinking, as well as their awareness of abstraction, automation, problem decomposition and analysis.

3.3 Robotics

Multiple studies have indicated that robotic activities can foster CT in children (Angeli & Valanides, 2020), (González and Muñoz-Repiso, 2018), (Hall & McCormick, 2022) and (Bers, 2019). González and Muñoz-Repiso (2018) suggest that robot activities can be approached differently. The robots themselves can be used both as an object of learning where the objective is to learn about robotics. They can be used as means of learning, e.g., build a robot or program it to learn about CT or the robot can be used as support for other learning activities. Different educational robots exist that are easy to control or program for children from around 4–5 years of age. Bee-bots are for example robots that can be programmed to move in different directions by entering a sequence of movements using built-in pushbuttons (Angeli & Valanides, 2020).

According to Hall and McCormick (2022), when children play with robots, they begin the process of observing the robot, interpreting its actions, and responding to them. During this process, children will gain a better understanding of the different dimensions of CT. This is e.g., evident in a study by Murcia & Tang (2019). During an open-play activity where children discussed ideas and created stories with the Cubetto robot, the researchers found that children understood the cause and effect of the coding sequences directing the robot's movement. In this way, a more tangible link is created between "code" and action. Cubetto is programmed by placing the coding blocks in a sequence on a physical control panel. With the robots, it also becomes easier to understand the link between the commands you give the robot and the actions it performs making the abstract programming task more tangible (Murcia & Tang, 2019). An environment that incorporates both robotics and a nautical game has been designed by Abreu et al. (2020). They suggest that robots can assist children in learning computational skills through play. Among children between the ages of 4 and 8, a tactile-rich environment is beneficial to their development of CT (Abreu et al., 2020). Bers (2012) describes how the development of educational robots in recent years has meant that they can be used to teach children various mathematical concepts such as number, size, and shape as well as various computer concepts. Which, among other things, has been achieved through the above-mentioned tools. However, Bers (2012) raises the question of what is important to teach children in early childhood. She states that: *"Teaching the ABC's, numbers, or computational concepts earlier might be appealing but might not make a difference in the long run. While these are activities that can pave the road for later academic transition, the mastery of new practices and knowledge is the fundamental developmental task for the next stage, the elementary school years"* (p. 9). To achieve this, robotic kits need to offer the possibility of creative open-ended construction where the behavior of the robots can be programmed and at the same time offer interactive responses through sensors. This way robotics encourages children to work with practices such as problem-solving, logical thinking and creativity. This is achieved through playful explorations where children engage in social interactions and negotiations with parents and other children. In this setting children can e.g., become engineers that explore robotic and programming concepts as well as storytellers that instruct how a character (robot) acts in response to the environment (Bers, 2012).

3.4 Unplugged Activities

The use of CT in early childhood classrooms should consider the developmental stage of children. Studies have demonstrated that children between the ages of four and five learn effectively through concrete and hands-on activities (Bers, 2018; Lee et al., 2022). Unplugged activities are based on the approach of exposing children to CT without using computers (Olmo-Muñoz et al., 2020) or digital devices. The activities can involve logic games, cards, strings, or physical movements that are used to represent and understand CT concepts (Brackmann et al., 2017). Studies have shown that unplugged activities positively affect the development of CT skills (Brackmann et al., 2017) and that the combination of plugged and unplugged activities for the early years of primary education can have a positive effect on CT skill acquisition and motivation. (Olmo-Muñoz et al., 2020). This study also found a gender effect where females were more motivated. In Critten, Hagon and Messer (2022), an example of an unplugged activity is given, where children as young as two years old learn about sequences by describing in what different sequence steps occur with simple activities such as bathing a doll. The study showed that the children initially had difficulties thinking about sequences but developed this skill through discussions with other children and adults. Moreover, CT-related literature in early childhood suggests unplugged activities in which children integrate stories or learn literacy skills to tell the story sequentially (Lee et al., 2022).

3.5 Making and Exploring

Assessing the literature of how children in the early years engage and learn about technology there seems to be two different modes of interaction: Children can either explore technology e.g., see what happens if I do this – if I want it to do this what do I do? Or they can make/create with technology. Making is a learner-driven inquiry-based approach that allows children to use their ideas in a powerful and generative way that supports participation, learning and conceptual understanding (Vossoughi & Bevan, 2014). A special type of making activity is tinkering. Resnick and Rosenbaum (2013) explain that the "*tinkering approach is characterized by a playful, experimental, iterative style of engagement, in which makers are continually reassessing their goals, exploring new paths, and imagining new possibilities*". It is a playful, explorative, and iterative approach where people are trying out new ideas and adjusting. Martinez & Stager (2013) makes a distinction between making and tinkering where they describe making as working on a planned project and tinkering as a mindset that involves a playful approach to solving problems through experimentation.

Opposite to planning tinkering is according to (Resnick and Rosenbaum 2013) a bottom-up process where they explore ideas by playing around with materials e.g., putting together LEGO bricks where they continually adapt their plans based on the interaction with the materials and people they are working with. They see tinkering as similar to play. Play is according to Resnick and Rosenbaum (2013) a way of engaging with the world where we test and experiment with new possibilities and that tinkering is a playful way of designing and making where children experiment and explore new ideas in the process of creation. Tinkering can be physical or virtual; a child can be tinkering when programming or writing a story. Tinkering is not defined by materials but the style of interaction (Resnick and Rosenbaum 2013). According to Vossoughi et al. (2013), it is essential to connect children's ideas with the significant sciences and STEM concepts and practices to support students in engaging in scientific activities. Children can participate in inquiry-based educational activities both inside and outside of school in settings that have been pedagogically transformed. The locations could be museums or libraries where they can work together on creating different artifacts to support their identity as makers and innovators. The activities typically build on children's prior experience and keep their identity as tinkers (Vossoughi et al., 2013). Similarly, it is important to create a connection between children's play, to engage them in CT supportive activities or ensure a transition from children's play to CT supporting activities.

3.6 Guided Play vs Free Play

There are different approaches to how play activities can be designed to support the development of CT. One of the discussions concerns how CT instructions could be designed regarding the degree of scaffolding, free play vs guided play, adults and children initiated (Bers, 2018, 2019). Most studies seem to suggest that the children need at least some level of guidance or scaffolding (Hall & McCormick, 2022; Critten, Hagon, & Messer, 2022; Wang et al., 2021; Stephen & Plowman, 2013). Stephen & Plowman (2013) argue that direct and indirect guidance are essential to support children's play and engagement with technology and according to Hall & McCormick (2022) dialogue, guidance and negotiation from adults are important to extend children's learning about CT. In their study the authors used a guided play approach that emphasized a specific CT learning goal that allowed the children to be explorative and self-directed in their play. Thus, they strived to balance openness, child-autonomy and scaffolding towards a learning goal.

As an example of guided play, Lee et al. (2022) identified that educators could create engaging scenarios to help children focus on relevant information. For example, children can play "Who am I?" by identifying the origin of footprints based on their shape, size, and imprint. By refining their observations, children eliminate the choices that do not match the attributes given. The footprint of a bare foot, for example, can be eliminated by removing everyone wearing shoes. The process of working through these scenarios develops abstraction skills in children. (p. 5).

In a study by Kotsopoulos and colleagues (2022), they explore to what extent CT is evident in children's free play in unplugged activities. Referring to Curzon (2013) the researchers claim that for unplugged free-play activities to lead to development of CT competencies, teachers need to perceive and capture situations where play activities can be linked to CT and nurture the children's thinking in that direction. The study concludes that a challenge is that teachers often do not have a sufficient understanding of CT to perceive and nurture CT elements, or conversely, they think they are observing an example of CT without these being present.

4 Analytical Discussion

The aim of this narrative review was to investigate existing literature on CT in ECE. Through the review, we found four perspectives related to CT, play and pedagogy.

(1) CT tools, (2) Unplugged CT, (3) Making and exploring, (4) Guided play vs free play. This chapter discusses the results of the review and identifies any gaps in the literature and is divided into two sections, *tool-mediated play activities* and *facilitating children's intention*s.

4.1 Tool-Mediated CT and Play Activities

The act of playing is an integral part of children's lives. Play helps a child to socialize, learn, think creatively, and feel intrinsically motivated. During the review, we discovered that many CT activities were created using CT tools. As one example of how these tools have been used to support children's CT development, Abreu et al. (2020) designed an environment that integrated both a nautical game and physical robots. In their study, they suggest that robots can be used to engage children in inclusive play experiments and to help them acquire computational skills through play. According to their study, children between the ages of four and eight benefit from playing in an environment that is tactile-rich. Nevertheless, Abreu et al., (2020) do not elaborate on what they consider as play. Tools, such as robots, fulfil a mediating function when it comes to children's development of CT. Hence, there exists an interplay between tools and CT activities, where CT is mediated by means of tools. In CT activities, CT can be considered as an abstract phenomenon, less concrete and real compared to physical tools and actions. Previously in this paper, the snowballing review has identified CT tools, robots, unplugged activities, and making and exploring as mediating tools contributing to children's CT play and knowledge creation.

The review shows that these different tools illustrate different kinds of mediation and thus mediate different perspectives of CT. We emphasize that it is pivotal that educators are aware of how different tools can mediate different understandings as these different forms of mediation can become effective resources for children to think with. This can create fruitful learning situations for children to appropriate knowledge about CT. Aligned with this, Bers (2018) argues that tools can become concrete and real by being considered as a playground where children can explore, create, imagine, interact socially, master skills, and solve problems together with each other. By using the metaphor of a playground, Bers (2018) emphasizes that children can choose among activities to do and use their imagination while making projects that they find meaningful. While engaging in computational thinking, children develop abstract, sequential thinking skills and problem-solving strategies (Bers, 2018, p. 2). Aligned with Abreu et al. (2020), Bers (2018) does not provide an explanation and definition of the phenomenon of play. It is crucial for CT development in ECE to foster a playground mindset in which children can express their creativity, joy, meaning, and play with things in an exploratory and open way. The educator must create a scaffolding relationship between children so that play does not cease. In this way connections are created between children, play, tools, educators, and computational play (Bers, 2018).

Despite the fact that the papers in the narrative review emphasize the role of CT in ECE, we argue that CT should benefit from being part of a pedagogical strategy that supports the role of play with children in ECE. As stated, play as an activity (Sutton-Smith, 2001) can involve different dimensions of unpredictability as well mutuality (Huizinga, 2004; Olofsson, 1987), which optimally contribute to children's meaning making processes. This means that play as such is children's own activity with a fruitful connection to learning and development. Play, then, can be understood as important for children as it engages and motivates children. Relating this to the outcomes of the scoping review, it is possible to state that children learn and play by exploring through e.g., imagination and creativity. However, when play is related to a learning environment such as ECE, both play and learning take on a special character. This is discussed by Jonsson and Pramling Samuelsson (2017), who emphasize this as participating in a communicative activity. A communicative activity in ECE is about doing something together; children together and teacher and child/children together. Doing something together hence develops both the play and the learning, where the mutuality and scaffolding become a matter of negotiation of meaning. Wood et al. (1976) and Bruner (1961) underlined this kind of mutuality and scaffolding afford the participants attention to the same object. Therefore, we argue that a pedagogical perspective on CT requires an authentic relationship between a teacher and children and, also, that this forms a foundation for establishing CT activities as social and communicative, where teachers' scaffolding consider teaching, learning and play as a pedagogical unity.

4.2 Facilitating Children's Intentions

The field of computational thinking is complex and involves many highly integrated concepts. There is a variety of prior experiences for the CT concepts that each learner brings to CT. Some individuals have experience with programming, while others are new to the field of coding. Some individuals can have expertise in pattern recognition, testing, or design, while others may not have heard of any of these. A person's learning process is characterized by enactive representations (e.g. mental models of the world), iconic representations (e.g. rough drawings for demonstrating concepts), and symbolic representations (e.g. formal application of modelling languages) (Lowe and Brophy, 2017). In computational thinking education, Lowe and Brophy (2017) observe that iconic and even symbolic representations are often presented without explaining how computation works. Therefore, and as stated in the above-mentioned section, we emphasize that learners and educators may benefit from replacing concepts with an operational pedagogical CT framework. Such a framework should be based on CT activities as social and communicative as well as on the concepts of mutuality and scaffolding. In such a framework, it is pivotal for teachers to learn to identify children's intentions. As this is a prerequisite for being able to participate in a spiral of activities (Bruner, 1977) together with others and thus considering teaching, learning and play as a unity become at the center for teachers. In the context of CT, this would mean that CT activities could be designed as a play-oriented activity which continues over time, and which is coordinated and developed by the children, with or without a teacher's participation. Kultti and Pramling (2017) add to this that a child also needs to identify and become aware that he or she is seen by others as someone with intentions. Vygotsky (1978) explained this process through the concept of 'to point'. To point is however not something humans are born with or naturally develop.

In the context of this paper, it becomes important to consider not only what a child expresses verbally, visually or through coding, but also through his or her gestures. Expressed differently, considering the child's multimodal palette of expressions becomes crucial when it comes to developing young children's CT by means of the unity of play, learning and teaching. Vygotsky (1978) considered verbal and other kinds of expressions as being cultural tools and emphasized those as crucial for what kind of knowledge, understanding and ways of seeing that a child develops. This is also a reason to why CT as a social and communicative activity should point to and talk with children by conceptualizing, questioning and telling them what is going on. In this way, the teacher becomes co-creator by mediating the world of CT and recognizing the child as someone with intentions that need to be scaffolded to move the CT project forward.

4.3 Concluding Comments

In formal and informal learning environments, there have been very few studies looking at how CT can be explored with young children in early childhood education. By examining how CT is embedded in children's activities and play, this study provides an overview of the literature. According to the literature, educators are not equally comfortable providing support that enhances the ability of children to use CT skills.

Playing is an effective way for children to socialize, learn, and be creative. As discussed in the review, children explore CT through tools and activities, allowing them to tolerate and understand CT. However, as we argue, play can be a way for children to make CT more familiar to them. CT activities should be viewed as social and communicative and based on the concepts of mutuality and scaffolding in an operational pedagogical CT framework. CT activities can therefore be designed as play-oriented activity that continues over time, with or without educators' guidance, and is coordinated and developed by the children. In the role of co-creator, the educator mediates the CT world and recognizes the child's intentions, which need to be scaffolded to move the CT activities forward. Further, hands-on activities based on children's play can be used to develop children's CT, but there is still a need to develop and create materials that can give confidence to early childhood educators, such as work development, so they can handle such activities in ECE. In this paper, we align with Green et al. (2006) comments about a narrative review by emphasizing that more research is needed to investigate how children in ECE engage in play to develop CT and how educators can support children's CT development.

Appendix A

	Authors	*Title*	*Journal*
1	Abreu, Lucia & Pires, Ana & Guerreiro, Tiago. (2020)	TACTOPI: a Playful Approach to Promote Computational Thinking for Visually Impaired Children	The 22nd International ACM SIGACCESS Conference on Computers and Accessibility (pp. 1–3)
2	Angeli, C., & Valanides, N. (2020)	Developing young children's computational thinking with educational robotics: An interaction effect between gender and scaffolding strategy	Computers in Human Behavior, 105
3	Bers, M. U. (2012)	Designing digital experiences for positive youth development: From playpen to playground	OUP USA
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6	Bers, Marina & Flannery, Louise & Kazakoff Myers, Elizabeth & Sullivan, Amanda. (2014)	Computational thinking and tinkering: Exploration of an early childhood robotics curriculum	Computers & Education. 72. 145–157
7	Brackmann, C. P., Román-González, M., Robles, G., Moreno-León, J., Casali, A., & Barone, D. (2017)	Development of computational thinking skills through unplugged activities in primary school	Proceedings of the 12th workshop on primary and secondary computing education (pp. 65–72)
8	Critten, V., Hagon, H. & Messer, D. Can (2022)	Pre-school Children Learn Programming and Coding Through Guided Play Activities? A Case Study in Computational Thinking	Early Childhood Educ J
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10	González, Y.A., & Muñoz-Repiso, A.G. (2018)	A robotics-based approach to foster programming skills and computational thinking: Pilot experience in the classroom of early childhood education	Proceedings of the Sixth International Conference on Technological Ecosystems for Enhancing Multiculturality
11	Hall, J.A. & McCormick, K.I. (2022)	"My Cars don't Drive Themselves": Preschoolers' Guided Play Experiences with Button-Operated Robots	TechTrends 66, 510–526
12	Kotsopoulos, D., Floyd, L., Dickson, B.A. et al. (2022)	Noticing and Naming Computational Thinking During Play	Early Childhood Educ J. 50, 699–708
13	Lee, J., Joswick, C. & Pole, K. (2022)	Classroom Play and Activities to Support Computational Thinking Development in Early Childhood	Early Childhood Educ J
14	Maloney, J., Resnick, M., Rusk, N., Silverman, B., & Eastmond, E. (2010)	The scratch programming language and environment	ACM Transactions on Computing Education (TOCE), 10(4), 1–15

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16	McCormick, K. I., & Hall, J. A. (2022)	Computational thinking learning experiences, outcomes, and research in preschool settings: a scoping review of literature	Education and Information Technologies, 27(3), 3777–3812
17	Murcia, K., & Tang, K.-S. (2019)	Exploring the multimodality of young children's coding	Australian Educational Computing, 34(1)
18	Olmo-Muñoz, J., Cózar-Gutiérrez, R., & González-Calero, J. A. (2020)	Computational thinking through unplugged activities in early years of Primary Education	Computers & Education, 150, 103832
19	Vossoughi, S., Escudé, M., Kong, F., & Hooper, P. (2013)	Tinkering, learning & equity in the after-school setting	FabLearn conference. Palo Alto, CA: Stanford University
20	Wang, D., Wang, T., & Liu, Z. (2014)	A Tangible Programming Tool for Children to Cultivate Computational Thinking	The Scientific World Journal
21	Zhang, L., & Nouri, J. (2019)	A systematic review of learning computational thinking through Scratch in K-9	Computers & Education, 141, 103607
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