Coding Apps to Support Cognitive Development in Early Childhood: A Systematic Literature Review

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Abstract. Cognitive development, which uses coding as one of its tools, has become more popular as a new kind of literacy for young children that is appropriate for the twenty-first century. It is thought to be a successful method of producing innovators and thinkers, giving them practical skills that they will surely need at some point in their lives. Several coding apps are designed to be suitable for children's cognitive development. This study aims to identify and analyze existing coding apps for early childhood cognitive development, complete with their descriptions and limitations. We conducted a systematic literature review of studies published between 2018 to 2023 over five electronic databases by using the PRISMA approach. Eventually, 9 primary studies were selected to be reviewed. Based on the results of the review, it was found that there were at least 15 coding apps that were suitable for children to use in coding. Among the 15 coding apps, ScratchJr is the most popular coding app.

Keywords: coding, apps, cognitive

1 Introduction

The paramount and dynamically active phase of cerebral development throughout the human lifespan transpires during the early infancy stage.During this period, there exists a dynamic process of synapse overproduction and pruning. Initially, this phenomenon takes place in the cerebral regions responsible for processing sensory data and subsequently extends to the association areas associated with higher-order functions, including working memory, attention, and planning. This stage of robust brain development significantly underpins optimal cognitive growth, establishing a fundamental groundwork for subsequent achievements in both academic and cognitive realms [1].

Cognition represents the mental processes individuals employ for the acquisition and interpretation of information. Within its domain, learning, perception, memory, and reasoning constitute integral processes. The influences of biological, environmental, experiential, social, and motivational variables collectively exert a significant impact on cognition [2]. There are four processes of cognition, such as memory, problem-solving, reasoning, and executive functions. Memory is among the domains of cognition that have been explored the most. The memory system is capable of a wide range of tasks, from quickly processing simple information (e.g. word recognition) to recalling intricate details (e.g. chess rules). These competencies are dependent on several capacities that have varied developing schedules. On the other hand, problem-solving is determining a goal, taking the necessary steps to achieve it, and overcoming any barriers along the way. It is a sophisticated cognitive ability that depends

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on several capacities, such as perception, memory, attention, ideas, and often symbolic processes like language. Meanwhile, the ability to employ reasoning to solve logical issues and draw conclusions or inferences from premises or facts develops over childhood. Lastly, executive functions refer to the capacity for self-control, goal-directed reactions, and conscious control over thinking and behavior [2].

Moreover, the significance of cognitive development in early childhood has ascended to a pivotal status, emerging as a contemporary literacy imperative for the twenty-first century. It is widely acknowledged as a successful methodology for cultivating innovators and critical thinkers, endowing them with practical skills that are deemed essential at various junctures in their lives. The integration of coding stands out as a particularly noteworthy tool within this cognitive development framework. This computational skill not only enhances problem-solving abilities but also instills a systematic and logical approach to challenges, thereby contributing to the holistic intellectual growth of young minds. In the present era, where technological proficiency is increasingly indispensable, fostering cognitive development through coding aligns with the evolving educational demands, positioning children to navigate and contribute effectively to the complexities of the contemporary world. As stated by [3], the analysis of coding may be approached as a domain-general problem-solving strategy and a procedural means that empowers users to generate shared goods. Contemporary discussions surrounding educational technology have shifted focus from the coding process itself in early childhood to the critical consideration of selecting tools and practices that align with developmental appropriateness. Coding environments must be designed for young children due to their special developmental demands. The environment must contain syntax and grammar, allow for a variety of combinations, and provide different approaches to solving issues. [3]. Though there are an increasing number of applications designed to encourage kids to code, the list and limitation of these apps in fostering kids' cognitive skills has not been well studied.

This systematic literature review (SLR) aims to collect and summarize published literature and present a holistic overview of coding apps to support early childhood cognitive development. In detail, the essence of this SLR is to review the available pieces of evidence regarding (1) the existing coding apps and (2) their description and limitations. Furthermore, this SLR can contribute to providing insight for both researchers and practitioners in their quest to utilize improved coding apps that are used to enhance cognitive development in early childhood.

The remaining sections of this paper are structured as follows: Section 2 provides a comprehensive overview of the research methodology, detailing aspects such as the search strategy, study selection, data extraction, and synthesis. In Section 3, the findings are thoroughly examined, elucidating their meaning and potential implications. This section will also explore any discernible trends or patterns that emerged during the review process, offering a nuanced understanding of the subject matter. The conclusive remarks and overall implications are presented in Section 4, summarizing the key takeaways and contributing to the broader understanding of the research.

2 Research Method

This study used Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) as the research guideline [4]. PRISMA consists of a four-phase flow diagram:

identification, screening, eligibility, and included. It is also equipped with a twenty-seven-item checklist to keep track of items that should be written on the report and ensure the report is well-organized.

2.1 Research Question

The research questions (RQs) and their respective motivations are shown in Table I. This study aims to get an understanding of coding apps (i.e. RQ1) and descriptions and limitations (i.e. RQ2) of coding apps to support early childhood cognitive development.

Table 1. Research Questions

	Research Question	Motivation
RQ1:	What are the existing coding apps used to support early childhood cognitive development?	To get an overview of various coding apps used for early childhood cognitive development.
RQ2:	What are the descriptions and limitations of existing coding apps that support early childhood cognitive development?	To get an understanding of the description and limitations of existing coding apps for early childhood cognitive development

2.2 Search Strategy

Defining a search strategy can help to retrieve several relevant studies. In this study, the search string is formulated based on three categories shown in Table 2.

Table 2. Search String

Categories	Keywords
Coding App	coding app, coding application
Early Childhood	early childhood, early age, kids, young age
Cognitive	cognitive, intellectual
Development	development

The keywords are then connected using a Boolean operator and give the following search term:

(“coding app” OR “coding application”) AND (“early childhood” OR “early age” OR “kids” OR “young age”) AND (“cognitive” OR “intellectual”) AND (development)

The studies were retrieved from five electronic databases. These include ScienceDirect, Scopus, ProQuest, IEEE Explorer, and Google Scholar. Additionally, the search string must be adapted to the format of each electronic database.

2.3 Inclusion and Exclusion Criteria

To define relevant primary studies should be included the inclusion and exclusion, which are shown in Table 3 were used in the search process:

Table 3. Inclusion and Exclusion Criteria

Inclusion	Exclusion
Written in English and Indonesia	No-full text article
Primary studies	Not focus explicitly on coding apps for early childhood cognitive development
Relevant to the search string defined	Review, short paper, tutorial summary, panel discussion, keynote
Published from 2018 to 2023	Duplicated studies from different electronic database

2.4 Study Selection

The selection of studies in this review was performed based on PRISMA. It is performed using the four-step process illustrated in Figure 1.

The search initially identified a total of 532 articles. Several inclusion and exclusion criteria were applied in this process using characteristics of each electronic database such as the language of articles, year of publication, and type of article. However, only 221 articles were retained after removing duplicate results. During the reading of titles and abstracts, 204 articles were distracted as not relevant to this review. This process focuses on two main criteria:

a. The article focuses on coding apps for cognitive development
b. Domain of the research the cognitive development of early childhood

The remaining 17 articles are fully read and further assessment is considered. In the end, 9 papers were selected as primary studies.

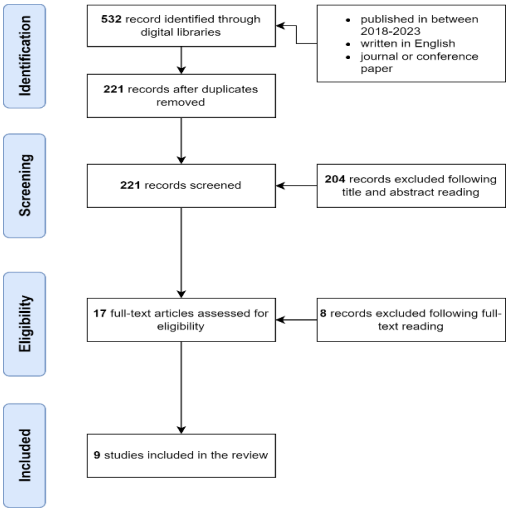

Fig. 1. PRISMA Flowchart for Selecting Studies

2.5 Data Extraction and Synthesis

The systematic literature review data extraction aims to identify relevant information that should be extracted from each selected article to answer the research questions. The extracted information was stored in a spreadsheet for further analysis. In the process of synthesis, a grouping of data elements is subject to examination through the application of thematic analysis. Thematic analysis serves as a methodological approach aimed at identifying, analyzing, and elucidating patterns or themes within the specified dataset. There are six stages of thematic analysis:

a. Familiarization with the data: The initial step involves extracting data into an Excel table, which is subsequently reviewed iteratively to grasp the depth and breadth of the content. This process is essential for discerning patterns across all coding apps that have been extracted.
b. Initial code generation: The extracted data undergoes a comprehensive reading to identify key points and fundamental elements crucial to the analysis.
c. Themes search: A meticulous review of all codes ensues, wherein they are organized and categorized based on potential themes, facilitating a systematic understanding of the dataset.
d. Review, identify, and name topics: These three stages are conducted simultaneously, ensuring a comprehensive and efficient approach to synthesizing the information.
e. Produce report: The culmination of the analysis results in the articulation of coding apps utilized to bolster early childhood cognitive development. This reporting phase encapsulates the key findings and their implications, providing a coherent and informative summary of the study's outcomes.

3 Result and Discussion

3.1 Overview of Selected Studies

After full-text reading, 9 studies published from 2018 to 2023 were selected for this review. Among them, 8 articles were published in journals and the other 1 article appeared in conference proceedings. The respective number of selected studies is shown in Fig 2.

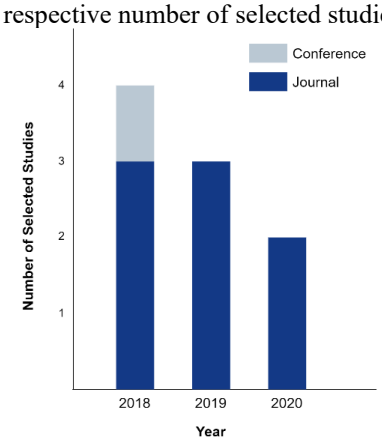

Fig. 2. Number of Selected Studies Per Year

3.2 Coding App for Early Childhood Cognitive Development

This section describes the results from data analysis of coding apps in early childhood cognitive development. This analysis is meant to answer RQ1, "What are the existing coding apps used to support early childhood cognitive development?". Details on the existing coding apps used to support early childhood cognitive development can be found in Table 4.

Table 4. Coding Apps Overview

Coding Apps	Reference
ScratchJr	[5] [3] [6] [7] [8] [9] [10] [11]
Lightbot Jr	[11]
Coda Game	[11]
Run Marco	[11]
Loopimal	[11]
Go for Dash	[11]
Blue-Bot	[11]
Bee-Bot	[11]
A.L.E.X	[11]
Osmo	[11]
Code Carts	[11]
Scottie Go	[11]
Daisy the Dinosaur	[12]
Kodable	[12]
Alpha 1	[9]

Derived from the data presented in Table 4, it is deduced that a minimum of 15 coding applications have been identified in the course of this literature review. Notably, ScratchJr emerges as the predominant coding app, obtaining the highest number of references across the examined studies, specifically cited in 8 out of 9 studies. This observation underscores the prevalence and recognition of ScratchJr within the context of the literature, indicating its substantial impact and widespread utilization in the field of early childhood cognitive development. The prominence of ScratchJr suggests a noteworthy trend worth exploring further to comprehend its specific attributes contributing to its popularity and effectiveness.

3.3 Description and Limitations of Coding Apps

This section explains the findings from analysis upon extracted data to answer RQ2, "What are the descriptions and limitations of existing coding apps that support early childhood cognitive development?" Table 5 displays the results of the description and limitations of coding apps. The description of the coding apps provides an understanding of how the coding apps operate. The limitations are provided as the basis for any consideration in selecting and using coding apps.

Table 5. Coding Apps for Early Childhood Cognitive Development

Coding Apps	Description	Limitation	Reference
ScratchJr	Utilizing the introductory programming language ScratchJr, children as young as five years old have the capability to independently craft interactive stories and games. This involves the creation of animated figures with movements, hops, dances, and singing, achieved through the connection of graphical programming blocks. Additionally, children can modify these figures using the paint editor, incorporate their voices and sounds, and even include self-portraits. Subsequently, the programming blocks serve as the means to animate and give life to the imaginative creations of the children..	Scratch Jr. is only allowed a maximum of six broadcasts on each page.	[5] [3] [6] [7] [8] [9] [10] [11]
Run Marco	Run Marco is a puzzle game designed to facilitate the learning of fundamental programming principles for beginners through the use of a visual language. Users can opt for a male or female character and navigate them through a forest to locate their companions. The player directs the character's movements by employing a drag-and-drop mechanism with bricks, strategically determining the path that leads to the intended goal. Each successful completion of a level in the game results in a reward for the player.	No exercises are using nested ifs and functions in Run Marco.	[11]
Lightbot Jr	A more basic version of the Lightbot software is called Lighbot Jr. It provides a simplified introduction to the fundamentals of programming for younger audiences. Children's puzzles are the foundation for their learning.	Becoming challenging quickly, children must be up to the task.	[11]

	Players must follow instructions to advance and complete tasks in the Lightbot Jr. edition, much like in the Lightbot version. By turning on lightbulbs or using a tiny robot, they accomplish this. They have to achieve this by turning on every light to finish each task. Players are rewarded with stars after each level for properly following the instructions and completing the code, which requires them to use their critical thinking and reasoning skills.		
Coda Game	A game called Coda Game was created in response to kids' requests to alter certain elements of their preferred applications and games. By using visual code blocks to create games, Coda Game chose to empower kids to be developers and owners of their games. The game's physics, including gravity, enemy addition, speed, point systems, and much more, will be taught to kids.	There are not many references or tutorials regarding Coda Game.	[11]
Loopimal	With Loopimal, children can build musical loops by layering melody and rhythm over a basic beat or sound using pre-programmed blocks. There are no guidelines, guidelines, or restrictions on what children can produce. Kids may watch animal creatures dance and move to the music by using the animated movement that corresponds with each sound block. Every piece of music was written in the key of C, and other instruments could readily be added to the mix.	The primary hindrance and essentially the only thing preventing this program from becoming a potent tool for educational purposes is its incapacity to export the beats and tunes the user creates.	[11]
Osmo	Osmo is a brand of interactive learning games available both digitally and physically. The "Reflective Artificial Intelligence" system, which	The camera settings may be incorrect, the device may need to be restarted, or there may be a camera hardware issue.	[11]

	Osmo has developed exclusively, powers its devices. It allows the front-facing camera of an iPad or iPhone to follow and identify things in the real play area in front of the device by using a clip-on mirror and a stand.		
Blue-Bot	Primary schools would benefit greatly from using the entertaining Blue-Bot floor robot to teach control and coding. Larger than Bee-Bot, Blue-Bot can be programmed remotely and offers greater possibilities for programming tasks because it is Bluetooth-enabled.	Blue-bot requires a special device to run.	[11]
Bee-Bot	In the coding game Bee-Bot, a programmable bee robot serves as an introduction to the fundamentals of directed language-based programming for pupils. To solve basic issues like herding sheep into a corral, students use the controls to build a series of steps that the bee bot follows. These steps include forward, backward, left, and right turns. The Bee-Bot game takes place in a flower garden and on farms, and as pupils go through the stages, it gets more difficult.	Bee-bot requires a special device to run.	[11]
Scottie Go	With the aid of the game Scottie, kids may learn programming and become proficient with fundamental ideas like loops, conditional functions, variables, and functions. This hybrid game asks players to arrange blocks to represent programming commands. The application then uses a camera to read the orders, which are subsequently translated into the movements and actions of the game's characters.	Scottie requires additional hardware to operate.	[11]
Go for Dash	Dash and Dot are a pair of robots that are compatible with Go for Dash & Dot	Playing "Go for Dash" requires both a Bluetooth Smart/LE-enabled device	[11]

	Robots, however, they require purchase. The robots can be controlled using a suite of five applications, starting with Go, which functions as a kind of remote control for the robots, and going up to apps that let youngsters create their orders for the robots to obey. Every time the robots are utilized, a device with a Bluetooth connection is needed, and they also need to be linked to the app. Youngsters can record their unique sounds to be played by the robots. Before moving on to the more complex programs, young pupils in kindergarten or even pre-K may simply manage Dash and Dot using Go. Before diving in, older kids will like checking out what Dash and Dot can do.	and a Wonder Workshop robot, Dash or Dot.	
Code Karts	Code Karts presents a few foundational ideas that are essential to comprehending coding. As they experiment with progressively more complicated concepts, children utilize drag-and-drop command blocks to guide a race vehicle across a course. Although extremely abstract, a different group of games also deals with binary code. This software is great for technology classes since it teaches kids how to solve problems with the type of problem-solving techniques that will come in handy if they want to learn how to program. Children must play independently on their account since every level brings something new.	There are 10 levels in the free edition; an in-app payment of $0.99 is needed to unlock all 70 levels.	[11]
A.L.E.X	For Key Stage 1 and 2 Computer Studies classes, Alex is a great tool for teaching the fundamentals of programming and coding. Students will find the	Additional levels may be unlocked with an in-app purchase, with the first 25 levels being available for free.	[11]

	program appealing for a variety of reasons and with great visuals. Alex the robot needs to be guided to his transporter by the learner through 60 levels that vary in difficulty from simple motions to intricate processes. Throughout the voyage, the learner will come across robots that are dancing, moving platforms, falling platforms, and spinning.		
Daisy the Dinosaur	Daisy the Dinosaur is one of the iOS apps designed to teach children the basics of programming. This app aims to teach children about sequences, conditional, and loops using a drag-and-drop interface with written commands. In the challenge mode, the app requires players to make Daisy, an animated dinosaur, complete certain tasks using programming instructions.	This application can only run on the iOS platform.	[12]
Kodable	Kodable is an additional drag-and-drop interface that operates based on directional arrows. On every level, a snake-shaped maze that runs from the left to the right side of the screen is unveiled with a "fuzz" character at one end. To aid the "fuzz" in rolling through this maze and on to the next level, players must place the proper directional arrows—that is, up, down, right, and left—into command boxes. Through solving the mazes at every level, players gain knowledge about conditions, loops, and sequencing.	The premium subscription contains additional lesson plans and progress-tracking capabilities, but it is more expensive and is probably best suited for purchases at the school or district level. The free edition just has a resource center for players and a small selection of game content.	[12]
Alpha 1	Alpha 1 is a humanoid robot well-suited for integration into play-based learning environments and is offered at a reasonable price. Facilitating ease of programming, the Alpha1	Playing Alpha 1 requires an Alpha Robot.	[9]

	app, compatible with both Apple and Android mobile devices, provides a straightforward interface for controlling Alpha 1.

4 Conclusion

This research endeavors to systematically review and analyze existing coding applications, inclusive of their comprehensive descriptions and limitations. The primary objective is to identify the coding applications most prevalent as tools in children's cognitive development. This systematic literature review (SLR) elucidates on 15 coding applications that emerge with notable frequency in the literature. Among these, ScratchJr emerges as the preeminent coding application, being cited in 8 out of the 9 studies employed in the analysis. It is noteworthy that the limitations associated with ScratchJr are comparatively minimal and less onerous in comparison to other coding applications, some of which necessitate additional equipment for operation. It is crucial to underscore that this SLR is delimited to specific databases for sourcing research studies, namely ScienceDirect, Scopus, ProQuest, IEEE Explorer, and Google Scholar. Consequently, it is acknowledged that these digital databases may not provide an exhaustive representation of all research pertaining to coding applications for cognitive development in early childhood. Subsequent research efforts could augment the present study by incorporating studies from alternative databases, thereby contributing to a more comprehensive understanding of the subject matter.

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