Preschoolers’ Mathematical Language Learning during Book Reading with an AI Voice Agent

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ACADEMIC ABSTRACT

Digital media technologies have been extensively utilized in children's daily lives and many researchers, educators, caregivers, and developers have been interested in finding ways to utilize these technologies in educational settings to facilitate early cognitive development. Among a wide range of media technologies, the accessibility of voice assistants and smart speakers powered by Artificial Intelligence (AI) has notably increased. However, there is a paucity of knowledge about how this advanced technology can be used to teach young children important mathematical concepts during shared book reading. The current study aimed to examine whether and under what circumstances shared book reading with an AI voice agent would enhance preschool-aged children's learning of mathematical language, a critical domain-specific language highly associated with early numeracy skills and vocabulary development.

Sixty-six participants who were recruited for home-visit and school-visit sessions were randomly assigned to one of three reading conditions to read a storybook with the AI voice agent three times: math storybook reading with dialogic questions, math storybook reading without dialogic questions, and non-math storybook reading with dialogic questions. The findings indicate that shared math storybook reading supports children's target mathematical language learning differently based on their initial understanding of numeracy skills. Children with higher levels of numeracy skills demonstrated greater benefits from simply listening to the story, whereas children with lower levels of numeracy skills showed a tendency to learn better when hearing questions and feedback from the AI voice agent. This study provides implications for the

use of advanced technology involving social interaction to support children's learning of key mathematical language that can benefit from repeated reading.

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GENERAL AUDIENCE ABSTRACT

Digital media technologies have been widely used in children's daily lives and many researchers, educators, caregivers, and developers have been interested in finding ways to utilize these technologies in educational environments to support children's early cognitive development. Among a wide range of media technologies, more and more families with young children have access to smart speakers using voice assistant technology where users can talk to and give commands verbally. However, we do not know much about how this advanced technology can be used to teach young children important mathematical concepts during everyday activities. The goal of this study is to look at whether and in what condition shared book reading with an AI voice agent would support preschool-aged children's learning of mathematical language such as fewer, fewest, and a little bit which is critical in developing numeracy skills and vocabulary.

Sixty-six participants who were recruited for home-visit and school-visit sessions were randomly assigned to one of the three reading conditions to read a storybook with the AI voice agent three times: math storybook reading with dialogic questions, math storybook reading without dialogic questions, and non-math storybook reading with dialogic questions. The findings suggest that shared math storybook reading supports children's target mathematical language learning differently based on their initial understanding of numeracy skills. Children with higher levels of numeracy skills benefited more from simply listening to the story, whereas children with lower levels of numeracy skills showed a tendency to learn better when hearing questions and feedback from the AI voice agent. This study provides implications for the use of

advanced technology involving social interaction to support children’s learning of mathematical language that can benefit from repeated reading.

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Chapter 1: Introduction

Digital media are ubiquitous in many societies. Young children growing up in these societies are now described as Digital Natives, being exposed to digital media devices immediately after birth (Prensky, 2001). A recent nationwide census on media use by children aged 0 to 8 in the United States reported the increasing presence of various digital media technologies in young children's home environments (Rideout & Robb, 2022). According to the census, nearly all children have access to a mobile media device, such as a smartphone or a tablet computer, at home. Notably, growing access to the Internet at home has narrowed the preexisting digital divide between lower- and higher-income households. The percentage of children that have access to the Internet at home was 94% and 74% for higher-income families and lower-income families, respectively in 2020, compared to 86% and 46% in 2013. Along with the growing ownership of electronic mobile devices and enhanced home internet access, there has been a sharp increase in the presence of emerging internet-based interactive technologies, such as smart speakers. About 41% of families were found to have smart speakers in 2020, which significantly increased compared to 9% in 2017.

Given the prevalence of digital media in young children's lives, understanding the effectiveness of digital media technologies in learning contexts has considerable importance for child development and education (Barr, 2019; Hassinger-Das et al., 2020; Hirsh-Pasek et al., 2015; Troseth et al., 2016). Education is one of the areas in which media use has significantly increased in the past decades. The percentage of top-selling applications in the education category targeting preschool or elementary school-aged children has increased from 47% in 2009 to 72% in 2012 (Shuler, 2012). In addition, after the breakout of COVID-19, online learning became a necessity for students regardless of age (Basilaia & Kvavadze, 2020).

An Artificial Intelligence (AI) voice agent is a software program designed to recognize and respond to human voice commands. As long as AI voice agents are connected to the Internet, users can make requests verbally for the systems to carry out various tasks, such as making phone calls and reading text messages (McFarland, 2022). These user commands are processed by the cloud, which is the server that is accessed over the Internet. The results of the requests are eventually transformed back into speech for the users to hear. This verbal nature enables young children, who have not fully mastered reading and writing skills, to directly interact with AI voice agent technologies (Terzopoulos & Satratzemi, 2020). With the advancement of AI voice agent technologies, children have a close acquaintance with such technological tools (Rideout & Robb, 2020), which is critical for promoting children's interaction with technological agents (Bartneck et al., 2007). Indeed, prior research has reported that young children's perceptions of AI voice agents were overall positive (Druga et al., 2017).

Given the increasing usability and familiarity of AI voice agents, these tools may be able to support children's learning through age-appropriate educational activities, such as shared book reading. In early childhood, children begin to construct core mathematical concepts and learn how to apply these concepts in their daily lives (Charlesworth, 2016). Early numeracy skills, such as numbers and operations, are important mathematical concepts and skills for this age range (Purpura et al., 2011, 2021; National Research Council [NRC], 2009; National Governors Association Center for Best Practices, 2010). Mathematical language, a domain-specific language for preschoolers and older, has been shown to be fundamental for children's acquisition of numeracy skills (Hassinger-Das et al., 2015; Hornburg et al., 2018, 2024; Schmitt et al., 2019; Powell & Nelson, 2017; Purpura, Logan, et al., 2017; Purpura, Napoli, et al., 2017, Purpura et al., 2021). Mathematical language concerns children's understanding of the keywords and concepts used in early numeracy. Quantitative language (e.g., many, fewer, and less than) and spatial language (e.g., before, above, and near) are considered key components of early mathematics education for preschoolers (Purpura, Napoli et al., 2017). Understanding mathematical language is strongly related to learning numeracy skills, and also predicts children's numeracy skills in early childhood (Hornburg et al., 2018; Purpura & Logan, 2015; Purpura & Reid, 2016). Together, these findings indicate that introducing mathematical language to young children is a fundamental step in promoting children's numeracy skills.

Shared book reading is a frequent and common activity for young children, and teaching words during book reading has shown considerable benefits in developing children's vocabulary and literacy skills (for reviews, see Bus et al., 1995; Dowdall et al., 2020; Mol et al., 2008). Researchers and child development professionals encourage parents to use dialogic reading techniques—ask relevant questions, reflect on children's responses, and provide proper feedback to make book reading more engaging for children (Whitehurst et al., 1988). A large body of research has demonstrated the positive effects of dialogic reading on children's vocabulary learning (see Mol et al., 2008 for a review). Despite the benefits of dialogic reading, parents have different levels of familiarity with and confidence in interacting with children during shared book reading (Bergin, 2001; Landry et al., 2012). Training parents on dialogic reading strategies has been shown to be effective in increasing both high-quality parent-child interaction and positive child outcomes, including mathematics domains (Purpura et al., 2021; Strouse et al., 2013; Troseth et al., 2020).

Given the nationwide emphasis on early mathematics education (National Research Council, 2009; OECD, 2019), high-quality mathematics curricula and parent-child home mathematics activities have been encouraged. However, parents of young children encounter several constraints, including time, resources, and parents’ own mathematics anxiety (Berkowitz et al., 2021). Emerging evidence has corroborated the possibility that AI voice agents may serve as effective reading partners for children. Preschool-aged children learn words when they read storybooks with an AI voice agent for a single session through dialogic reading (Xing et al., 2021; 2022). However, it remains unclear whether the advantages of reading with AI voice agents would persist in different learning domains that necessitate prolonged exposures for knowledge acquisition, such as mathematics learning.

In previous intervention studies on children’s mathematical skills and vocabulary using storybooks, instructions involved multiple sessions over a period of several months (Hassinger-Das et al., 2015; Jennings et al., 1992; Young-Loveridge, 2004). It is therefore an imperative question whether AI-based voice agent technologies can be integrated into children’s regular, everyday activities to create continuous educational opportunities that make learning more active, social, interactive, and meaningful (Hirsh-Pasek et al., 2015). The current study aims to examine the impact of a socially contingent AI voice agent on preschoolers’ mathematics learning during storybook reading. The new knowledge gained from this work is anticipated to provide insights for parents of young children, educators, and developers about how to design and use digital media technologies to guide children’s learning.

In the following section, Chapter 2, two theoretical frameworks are introduced to guide research on young children’s learning from digital media technology in social contexts. Next, Chapter 3 includes a literature review of previous studies investigating the effectiveness of storybook reading with human and technological agents on children’s vocabulary and mathematics learning. In Chapter 4, the participants and study design are delineated, alongside a set of measures assessing children’s mathematical and general vocabulary, numeracy, and reading interests. This chapter also introduces the analytical plan. Chapters 5 and 6 present the research findings and discussion, respectively, followed by the conclusion of the study.

Chapter 2: Theoretical Framework

The current study is grounded in two theoretical perspectives: Information-processing theory and sociocultural theory. The information-processing theory places its emphasis on the specific processes and structures of cognition to explain children's cognitive development. The sociocultural theory highlights the role of social interaction in supporting children's intellectual growth. I proposed to combine these two theoretical perspectives to guide research on the impact of socially contingent AI voice agent technologies on children's learning.

Information-Processing Theory

The information-processing theory became one of the primary theories in cognitive science in the 1960s after important social movements such as a critique of learning theory and the introduction of communication engineering and information theory (Miller, 2011). The information processing theory uses a computer metaphor in an attempt to explain how human minds work, and its basic premise is that human information processing, similar to that of computers, is limited in terms of cognitive capacity and speed of processing (Klahr & MacWhinney, 1998). According to the information processing theory, the complexity of human cognition is broken down into specific structures and processes (Sigler & Alibali, 2000). The specific structures include attention and memory, each of which is further divided into specified systems. The processes involve how individuals encode, store, and retrieve information. The information processing theory posits that cognitive development is explained through quantitative changes in children's cognitive structures in terms of their capacity and efficiency of information processing (Siegler & Alibali, 2020).

According to the information processing theory, both maturation and experience influence specific structures or processes involving children's cognitive functions. The information processing theory allows researchers to consider not only children's own developmental characteristics, such as chronological age and cognitive abilities, but also to identify the specific design features of media technologies that influence children's developing information processing systems. The specificity of the information-processing theory serves as a useful framework to explain and predict the impact of digital technologies on cognitive development.

One of the core cognitive structures in the information processing theory is memory, which can be further specified into several sub-components, including sensory memory, working memory, and long-term memory (Atkinson & Shiffrin, 1968). *Sensory memory* is defined as a capacity used for retaining a large amount of information for a very short time. *Working memory* is a key system where information from sensory memory is combined with information from long-term memory. Some scholars posit that verbal information and visuospatial information are processed separately in the working memory system (Baddeley, 2000; Baddeley & Hitch, 1974). Working memory serves a critical role in learning by allowing children to combine information coming from sensory memory with prior knowledge stored in their long-term memory. Further, working memory allows individuals to not only maintain but also update information in their minds, which is essential for problem-solving. However, the capacity of working memory is constrained; thus, the amount of information that can be processed simultaneously in working memory is limited.

Long-term memory refers to a place storing unlimited information for a long period of time. The information consolidated in long-term memory can be further specified into different categories based on consciousness and intentionality. Explicit memory is the type of memory that is remembered with intentional effort and retrieved unconsciously. Explicit memory includes episodic memory, which is related to a specific event (e.g., who they played with yesterday), and semantic memory, which is related to general knowledge about the world (e.g., birds can fly). Implicit memory includes information that is unconscious and automatic. Implicit memory includes procedural knowledge, which is related to specific procedures (e.g., how to ride a bicycle), and emotional memory, which is related to emotions felt during an experience (e.g., anxiety associated with bicycling).

According to the information processing theory, children have limited capacity and speed for processing information in these memory systems at the beginning of their life span. As children age, the capacity for sensory memories increases (Cowan et al., 1999) along with working memory (Gathercole et al., 2004). Older children are more effective in separating verbal and visuospatial processes than younger children (Hale et al., 1997). Further, accumulated prior knowledge makes it possible for children to integrate new information more easily and automatically, which in turn decreases demands on working memory resources (Miller, 2011; Shiffrin & Schneider, 1977). The age-related increase in working memory capacity and efficiency in retrieval is proposed to be closely related to children's developmental changes in various cognitive functions (Baddeley, 1992).

Informed by the information-processing theory, scholars have hypothesized the role of cognitive structures and processes in children's learning from educational media technologies (Fisch, 2000; Plass et al., 2010; Swell, 2004, 2020). A capacity model proposed by Fisch (2000) is one of the most influential models that have guided educational media production as well as research on the design and effectiveness of young children's educational media. The core component of the capacity model is the limited capacity of children's working memory. Fisch (2000) posits three primary factors that create demands on children's working memory: Processing of narrative, processing of educational content, and the distance between the two factors. *Narrative* represents the story covered in a program, and it includes the sequence of events and how the main characters achieved their goals. On the other hand, *educational content* refers to the target messages or main concepts the program intends to deliver. The last factor, *distance*, concerns to what extent the educational content is integral to the narrative.

According to the capacity model, helping children allocate greater cognitive resources to the educational content is key to supporting children's comprehension and learning. To support children's learning of educational content from digital media, the model proposes to adjust demands for processing narrative and educational content to an adequate level in consideration of children's limited working memory capacity. In particular, it is expected from the model that children's learning of educational content from digital media will be improved by reducing the distance between the narrative and the educational content. The model posits that these two factors compete for children's limited cognitive resources. Thus, if the distance between the narrative and educational content is too far, it is expected to constrain children's working memory capacity, resulting in insufficient space for processing educational content. The focus of Fisch's original model was on television, but the model has been updated to reflect interactive media technologies (Fisch, 2004).

The proposed relations among the components in Fisch's model (2000; 2004) have been supported by evidence from a body of empirical studies (Anderson et al., 2000; Barr et al., 2007; Barr & Wyss, 2008; Choi, 2021; Crawley et al., 1999; Jing & Kirkorian, 2020). In many successful educational programs, educational content and narrative are intentionally intertwined to reduce the distance between the two factors (Anderson et al., 2000; Choi, 2021). Repeated exposures appear to be an effective strategy to reduce the existing distance between narrative and educational content. Using previews in a television program to introduce children in advance to the story narrative increases children's content comprehension and in turn, increases learning from educational videos (Jing & Kirkorian, 2020). In addition, repeated exposures to video enhance children's content comprehension and performance (Barr et al., 2007; Barr & Wyss, 2008; Crawley et al., 1999). Specifically, 2-year-old children performed better when the target actions were demonstrated on TV twice (Strouse & Troseth, 2008) and 3- to 5-year-old children received a higher score on the comprehension test as they watched a single episode of the educational TV program repetitively (Crawley et al., 1999).

While explaining the relations among the three program characteristics—narrative, educational content, and distance, Fisch (2000) noted viewer characteristics, such as individual differences in prior knowledge and cognitive characteristics, as important factors that contribute to working memory demands, which in turn influence the understanding of narrative and educational content of the program. Consistent with Fisch's model, Choi et al. (2018, 2021) have found the direct role of visuospatial working memory in children's learning from non-interactive videos and interactive touchscreens. Additionally, children's verbal skills (Neuman et al., 2019) and executive functions (Nathanson et al., 2014) are shown to be important factors that explain children's individual differences in learning from video. Further, researchers have found that having familiar or trustful media characters, compared to not having such characters, is beneficial for preschoolers' learning by facilitating accurate responses from preschoolers during a video-based mathematics game (Calvert et al., 2020) and promoting engineering-related problem-solving learning (Schlesinger et al., 2016).

Together, the information-processing theory and the related educational media-specific models highlight the understanding and consideration of young limited cognitive resources in creating educational media (Fisch, 2000, 2004; Swell, 2004). This theoretical perspective is relevant beyond TV watching, including interactive digital technologies. Children can achieve successful learning outcomes if an emerging technological tool is designed to help children allocate limited cognitive resources effectively when processing educational and other types of information (Choi, 2021). It is expected that the learning outcomes are likely different depending on children's prior knowledge and experience related to educational content or technological tools.

However, there exists a limitation in Fisch's models and the information processing approaches in general when it comes to specifying the influences of social contexts that surround young children's digital technology use, including the role of social partners. Fisch (2000, 2004) has mentioned that parental commentary or adult involvement during the co-viewing of educational media would guide children's effective allocation of limited cognitive resources and improve children's understanding of content through elaboration or enrichment. Indeed, the findings from multiple empirical studies on socially contingent media corroborate this claim (Collins et al., 1981; Myers et al., 2018; Strouse et al., 2018). However, Fisch's models do not directly specify what particular aspect of the co-viewer's behaviors or which type of child-adult social interaction may lead to effective learning outcomes. The sociocultural theory, which will be reviewed in the following section, provides detailed explanations about how social interaction shapes young children's learning, including specific types of social interaction.

Sociocultural Theory

Developed by Vygotsky, a sociocultural approach centers on child-in-context, rather than solely focusing on an individual child (Vygotsky, 1978). The sociocultural approach postulates that individuals cannot be separated from the social and cultural contexts in which they are situated. According to the sociocultural approach, children's minds are socially formed in a cultural embedding, and social interaction and communication allow the transmission of culture (Miller, 2011). Social interaction is considered to be fundamental to development by enabling children to internalize socially shared processes, and such internalization is the key mechanism through which children make developmental progress (Siegler & Alibali, 2020). The sociocultural theory provides specific types of social interaction that enable children to gain knowledge and skills. That is, children can acquire new information by engaging in question-asking and answering processes and learn new skills from advanced others through observation, imitation, or direct instruction (Vygotsky, 1978).

Vygotsky (1978) posits that children's internal course of development can be understood through the concept of *Zone of proximal development (ZPD)*. He defined ZPD as "the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem-solving under adult guidance or in collaboration with more capable peers" (p.86). Even though children have not yet mastered a task, the children can accomplish the task with some help from adults or more skilled peers. Parents and teachers often ask leading questions and provide detailed explanations to assist children's understanding of learning materials. The process by which the more knowledgeable social partners provide appropriate support to learners is often described with the metaphor of scaffolding (Shvarts & Bakker, 2019). By interacting and collaborating with others, children can accelerate their internal developmental processes, which will be integrated into children's independent developmental achievement (Vygotsky, 1978). In this learning context, children are considered as active learners who construct their learning rather than passive recipients of the information. Thus, the role of the more knowledgeable partners is to encourage children to be engaged in learning (Lee & Tu, 2016).

The importance of social interaction in children's learning and development has been highlighted in multiple theories and models of cognitive development. From an evolutionary perspective, Csibra and Gergely (2009) propose that what distinguishes human infants from other species is a specific human communication system that is adapted to transmit culturally relevant knowledge between society members. Under this framework, ostensive signals, such as direct gaze, dynamic eye contact, and child-directed speech, are considered as a critical component of learning because such signals allow learners to identify the target of and the intentional nature of communication (Csibra & Gergely, 2009). Indeed, human infants are sensitive to adults' eye gaze and pointing to a target object, and treat them as meaningful social cues to guide learning (Brand et al., 2002; Brand & Shallcross, 2008; Cooper & Aslin, 1990; Farroni et al.,2005; Kampe et al., 2003, 2006; Tomalski et al., 2009). Such sensitivity to and interpretation of communicative intentions have been proposed to act as an underlying mechanism for cognitive development, including language acquisition (Clark, 1996, 2003; Kuhl, 2007) and imitation (Barr, 2013). From infancy to adulthood, learners are increasingly capable of reasoning about others' knowledge and intent based on a wide range of social cues and using such inferences to learn intentionally from others (Koenig & Harris, 2005; Shafto et al., 2012). Children's sensitivity to social information that guides subsequent learning has formed the basis of many fundamental accounts of social learning in cognitive development (Bonawitz et al., 2011; Shneidman et al., 2016; Harris, 2012).

Contingency is one of the critical concepts that explain the role of parent-child interaction in cognitive development. Contingency, along with contiguity, refers to "the temporal and conceptual co-dependencies between infant action and parent response" (Tamis-LeMonda et al., 2014, p.123). Similarly, Siegler and Alibali (2020) define contingent interaction as "reciprocal actions and reactions that resemble the mutual give-and-take of conversation" (p.80). The effects of contingency have been studied in a wide range of cognitive developmental domains, including word learning, imitation, and symbolic understanding (Kirkorian et al., 2016; Nielsen et al., 2008; Roseberry et al., 2014). Contingent interaction with social partners is proposed to be a critical mechanism underlying a child's attention allocation to the central learning goal (Kuhl, 2007; Tamis-LeMonda et al., 2014). That is, by interacting with children in a socially contingent way, adults encourage children to attend to the shared objects or focused target (Masek et al., 2021). Infants showed longer attention and more engagement while interacting with a contingent caregiver than with a stranger (Miller et al., 2009; Miller & Gros-Louis, 2013). Increased attention allows infants to encode and store a large amount of speech information (Kuhl, 2007). When caregivers respond to their child's utterances or interests in a contingent and sensitive matter, it has a positive effect on young children's language development (Estrada et al., 1987; Hirsh-Pasek & Burchinal, 2006; Tamis-LeMonda et al., 2001) as well as social development (Mcquaid et al., 2009; Raver, 1996). Thus, through engaging in contingent social interaction with more advanced others, young children receive a wide range of communicative and pedagogical signals, which create rich educational opportunities for young children.

Dialogic reading, an interactive book-reading practice helping children improve language and literacy skills (Institute of Education Sciences, 2007), is one particular educational context where the benefits of contingency may be maximized. During dialogic reading, parents who are knowledgeable persons to the children ask questions and provide contingent feedback as they interact with children in a teaching and learning context, which in turn provides a particularly beneficial pedagogical context for young children. Direct instructions deliver communicative signals to young children that knowledgeable others have the intention to teach learning materials and questions are intentionally introduced (Csibra & Gergely, 2009; Daubert et al., 2020). In addition to the pedagogical intent, dialogic questions provide additional opportunities for children to engage in socially contingent interactions that allow children to actively engage in the processes of learning. Indeed, dialogic questions have been studied to understand children's cognitive development as well as to improve early childhood educational practices (Institute of Education Sciences, 2007; Hargrave & Sénéchal, 2000; Whitehurst, 1992). The benefits of pedagogical questions have been found not only in direct learning outcomes (Dale et al., 1996; Strouse et al., 2013; Towson & Gallagher, 2014) but also in exploratory behaviors (Bonawitz, 2011). That is, children learn content effectively from both direct instruction and pedagogical questioning provided by adult teachers, but dialogic questions make children broaden the range of possibilities during children's exploration (Bonawitz et al., 2011)

The sociocultural theory and related perspectives posit that social interaction with a knowledgeable other that involves pedagogical communicative signals would be a key to young children's learning. Although some scholars argue the importance of human presence in the learning process for young children (Kuhl et al., 2003), the discussion so far does not fully answer if conversational exchanges with a non-human agent who engages in pedagogical questions and contingent feedback on children's answers would impact children's language learning and if the impact would vary across the age range. The current study expects to answer those questions.

Summary of Theoretical Framework

The current study draws on two theoretical perspectives, the information processing theory and sociocultural theory, to describe and explain how young children interact and learn with emerging technology. The information-processing theory centers on children's limited capacity and speed to process information from educational technology, depending on children's individual characteristics (e.g., age, prior knowledge) and content characteristics (e.g., relation between educational content and narrative, repeated exposures). However, the information-processing theory does not fully explain how technology can be introduced to promote social interaction. The social contextual perspectives specify the facilitative role of contingent interaction between social partners and children, with particular emphasis on question-asking. By combining the two theoretical perspectives, the present study aims to examine whether contingent interaction through question asking between a child and a non-human AI voice agent in a form of dialogic reading would support children's learning through repeated exposures.

Chapter 3: Literature Review

The following section first discusses how the extant literature has described the relation between social interaction and cognitive development within early childhood, including general vocabulary and mathematics learning. Following this overview, specific research on preschoolers' learning from social interaction during shared book reading is reviewed with a focus on dialogic reading. Next, children's learning from an AI voice agent and other related interactive media technologies is discussed.

Social Interaction and Cognitive Development During Early Childhood

Vygotsky's sociocultural theory and related perspectives mentioned in Chapter 2 highlight the role of social learning in children's cognitive development. Consistent with these perspectives, contingent social interaction between children and their caregivers has been hypothesized to lay a critical foundation for development (Siegler & Alibali, 2020). Children's sensitivity to contingent social interactions is observed early in infancy (Kuhl, 2007; Miller et al., 2009; Miller & Gros-Louis, 2013). Parents' and caregivers' sensitiveness and responsiveness during infancy have been shown to be significant predictors of children's trajectories of language and academic outcomes (Hirsh-Pasek & Burchinal, 2006; Tamis-LeMonda et al., 2001). The importance of contingent social interaction is emphasized in other developmental domains such as young children's social and emotional development (Denham et al., 1997; Mcquaid et al., 2009; Spinrad et al., 2004). Contingent social interaction continues to have significance during the preschool period. Interaction with peers, in addition to adults, stimulates preschoolers to practice advanced language and express their thoughts verbally (Pellegrini et al., 1997). Further, preschool settings provide important opportunities for comprehensive and diverse social interaction, which have been shown to facilitate preschoolers' language development (Hoff, 2006). Although the focus of the current review is early childhood, the importance of social interaction for learning continues to middle childhood (Downer et al., 2010). During the teacher-student interactions, teachers take into account both their educational goal and children's current cognitive level, and the reciprocal conversation helps elementary and middle school students integrate the important information the teachers intended (Downer et al., 2010; Pontecorvo, 1993).

Among diverse ways to support children's cognitive development, shared book reading is one of the most common educational activities for young children. Shared book reading with adults is particularly prevalent for children in early childhood as adults can guide children who are still developing their abilities to read and learn from books. When reading with young children, adults, typically parents or teachers, go beyond simply reading text from books. They label objects shown in the book, give extratextual talks, make comments, or ask questions to the children (Fisch et al., 2002; Hendrix et al., 2019; Snow & Goldfield, 1983). Such interactive book reading is defined as *Dialogic Reading*. Dialogic reading is "an interactive shared picture book reading practice designed to enhance young children's language and literacy skills" (Institute of Education Sciences, 2007, p.1). The specific practice of dialogic reading is most widely known as mnemonics of CROWD (Completion, Recall, Open-ended, Wh-, and Distancing) and PEER (prompt, evaluate, expand, and repeat) proposed by Whitehurst and colleagues (Whitehurst, 1992; Whitehurst et al., 1988). According to Whitehurst (1992), the critical techniques of dialogic reading include adults' prompting (P) the child to say something, evaluating (E) the child's response, expanding (E) the response by assuring and adding information to it, and repeating (R) the prompts to check if the child actually learned. The authors' five suggested prompts are 1) to ask the child to complete the sentence, 2) to ask the child what happened in the book, 3) to ask the child open-ended questions about detailed pictures, 4) to ask questions beginning with what, where, why, when, and how, and 5) to ask questions that make the child relate book contents with his/her own experience.

A large body of research provides evidence that dialogic reading strategies are beneficial for children's vocabulary and language development (Bus et al., 1995; Morgan & Meier, 2008) as well as new knowledge acquisition (Dickinson & Smith, 1994; Lever & Sénéchal, 2011; Xu et al., 2021). Shared book reading activities give children ample opportunities to be introduced to new words and knowledge with the support of knowledgeable others. Through reading and discussing storybooks with adults, children learn new words even after a brief single-time exposure (Carey & Bartlett, 1978; Rice et al., 1990). Learning new words is critical for young children as it forms a foundation for effectively sharing their thoughts and feelings with others

(Tomasello, 2003). Further, the benefits of dialogic reading for young children have been found in various learning domains, including science (Chandler-Campbel et al., 2020) and mathematics learning (Purpura, Napoli, et al., 2017, Purpura et al., 2021).

Effects of Dialogic Reading on Children's General Vocabulary Learning

Regarding the effects of shared book reading between parents and preschool-aged children, Bus et al. (1995) conducted a meta-analysis based on the findings from 33 studies and reported a medium effect size (d = .59) for a higher frequency of shared book reading predicting preschoolers' higher level of emergent literacy and language skills. As this meta-analysis by Bus et al. (1995) included various research designs ranging from correlational and retrospective studies to experimental and longitudinal studies, the causal relation between book reading and children's learning remains unclear. Focusing solely on parent-child dialogic reading intervention studies, Mol et al. (2008) reviewed 16 studies and found a similar effect size in that dialogic reading is particularly effective with respect to expressive vocabulary with a medium effect size (d = .59). Additionally, Mol et al. (2008) found that the effect of dialogic reading with 4- to 5-year-old children was not as large as the one with 2- to 3-year-old children. In addition, the effect size was reduced for children at risk for language impairments. A more comprehensive meta-analysis conducted by Dowdall et al. (2020) reviewed 19 empirical studies, including children from diverse economic backgrounds. The reviewed 19 studies also differed in modality (i.e., individual, group, video, and telephone) as well as the total intervention time (15 min to 720 min). Their main findings showed that interventions had a small-sized effect on children's expressive and receptive language whereas caregiver education had no significant effect on children's language learning, which corroborates the benefits of shared book reading on children's vocabulary learning reported by the previous two meta-analysis papers. Together, prior work shows the facilitative effect of dialogic book reading, which can be extended to contexts that do not involve parents. Further, previous research suggests the importance of considering the effects of child characteristics such as child age and language ability. The following section reviews the use of dialogic reading for mathematical language learning in particular and discusses the limitations of the extant literature. To do that, the importance of early mathematics education and primary mathematical concepts for preschool children are first discussed.

Effects of Dialogic Reading on Children's Mathematics Learning

Early Mathematics Learning and Mathematical Language. Beyond general vocabulary learning, early mathematics learning has been emphasized for all children ages 3 to 5 years (Charlesworth, 2016; National Governors Association Center for Best Practices, 2010; National Research Council [NRC], 2009). The preschool period is a significant time when children start to construct fundamental mathematical concepts and learn how to apply newly acquired concepts in their daily lives (Charlesworth, 2016). The Core Curriculum State Standards for Mathematics (CCSSM) suggests that preschoolers should know the names of numbers, use counting to tell the number of objects, and compare different numbers (National Governors Association Center for Best Practices, 2010). Classifying objects into different categories and comparing two objects with different levels of measurable attributes (e.g., length, amount) are other important developmental tasks for preschoolers (Charlesworth, 2016). For children's early mathematics learning, it is critical to embed high-quality intentional mathematics teaching in children's everyday lives (NRC, 2009).

To make children familiar with mathematical concepts, it is inevitable to introduce mathematical language and use it during interaction with children. There has been a growing interest in mathematical language, a domain-specific language for preschoolers and older (Hassinger-Das et al., 2015; Hornburg et al., 2018; Schmitt et al., 2019; Powell & Nelson, 2017;

Purpura, Napoli, et al., 2017, Purpura et al., 2021). Mathematical language concerns children's understanding of the keywords and concepts that are used in early mathematics, and quantitative language (e.g., many, fewer, and less than) and spatial language (e.g., before, above, and near) are considered key aspects of early mathematics education for preschoolers (Purpura, Napoli, et al., 2017). Understanding mathematical language is closely related to learning numeracy skills and mathematical language was reported to be a predictor of numeracy skills (Purpura & Logan, 2015; Purpura & Reid, 2016).

Interventions for Supporting Mathematics Language Development. To support early mathematical language, researchers and early childhood educators recommend parents and teachers provide explanations of mathematical language to children and use them in children's daily lives (Marzano, 2004). Opportunities to be frequently exposed to new mathematical words are critical for supporting children's fluency in mathematics (National Institute of Child Health and Human Development, 2000). Several mathematical language intervention studies have utilized storybooks to introduce mathematical language to young children (Hassinger-Das et al., 2015; Jennings et al., 1992; Purpura, Napoli, et al., 2017, Purpura et al., 2021). For example, Jennings et al. (1992) asked teachers to use children's literature to teach mathematical concepts during demonstrations and weekly book discussions. Hassinger-Das et al. (2015) used storybooks as part of class instruction along with regular mathematics materials in the curriculum. Young-Loveridge (2004) also used 31 games and more than 50 books over two months to support the development of number skills for 5-year-olds, and these activities were led by a specialist teacher. The studies mentioned above have revealed that storybook reading is an effective intervention activity to improve children's target mathematical language learning (Hassinger-Das et al., 2015; Jennings et al., 1992); however, these studies have not directly specified the role of dialogic reading.

On the other hand, a group of researchers has explicitly incorporated the benefits of dialogic reading into preschoolers' mathematical language learning. Purpura, Napoli, et al. (2017) found that 3- to 5-year-old children who read mathematics storybooks that include dialogic reading prompts as a group with a teacher in a preschool over eight weeks performed better in mathematics language tests than their counterparts who did not read any mathematics storybooks (i.e., business-as-usual group). More recently, Purpura and colleagues (2021) designed an intervention study where 3- to 5-year-old children read three different math books that included dialogic reading questions. Each storybook targeted different words, and the children read them with their parents at home over four weeks (12 reading sessions in total) to learn mathematical language. In this study, dialogic reading of math books was found to be effective in improving children's targeted mathematical language and numeracy skills. The effect of the intervention on improving numeracy skills was maintained even after eight weeks.

Research has revealed the importance of considering the role of parental factors in supporting children's mathematics learning. Early child mathematics outcomes have been reported to be significantly influenced by parental education level or socioeconomic status (SES) (Crosnoe & Schneider, 2010; Duncan & Magnuson, 2011; Elliott & Bachman, 2018). The average mathematics assessment scores were higher for children attending schools serving middle- and high-SES families than the average scores for those attending schools serving lover-SES families (Klibanoff et al., 2006). Also, researchers found that parents with higher SES indicated by higher family income and higher education level tended to talk more about numbers cumulatively over multiple sessions with their child (Levine et al., 2010). Some researchers reported that parental education level was a significant predictor of children's mathematics outcomes, even after controlling children's performance on the pretest and age (Purpura et al., 2021). This line of findings highlights the importance of taking parental factors into consideration when designing programs and evaluating the effectiveness of them.

Another important individual aspect to consider when teaching mathematical language to young children is their prior knowledge of mathematical language and numeracy along with general vocabulary skills. As found in many earlier studies, each of the mathematical language, numeracy, and general vocabulary stand as distinct constructs, however, they are highly correlated to each other (Hornburg et al., 2018, Purpura, Napoli et al., 2017; Purpura & Reid, 2016). Previous studies have reported that individual differences, such as cognitive characteristics, prior knowledge, working memory, and vocabulary, influence children's learning outcomes differently (Bar & Kirkorian, 2023; Choi et al., 2021; Neuman et al., 2019; Ruston & Schwanenflugel, 2010). It can then be speculated that the extent to which children know mathematical language and the extent to which they have numeracy skills before the intervention may influence their learning differently.

Taken together, prior research has indicated the crucial role of dialogic reading with human partners (e.g., parents or teachers) in scaffolding children's understanding of and learning from books. The majority of studies that used dialogic reading practice were conducted in children's familiar places like home or classroom involving parents and teachers. What remains relatively underexplored in the extant literature is the effect of dialogic reading with non-familiar partners, including technological agents, on supporting children's learning of mathematical language in particular.

Social Interaction Through Technology and Learning During Early Childhood

With the advancement of technology, socially contingent interaction, a gist of dialogic reading, has become available through technological tools. There are ebooks that accompany audio narrators that ask questions related to stories in addition to embedded games and hotspots as key interactive features for children (Takacs et al., 2015; Troseth et al., 2020). Some of the ebooks have advanced features that provide contingent responses, such as corresponding animations, to children's vocalization (Eng et al., 2020). In addition, video chat technology such as Zoom, FaceTime, and Skype have become widely available for children regardless of age, particularly as a consequence of the global pandemic (Dore et al., 2021; McClure et al., 2015). Recently, more advanced video chatting services have been made commercially available where children can play games or read books with remote family members simultaneously on screens during a video call (Bohn & Hollister, 2021). One of the recent additions to the emerging interactive technological tools is AI-empowered voice agent technology. Below, the literature on AI voice agent technology will be reviewed based on its potential to promote social interaction with and learning for young children. Given the relative novelty of the AI voice agent technology research with young children, evidence from other interactive technological tools will be drawn when needed.

AI Voice Agents as Contingent Media Technology

AI-based voice-assisted systems serve as the core technology to support smart speaker systems such as Amazon's Alexa, Apple's Siri, and Google's Assistant. These commercial voice agents became increasingly common parts of young children's everyday lives. According to a nationally representative survey of children ages 0-8 years in the United States (Rideout & Robb, 2020), the ownership of smart speakers by these families increased sharply from 9% in 2017 to 41% in 2020. The increase in children's exposure to smart speakers corresponds to the overall increase in home internet access and smartphone ownership among families of young children in the United States.

The AI voice agent is a software program designed to respond to human voice commands. As long as AI agents are connected to the internet, users can access and ask them to carry out tasks (McFarland, 2022). AI voice agent technology registers users' voice commands and provides contingent feedback; thus, allowing user-technology interaction without relying on additional input devices, such as keyboards and mice. Using such external input devices to engage in communicational exchanges with technologies is particularly challenging for young children, who are still developing fine motor skills and written communication skills (Kirkorian et al., 2020; Strommen, 1993). Once users make requests to voice-activated devices, these requests are processed in the cloud, a server that is accessed through the Internet. The results of the request are eventually transformed into speech for the users to hear back. Thus, young children who have not fully mastered reading and writing skills can directly talk to AI voice agents (Terzopoulos & Satratzemi, 2020).

An emerging line of work provides evidence to support the potential social roles that AI-voice agents can play in children's learning. Druga and colleagues (2017) investigated how children aged between 3 and 10 years play with and perceive autonomous "agents," including smart speakers. The findings showed that children in general perceived agents as being friendly and trustworthy although a relatively younger age group (3-4 years old) found it challenging to interact with the agents. Lovato et al. (2019) observed 5- to 6-year-old children's question-asking to AI voice agents and reported that these children naturally engage in conversations with AI voice agents and ask questions related to learning about science/technology and culture. However, when directly comparing talking to a human partner to communicating with an AI voice agent, older preschoolers aged 5 and 6 years tended to communicate less with the AI voice agent than the human while playing a game, and only the kind of information provided by the human partner influenced children's subsequent decision making (Aeschlimann et al., 2020).

Effects of Dialogic Reading with Technology on Children's Learning

The increasing presence of voice-assisted technology in young children's lives, together with its voice-based command features that allow young children to engage in socially contingent interaction with technology, suggest the potential for educational benefits (Terzopoulos & Satratzemi, 2020). A growing body of research has examined how contingent media such as video chat and touchscreens impacts young children's learning in a wide range of developmental domains, including symbolic understanding (Choi & Kirlorian, 2016; Lauricella et al., 2010), imitations (see Barr, 2010), and word learning (Baldwin & Moses, 2001; Gaudreau et al., 2020; Myers et al., 2017, 2018; Nussenbaum & Amso, 2016; Roseberry et al., 2014; Strouse et al., 2018; Troseth et al., 2018). However, the findings are mixed regarding the impact of interactive technologies on young children's learning (Choi et al., 2021; Kirkorian, 2018), resulting in a mixed picture of the role of the varying level of social cues of technological agents in children's learning outcomes.

To study the impact of social cues provided by technological agents, scholars have examined whether the presence of a human partner influences preschoolers' learning from shared book reading by comparing face-to-face and online interactions (Escudero et al., 2021; Gaudreau et al., 2020). In these studies, 4-year-old children did not show differences between in-person or on-screen learning contexts. Escudero et al. (2021) found that 4-year-old children's word learning outcomes did not differ between in-person and online reading. Gaudreau et al. (2020) also showed that 4-year-old children performed equally well on vocabulary and comprehension tests regardless of whether they read a book live, via video chat, or by watching a pre-recorded video. These patterns are different from those of infants and toddlers, who show less learning from video demonstrations than in-person demonstrations, referred to as a *video deficit* (Anderson & Pempek, 1995; Strouse & Samson, 2020). Together, these findings suggest that the mere presence of live human partners may not be sufficient enough to cause differences in preschoolers' learning outcomes.

Another line of work has examined contingency as physically relevant and timely actions without the presence of social partners (Choi & Kirkorian, 2016; Choi et al., 2018, 2021; Etta & Kirkorian, 2019; Kirkorian & Choi, 2016). Etta and Kirkorian (2019) manipulated the interactivity of a digital reading device in terms of tapping story-relevant images or story-irrelevant images on the screen. The results showed that preschoolers (3-6 years old) did not perform differently in word learning and story comprehension between those two conditions as well as in the control condition where children watched the experimenter tap the screen herself. Similar findings are found with preschoolers' mathematics or science learning in that such simple physically contingent actions either do make a difference in preschoolers' learning or sometimes it is better to simply watch a video rather than physically interacting with the video (Aladé et al. 2016; Schroeder & Kirkorian, 2016).

Given these mixed findings with interactive technologies, scholars have posited that interactive technologies need to be carefully designed to promote active, engaged, meaningful, and socially interactive learning in order to be educationally beneficial for young learners (Hirsh-Pasek et al., 2015). Perhaps what matters more for preschoolers who are under less influence of the video deficit may be the specific type of social interaction such as meaningful communicational turn-taking between a reading partner and a child during learning activities involving technology. Identifying specific social interaction types that are particularly beneficial for learning may be one of the puzzles to be solved to explain the mixed findings.

Dialogic reading, which refers to an interactive book-reading method that supports young children's language and literacy development (Institute of Education Sciences, 2007), has been shown to be effective in both in-person and digital settings (Purpura et al., 2021; Strouse et al., 2013; Xu et al., 2022; for a review, see Noble et al., 2019). Thus, engaging in meaningful social interactions with a knowledgeable social partner through content-related questions and contingent feedback in response to children's responses may play a particularly critical role in children's learning from technology. Indeed, Strouse et al. (2013) designed a between-subject study where 3-year-old children watched educational videos in one of four different conditions and compared their story comprehension and vocabulary learning. Children watched a television program in one of the following ways: 1) with parents who asked questions to children and helped them be engaged in the story, 2) with parents who only provided comments, 3) with an on-screen character who asked questions, or 4) without any assistance. The results showed that children who read the books with the on-screen character scored in the middle between the highest group (i.e., reading with dialogic questioning parents) and the lowest group (i.e., non-dialogic questioning parents and no assistance). This implies that children may learn words better during shared book reading if technological social agents ask questions and provide proper feedback compared to when reading books without any assistance. This is in line with previous research showing that pedagogical questions asked by a knowledgeable person influence children's content comprehension and knowledge transmission (Daubert et al., 2020; Yu et al., 2018).

Thus, the extent to which the technology engages young children as active participants in socially contingent and meaningful interaction with technology is likely to be the key to integrating AI voice agents with educational activities. Indeed, previous studies have revealed that children are sensitive to interactive social cues from technology including child-directed TV programs, such as *Dora the Explorer* and *Blue's Clues* (Calvert et al., 2020; Calvert et al., 2014; Howard et al., 2013; Lauricella et al., 2011; Strouse et al., 2013), social robots (Beran et al., 2011; Kahn et al., 2012; Tanaka et al., 2007), or a voice agent (Aeschlimann et al., 2020; Xu et al., 2022). Children respond to participatory cues provided by media characters, which are prevalent in educational programs for young children (Richards & Calvert, 2016; Krcmar & Cingel, 2019; Piotrowski, 2014). Further, Calvert et al. (2020) designed an interactive mathematics game including a popular media character that can verbally interact with children in an adaptive manner to teach preschoolers mathematics, with a focus on adding one rule. The researchers found that preschoolers learn the target mathematical concept from contingent verbal interactions with the character through engaging in mathematics talk (Calvert et al., 2020). This line of work sheds light on the possibility that non-human agents serve as meaningful social partners and influence children's learning as long as they are designed in an age-appropriate and educationally supportive manner.

Here, we focus on dialogic reading as one type of meaningful social and contingent interaction to support children's learning. Researchers have begun to examine the effectiveness of AI voice agents as reading partners in children's book-reading contexts (Xu et al., 2021, 2022; Xu & Warschauer, 2020). Despite concerns raised regarding using AI voice agent technology for young children's learning–the hardship of recognizing children's voices and children's lack of conversational skills (see Terzopoulos & Satratzemi, 2020, for more), emerging evidence suggests the facilitative role of contingent interactions with AI voice agents, particularly during dialogic reading, in children's learning.

Specifically, Xu and colleagues (2021, 2022) investigated the role of an AI voice agent in shared book reading with preschoolers in comparison with a human reading partner. Preschool children aged three to six years showed an equal level of performance in story comprehension when they read a book with an adult and when with an AI voice agent. In those studies, both the human partner and the AI voice agent partner asked guiding questions throughout the reading and provided appropriate feedback depending on the children's responses (Xu et al., 2021). The effect of the AI voice agent as a reading partner on children's story comprehension was also replicated in another study with a larger sample size (Xu et al., 2022). In Xu et al. 's (2022) study, preschoolers' story comprehension score in the AI voice agent condition matched that of the human condition as long as the dialogic reading practice was used. Additionally, dialogic reading with the AI voice agent was more beneficial for children's story comprehension than simply reading the book with the AI voice agent without any questions.

Even though the existing line of work suggests the facilitative role of AI agent reading partners in preschoolers' learning from a single shared book reading session, it remains unclear how dialogic reading with an AI voice agent influences preschoolers' learning outside the domain of story comprehension—particularly mathematics learning—that can be supported by a relatively extended period of reading. Previous literature on children's mathematical language learning have used repetitive readings of the same books for at least a month (Hassinger-Das et al., 2015; Jennings et al., 1992; Purpura, Napoli, et al., 2017, Purpura et al., 2021; Young-Loveridge, 2004). It remains unclear whether children communicate with AI voice agents in a similar way across multiple reading sessions or the extent to which the effectiveness of dialogic reading from a single reading session holds for repetitive reading sessions. On the one hand, research on participatory cues (Crawley et al., 1999; Krcmar & Cingel, 2019; Piotrowski, 2014) suggests that it takes time for children to engage in contingent interactions with video. Thus, it is possible for children to get benefits from multiple exposures to AI voice agents. Another possibility is that children may lose interest in contingent interactions with the AI voice agent over time as the novelty of the device wears off. Xu et al. (2021, 2022) found that children tend to produce less diverse and less narrative-relevant vocalizations in dialogic reading with a voice agent compared to dialogic reading with a human partner in a single reading session. In the single exposure, this reduced vocalization did not lead to differences in children's learning outcomes (Xu et al., 2021, 2022). However, it is an open question as to whether the reduced amount of vocalization across repeated reading sessions with the AI voice agent cumulatively results in a decline in children's learning outcomes. Although preschoolers' less diverse and narrative-relevant vocalizations during a dialogic reading with an AI voice agent (compared to dialogic reading with a human partner) did not lead to differences in learning outcomes in a single reading session (Xu et al., 2021, 2022), reduced interaction at each reading may cumulatively result in decreased learning from multiple dialogic reading sessions with AI voice agents (Aeschlimann et al., 2020; Garg & Sengupta, 2020). More research is needed to examine whether shared book reading with the AI voice agent is an effective educational intervention tool in mathematics learning as well and whether the benefits of dialogic reading can be replicated in children's mathematics language learning.

The Overview of the Current Study

The purpose of the current study was to examine the impact of dialogic reading with an AI voice agent on preschoolers' mathematical language learning. The specific aims of the study were twofold. The first aim of the study was to examine the impact of a math storybook intervention with an AI voice agent on children's mathematical language learning. The second aim of the study was to examine the role of dialogic reading with an AI voice agent on children's mathematical language learning.

To address these questions, a randomized pretest-posttest experimental design was used. Children aged between 3 and 5 years (*N* = 66) were randomly assigned to one of three conditions: 1) Reading a math book with an AI voice agent that uses dialogic reading (Math-DR), 2) Reading a non-math book with an AI voice agent using dialogic reading (Non-math DR), and 3) Reading a math book with an AI voice agent without dialogic reading (Math non-DR). For each condition, the assigned book was read three times, once each in three separate reading sessions. Before and after the three reading sessions, children completed one pretest session and one posttest session, respectively. Each test session included mathematical language, numeracy, and general vocabulary tests with an additional story comprehension test on posttest. All five sessions were asked to be scheduled 2-3 days apart so that all sessions could be completed within a 2-week period.

To address the first aim of the study, the Math DR and Non-math DR conditions were compared in terms of children's mathematical language after controlling for age, sex, general vocabulary, numeracy pretest scores, and mathematical language pretest scores. Based on prior research demonstrating the effectiveness of math storybook reading interventions on preschoolers' mathematical language learning and numeracy skills (Purpura, Napoli, et al., 2017, Purpura et al., 2021), it was hypothesized that children would show better mathematics language learning outcomes indicated by higher gains in the mathematical language test when reading a math storybook rather than when reading a non-math storybook with an AI voice agent. Specifically, we anticipate a more pronounced distinction in the learning of targeted mathematical language, which the storybook is designed to teach, than in the learning of general mathematical language.

To address the second aim of the study, the Math DR and Math non-DR conditions were contrasted in terms of children's mathematical language controlling for the same variables aforementioned. It remains an open question as to whether the effectiveness of dialogic reading would extend to children's mathematical language outcomes, which can be supported by multiple reading sessions. Given a large body of research documenting the effectiveness of dialogic reading on children's word learning (Morgan & Meier, 2008; Noble et al., 2019; Strouse et al., 2013) and story comprehension (Xu et al., 2021), and the positive effects of repetitive viewing on children's responses to participatory cues from educational television programs (Crawley et al., 1999; Krcmar & Cingel, 2019; Piotrowski, 2014), children may show better learning outcomes indicated by higher gains in mathematical language with dialogic questions than without dialogic questions during book reading with the AI voice agent. Specifically, a more pronounced distinction was expected in the learning of targeted mathematical language, which the storybook is designed to teach, than in the learning of general mathematical language. Alternatively, children's performance in the mathematical language test may not be different between the two experimental conditions if children's interaction with the AI voice agent reduces significantly over multiple reading sessions (Beneteau et al., 2020; Garg & Sengupta, 2020), which may cumulatively affect children's learning outcomes.

In addressing both aims of the study, we explored the potential moderating role of key prior knowledge, including vocabulary, mathematical language, and numeracy skills based on the theory and empirical evidence (Barr & Kirkorian, 2023; Fisch, 2000; Plass et al., 2010) suggesting the importance of prior knowledge.

Chapter 4: Method

Participants

The current study included children aged between 3 and 5 who could speak English and had not yet started kindergarten. The data were collected from July 2023 to June 2024. Eighty-one children were initially recruited for home-visit sessions and school-visit sessions from five childcare centers serving families in the New River Valley and surrounding areas (e.g., Blacksburg, Christiansburg, and Radford). For school-visit children, parent packets including parent letters, permission forms, consent forms, child date of birth forms, and brochures about research were distributed to the childcare centers and preschools after getting approval from the directors of the institutions. Recruitment flyers with a QR code directing to the online forms were distributed to the parents as well depending on schools' preferences. At some schools, we also set up a booth during pick-up time to recruit participants and answer any questions parents might have had. Parents completed and returned the forms either by sending them back to school or signing them online. For home-visit children, recruitment flyers were distributed on social media and email listservs, and to public places such as public libraries and children's museums. Participants could access all forms in the same way as the ones for school-visit children through a QR code on the flyers. Parents also completed a brief online survey on demographics and their children's media use using the Virginia Tech REDCap (Research Electronic Data Capture) platform and the survey was sent to the parents with individual codes via email.

Among 81 recruited children, one student never started a session due to long absences and five children (three girls and two boys) dropped out after completing the pretests because they did not want to leave the classrooms or playgrounds. Seven children (all boys) dropped out after completing some reading sessions. Four children were in the Non-math DR condition, two children were in the Math-DR condition, and one child was in the Math non-DR condition. One child turned out to attend kindergarten. Another one child partially completed posttests. These 15 children were excluded from our final sample. Additionally, we had two more children who partially completed posttests, however, these children at least completed our primary outcome measure (e.g., mathematical language), hence they were included in the final sample.

A total of 66 children comprised the final sample (*M* = 53.2 months, *SD* = 8.18 months, range 37 - 68 months) and 41% were girls. Most of the final sample (85%) completed sessions at their schools, while 15% did so at their home. Twenty-five children read the book in the Math-DR condition, 22 in the Math non-DR condition, and 18 in the Non-math DR condition. All book reading sessions were completed within 4 days to 32 days (*M* = 12.94, *SD* = 5.11). Fifty-one (82.4% mothers, 17.6% fathers) out of 66 parents (77.3% of the sample) completed a parental survey that provided demographic information. Among 51 children, 64.7% of the children were White, 11.8% and 2.0% of children were Asian and Black respectively, and 21.6% of children were multiracial. Based on the parent survey, it was reported that 70.6% of families only spoke English and 29.4% of families used two or three languages including English at home. Based on 51 survey responses regarding parental highest educational level, 9.8% reported less than a 4-year college degree, 19.6% reported a college degree, 17.6% reported a master's degree, 45.1% reported a doctoral degree, and 7.8% did not provide information. It was also reported based on 51 parental responses about their child's smart speaker use experience that 25.5% have never used a smart speaker, 27.5% less than once a month, 9.8% less than once a week, 7.8% once a week, 3.9% several times a week, 7.8% once a day, and 9.8% several times a day; 7.8% of parents did not report their child's smart speaker use experience.

Experimental Stimuli and Apparatus

Two storybooks from Purpura et al. (2021) were used in the study. For the math storybook, Picnic with Some Peanuts (Figure 2) was used, which contained nine target mathematical words (e.g., few, fewer, least, and several) and six non-target mathematical words (e.g., more and most). For the non-math storybook, Maria's Perfect Day was used, which did not include mathematical words on purpose (Figure 3). The non-math book was purposely designed in a similar way as the math book in terms of text length (N_{math} = 341 words; $N_{\text{non-math}}$ = 345 words) and age-appropriate topics. Both books had text on the left page and illustrations on the right page (see Figures 2 and 3). At the bottom of each text page, three questions were written in different colors (red, blue, and purple). The questions in red, blue, and purple were asked during the first, second, and third book reading, respectively. Both storybooks had a total of 14 dialogic questions per reading. Children were prompted by the AI voice agent to turn the page whenever the AI voice agent completed reading each page (in Math non-DR condition) or providing feedback (in Math DR and Non-math DR conditions). Once the experimenter confirmed the child was on the correct page, the AI voice agent continued reading the next page.

The math storybook is about two elephants going out for a picnic. The non-math book is about a raccoon's day to find ways to help her cool off. Example questions of the math storybook are "*Who has fewer books than Lucy?*" and "*If Lucy ate all of her apples, who would have the most?*". Example questions of the non-math storybook are "*The lemonade has ice. Why hasn't it melted yet?*" and "*What can Maria do to make the lemonade sweet?*".

Google Nest smart speaker (3.07 in. × 4.88 in.) was used for all sessions to deploy the AI voice agent system.

Figure 2

Example Pages of the Math Book

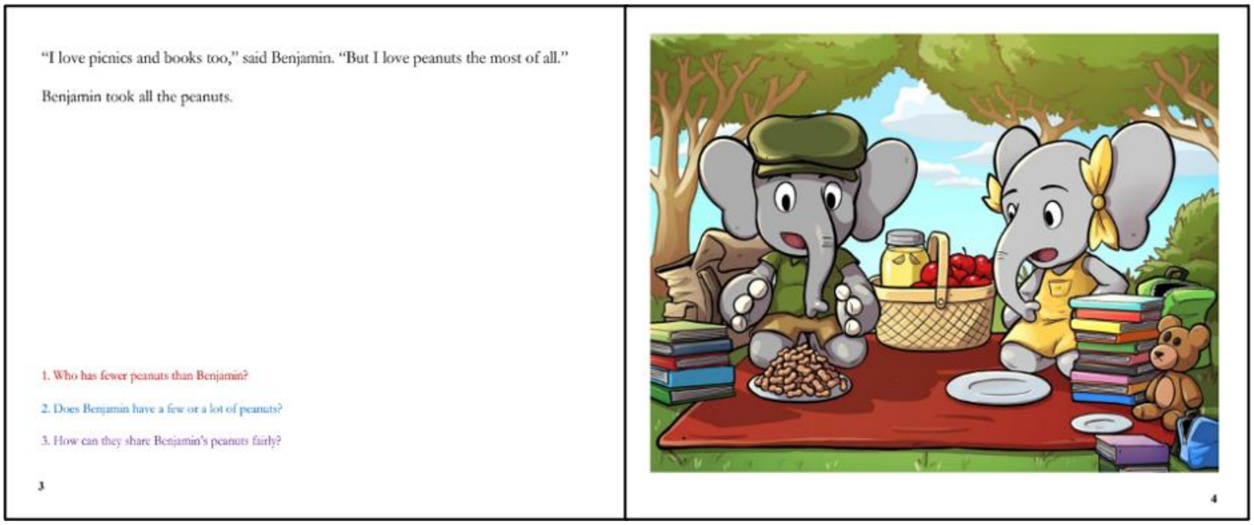
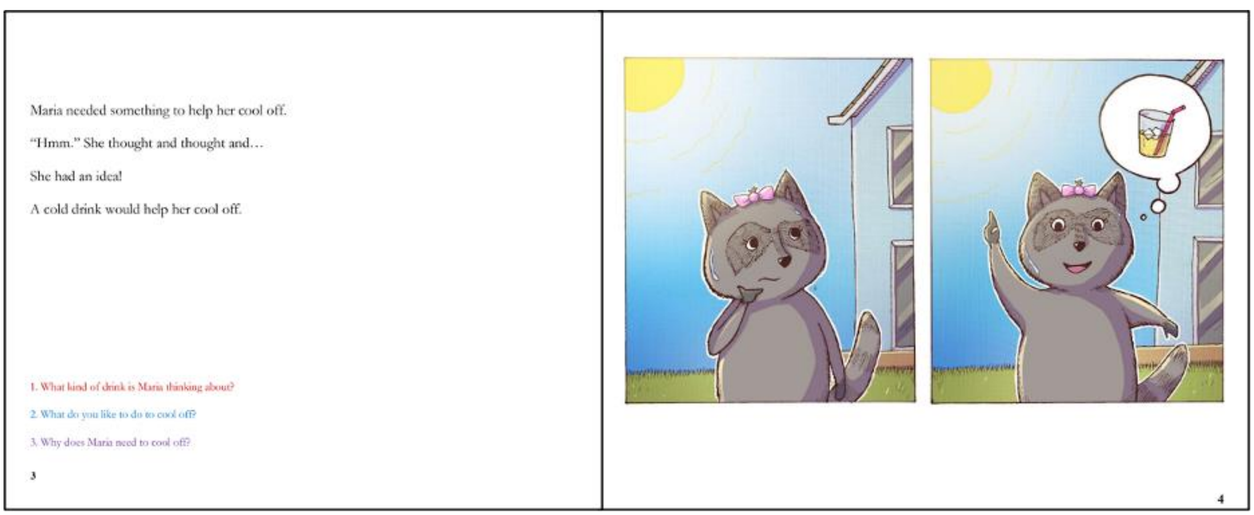


Figure 3

Example Pages of the Non-Math Book



Study Design

The current study used a pretest-posttest experimental design where the children were randomly assigned to one of three reading conditions. The reading conditions were as follows:

Math Book Dialogic Reading (Math DR). Children in this condition read a math storybook (i.e., Picnic with Some Peanuts) with the AI voice agent. The agent narrated the story and asked a question per page. Depending on the children's responses, the AI voice agent provided contingent feedback. Different questions were asked per page across reading sessions.

Math Book Non-Dialogic Reading (Math non-DR). Children in this condition heard the same story from the AI voice agent as the children in the Math DR condition. However, no questions or feedback were provided.

Non-math Book Dialogic Reading (Non-math DR). In this condition, the AI voice agent narrated a non-math storybook (i.e., Maria's Perfect Day) and asked a question per page. Appropriate feedback was followed by children's answers. Similar to the Math DR condition, different questions were asked per page across reading sessions.

Procedure

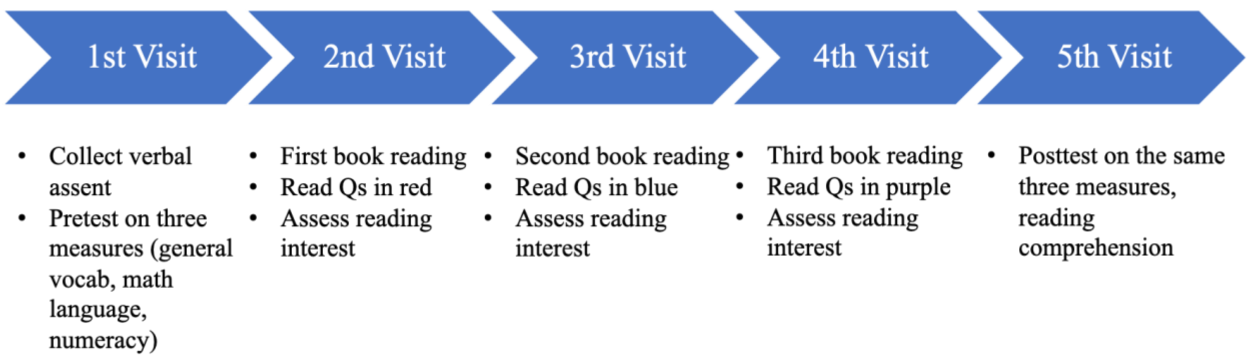
All five sessions were conducted either in quiet places at children's schools or at home. The children were seated on either a portable chair brought by the experimenter or one belonging to the school or home. The laminated storybook was positioned on the table in front of the children, along with the smart speaker, which was also placed on the table above the book. The experimenter sat across from or next to the child to administer tests and to provide technical assistance as needed. All sessions were video-recorded. In the first session, the experimenter introduced herself and explained the activity, which was followed by collecting children's verbal assent. Then children completed a numeracy skill test, a mathematical language test, and a general vocabulary test in order. After all tests were completed, the experimenter introduced main characters or things from the book using laminated pictures depending on the assigned conditions (*Benjamin*, *Lucy*, and *Bear* for the two math book reading conditions; *Maria*, *Lemonade*, and *Stepstool* for the non-math book reading condition). Next, the children had opportunities to meet the AI voice agent, which we introduced as a special friend *Toma* who can talk and listen to them, and to learn about how it works (e.g., when Toma asks them questions, they first need to wait for a small beep sound to answer), and had a short conversation with the AI voice agent to get used to talking to the AI voice agent. The first session took about 15-20 minutes.

During the next three visits, children read the same storybook with the AI voice agent in the same assigned conditions. The number of reading sessions was decided based on the average reading duration of 19 storybook intervention studies reviewed by Dowdall et al. (2020). During book reading sessions, the experimenter first asked the children whether they remembered the key information (i.e., character names, object names) using the same laminated pictures that were shown to them in the first session. Then children had a short conversation with the AI voice agent about their favorite colors, toys, ice cream flavors, and other similar topics. Following this, children heard the same questions (e.g., "can you tell me this friend's name?) again from the AI voice agent asking the key information the experimenter asked them earlier. During this rapport-establishing phase, the AI voice agent provided contingent feedback to all children. These interactions occurred to all children regardless of their reading conditions. Each reading session had different rapport-establishing questions, and all children heard the same questions regardless of the reading conditions within the reading session. Following reading sessions, the experimenter asked the children how much they enjoyed the reading by showing them three circles in different sizes. The reading sessions took about 20 minutes for Math DR Non-math DR conditions and took about 10 minutes for Math non-DR condition.

On the last visit, children were asked to complete the same three tests (mathematical language, numeracy, and general vocabulary) as in the first visit and an additional reading comprehension test. At the end of the last visit, the children received a certificate and a set of stickers as a gift upon the approval of the schools and parents. Once the data collection was completed with all participating classrooms at the schools, the classrooms received five children's books as compensation. For the home-visit families, an e-gift card of $25 was sent to parents via email.

Figure 4

Study Procedure



AI Voice Agent Development

The AI voice agent was developed using Google DialogFlow CX (Google Cloud, 2022), which is a natural language understanding platform for analyzing speech input and responding to users through synthetic speech. Each reading session for both books was designed in DialogFlow CX based on the transcripts of actual child-parent conversations reading the same book we used in the study upon approval of the first author of a prior study using the same storybooks as in the current study and sharing of de-identified data (Purpura et al., 2021). All storylines, questions, children's expected answers to the questions, and AI voice agents' responses were entered into the DialogFlow platform. Children's expected answers were added as training phrases of *intents*. For example, one correct answer to a question from the math storybook was "bear", which was one intent, and training phrases such as *bears, teddy, pair, fair* were also included as correct answers under bear intent. The way how training phrases work is that based on this small set of answers entered, the AI voice agent would learn and expand them, so children's verbal responses that were not included in training phases can be also captured as correct responses to the questions.

In DialogFlow CX, we designed a dialog flow project for each reading of two books, creating a total of six different projects. We also developed a Graphical User Interface (GUI) so that the experimenter could easily start each reading session. There were multiple buttons for initiating the first, second, and third reading of each book and for start and stop recording. Each reading on the DialogFlow CX platform was initiated with specific initial user input (i.e., "Hi"), and clicking a button on the GUI replaced this user input, which was followed by child-directed questions ("What is your name?", "What is your favorite color?") to introduce the child to how the AI voice agent works. Next, the reading began, and the voice agent read the text starting from the first page of the relevant book (i.e., the math book for the Math DR and Math non-DR conditions, and the non-math book for Non-math DR condition). Regardless of the reading conditions, children were asked by the AI voice agent to turn to the next page following the text (for the Math non-DR condition) or feedback to children's answers (for Math DR and Non-math DR conditions).

For the Math non-DR condition, the AI voice agent continued reading by moving on to the next page without interacting with the child. For the Math DR and Non-math DR conditions, the AI voice agent read the text and asked one question per page, with a total of 14 questions during each of the three book reading sessions. There were three types of questions depending on the number of possible correct answers. The first type of question had a single possible correct answer (e.g., Question: *"Does Benjamin have a few or a lot of peanuts?"*; Answer: *"A lot"*). The second type of question had two possible correct answers (e.g., Question: *"Who has fewer books than Lucy?"*; Answer: *"Benjamin and Bear"*), thus children could provide partially correct answers. The third type of question was open-ended questions without correct answers (e.g., Question: *"What books do you like to read?"*). For the first type of question (1 correct answer), children were allowed to make up to two attempts. For the second type of question (2 correct answers), children could make up to three attempts if their responses involved partially correct answers. For the last type of question (no correct answer), children had one conversational exchange with the AI voice agent, and generic feedback (e.g., *"Great! That sounds like a great idea!"*) was provided. The number of questions of each type was the same across storybooks. This predetermined flow was deployed on the experimenter's laptop.

Regarding the types of questions that involve one or two correct answers, children were engaged in up to two or three conversation turns with the AI voice agent. Specifically, if a child provided the correct answer on the first trial, the AI voice agent acknowledged the correct answer and moved on to the next page. When the child provided a partially correct answer (i.e., one correct answer) to questions with two correct answers, the AI voice agent acknowledged the partial correctness and asked a follow-up question asking for another answer (e.g., *"What else?"*). If the child answered using unclear words (e.g., pronouns), then a clarifying question was asked. For the rest of the answer types, the AI voice agent repeated the question with hint phrases. If the child did not provide the correct answer on the second attempt, the voice agent provided the correct answer and moved on to the next page.

For all question types, the AI voice agent provided appropriate feedback based on the child's responses. To enable the AI voice agent to provide contingent feedback on the user's input, *intents* were used to categorize the users' conversational intention for each conversational turn (Google Cloud, 2022). In the current study, children's predicted answers and corresponding feedback were formulated based on parent-child conversational data from prior work using the same storybooks as in the current study (Purpura et al., 2021). The AI voice agent in our study was designed to categorize children's answers into four different types of intents: 1) Correct answers, 2) Partially correct answers, 3) Unclear answers, and 4) Others.

In the current study, Google's Speech-to-Text application programming interface (API) was used to convert children's utterances into text using Google's machine-learning models. Using Google's natural language processing, the converted text was further classified into one of the four intents based on semantic similarity. To improve accuracy in children's speech detection, which in turn allows natural conversational exchanges between the child and the AI voice agent, a wide range of variations of correct answers containing the same meaning was included in each intent. For example, *a bear*, *the bear*, *this bear*, and *the bear*s were all perceived as one answer to the question. Additionally, words that may be similarly perceived as the correct words were also included as synonyms. For example, *Lucci*, *you see*, and *newsie* were included to be recognized the same as Lucy. In the event that the AI voice agent did not recognize the child's vocal response, predetermined responses (i.e., the fallback intents) were employed in the form of either repeating the question or offering generic feedback to the child's opinion, contingent on the question.

Measures

Mathematical Language

The Preschool Assessment of the Language of Mathematics (PALM; Purpura & Logan, 2015) was used to measure children's mathematical language learning. This test consists of quantitative words (e.g., more, least, and some) and spatial words (e.g., above, below, and inside). However, only quantitative word items were used in the current study because the selected math storybook focused on teaching quantitative words. This test was administered on paper. Children were asked to select the correct pictures after hearing instructions. Example items are *"Which side has more dots?"* and *"Which glass has the least amount of water?"*. One point was given when the child answered correctly and the possible score range was from 0 to 21. This measure showed good reliability (Cronbach's α = .75). This test took about 5-7 minutes. Among 21 items, nine items assessed children's understanding of mathematical words that the math storybook targeted (Purpura et al., 2021): few, fewer, fewest, least, less, some, and a little bit. We created a separate variable for children's core mathematical language scores. Among these nine items, one item ("take away a few blocks from my pile?) showed lower reliability (Cronbach's α = .76 after removing the item) and, hence was excluded from core mathematical language, which made core mathematical language range from 0 to 8.

Early Numeracy Skills

Children's early numeracy skills were assessed using Preschool Early Numeracy Skills Test-Brief Version (PENS-B; Purpura et al., 2015). This 24-item task using a testing binder asks children to respond either verbally or by pointing to correct images or numerals after hearing the questions. Example items are "How many dogs are there?" and "Count these dots. Point to each one as you count." It was developed to identify children who are at risk of mathematics difficulties and was validated by assessing 522 preschool children. The possible score range was from 0 to 24. The assessment was stopped if a child got three incorrect answers in a row based on the examiner manual. This test took about 5-7 minutes.

General Vocabulary

To measure children's general vocabulary skills, the National Institute of Health (NIH) Toolbox Picture Vocabulary Test (Gershon et al., 2014) was used. The NIH Toolbox Vocabulary Test is a standardized test to measure children's receptive vocabulary who are between 3 and 18 years old. The test was administered on an iPad Pro 10.5-inch. Children were asked to choose one picture among four pictures after they heard each word per trial. There were two practice items asking them to touch the picture of "banana" and "spoon", which was followed by test items. The entire test took about 4 minutes. There were up to 25 test trials, and the exact number of trials varied by individual because the test is adaptive to children's performance. The difficulty of the test and the starting item depended on the children's age and performance on earlier items. Children's test scores were exported from the iPad upon completion. The test results included children's uncorrected standard score, age-corrected standard score, and age-adjusted national percentile. The age-corrected scores were used in the analyses.

Reading Interest

To gauge children's interest in reading, the question, "How much did you like the reading today?" was asked after each reading was completed. Children chose one of three circles in different sizes, each representing a little (1), a medium amount (2), and a lot (3), respectively, to present their interests, which scored from 1 to 3.

Demographic Survey

Parents were asked to complete a brief demographic survey through Virginia Tech REDCap to report demographic information (e.g., child age, child sex, and the highest level of education) and their child's prior experience with AI voice agents. The survey was expected to take less than 10 minutes to complete and the link to the survey was delivered to parents via email.

Analytical Plan

First of all, descriptive statistics for each study variable and bivariate correlations among study variables were calculated. Next, to examine the effect of math storybook intervention and dialogic reading, two separate regressions were conducted for each outcome variable (i.e., mathematical language, core mathematical language). The three reading conditions were included in the models as two dummy variables with Math DR condition as a reference group. Covariates included child age, sex, general vocabulary, (core) mathematical language pretest scores, and numeracy pretest scores. Child age, general vocabulary, (core) mathematical language pretest, and numeracy pretest scores were continuous variables and were centered at the lowest scores. To examine whether the math storybook intervention and dialogic reading effects would be moderated by either vocabulary, numeracy skills, and mathematical language, we performed a log-likelihood ratio (LLR) test per each cognitive characteristic. For each cognitive characteristic, a full model with interaction terms was compared with a reduced model without the interaction term. Based on the LLR test results, the full model with the interaction terms was reported when it provided a better fit for the data relative to the reduced model without the interaction term. Preliminary analyses were conducted using IBM SPSS Statistics (version 29) and R software environment (version 4.3.1), and primary analyses were conducted using R software environment (version 4.3.1).

Chapter 5: Results

Preliminary Analyses

Demographic information and descriptive statistics of all study variables are represented in Table 1. Raw scores of study variables were used in the analyses except for general vocabulary which used age-corrected standard scores. Preliminary analyses indicated that children in Math DR, Math non-DR, and Non-math DR conditions did not significantly differ on child age, F (2, 63) = 0.51, p = .601; parent highest education, F (2, 44) = 1.22, p = .306; sex, F (2, 63) = 0.47, p = .624; general vocabulary, F (2, 63) = 1.12, p = .333; mathematical language pretest scores, F (2, 63) = 1.16, p = .319; core mathematical language pretest scores, F (2, 63) = 2.41, p = .098; and numeracy pretest scores, F (2, 63) = 2.37, p = .101.

Next, bivariate correlations among study variables are presented in Table 2. All study variables showed overall significant correlations with each other except for child sex. Both child age and general vocabulary skills were positively associated with all outcome measures.

Table 1

Descriptive Statistics for Study Variables

Variable	Math DR			Math non-DR			Non-Math DR			All		
	n	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*	*N*	*M*	*SD*
Age	25	54.4	8.06	23	52.0	8.15	18	53.0	8.61	66	53.2	8.18
Sex (female = 1)	25	0.40	0.50	23	0.35	0.49	18	0.50	0.51	66	0.41	0.50
Parent education	19	5.84	1.30	14	5.93	1.14	14	6.43	0.76	47	6.04	1.12
General vocabulary	25	96.2	16.4	23	92.2	16.5	18	99.3	11.6	66	95.7	15.3
Pretest mathematical language	25	15.7	3.54	23	14.5	3.49	18	15.3	2.81	66	15.1	3.32
Pretest core mathematical language	25	5.40	1.76	23	4.48	1.24	18	4.67	1.53	66	4.88	1.56
Pretest numeracy	25	18.2	6.94	23	14.4	5.77	18	16.0	5.11	66	16.3	6.21
Posttest mathematical language	25	16.2	3.16	22	15.6	3.67	18	16.3	2.89	65	16.0	3.26
Posttest core mathematical language	25	5.92	1.38	22	5.64	1.84	18	5.61	1.29	65	5.74	1.51
Posttest numeracy	25	18.9	6.63	22	16.1	6.68	17	17.8	5.25	64	17.7	6.33

Table 2

Bivariate Correlations Among Study Variables

Variable	*n*	1	2	3	4	5	6	7	8	9	10
1. Age	66	—									
2. Sex (female = 1)	66	-.20	—								
3. Parent education	47	.05	.11	—							
4. General vocabulary	66	**.40*****	.17	**.37***	—						
5. Pretest mathematical language	66	**.58*****	-.01	.24	**.61*****	—					
6. Pretest core mathematical language	66	**.48*****	-.22	.15	**.40*****	.70***	—				
7. Pretest numeracy	66	**.57*****	-.06	**.41****	**.64*****	**.70*****	**.55*****	—			
8. Posttest mathematical language	65	**.48*****	-.01	.26	**.62*****	**.85*****	**.57*****	**.69*****	—		
9. Posttest core mathematical language	66	**.46*****	-.19	.12	**.45*****	**.67*****	**.68*****	**.55*****	**.77*****	—	
10. Posttest numeracy	64	**.55*****	-.07	**.41****	**.61*****	**.62*****	**.48*****	**.89*****	**.67*****	**.51*****	—

Note. $^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$.

Primary Analyses

First, to examine the effects of math storybook reading and dialogic reading on children's mathematical language learning, two regression models were fitted for the two different mathematical language outcomes: The first model with children's total mathematical language scores as a dependent variable (Model 1) and the second model with children's core mathematical language scores as a dependent variable (Model 2). Reading conditions were included as two dummy variables with Math DR condition as a reference group, which represented the contrast between Math DR and Math non-DR, and the contrast between Math DR and Non-math DR, respectively. Covariates included child sex, age, general vocabulary, (core) mathematical language pretest scores, and numeracy pretest scores. Child age, general vocabulary, (core) mathematical language pretest, and numeracy pretest scores were continuous variables and were centered at the lowest scores. Additionally, it was examined whether children's reading interests differed by reading condition.

Total Mathematical Language. The first regression model (Model 1) was fitted to predict children's total mathematical language scores (Table 3) and the results indicated that only mathematical language pretest scores predicted children's mathematical language posttest scores ($b = 0.69$, $p < .001$). Children with higher initial levels of mathematical language received higher posttest mathematical language scores. There was no significant effect of the Math non-DR condition ($b = -1.21$, $p = .376$) on children's posttest mathematical language scores, nor did its interaction with pretest numeracy scores ($b = 0.12$, $p = .130$). Similarly, the Non-math DR condition ($b = -2.49$, $p = .131$) and its interaction with pretest numeracy scores had no significant effects ($b = 0.18$, $p = .054$).

Table 3

Regression Model Predicting Posttest Mathematical Language

Variables	*b*	*SE*	*t*	*p*	95% CI
Intercept	**9.81*****	1.72	5.72	< .001	[6.37, 13.25]
Child age	-0.03	0.03	-0.94	.347	[-0.10, 0.04]
Female	-0.05	0.46	-0.11	.909	[-0.96, 0.86]
General vocabulary	0.02	0.02	1.05	.297	[-0.02, 0.06]
Pretest numeracy	0.03	0.06	0.54	.589	[-0.10, 0.16]
Pretest mathematical language	**0.69*****	0.10	7.23	< .001	[0.50, 0.88]
Math non-DR condition	-1.21	1.35	-0.89	.376	[-3.92, 1.51]
Non-math DR condition	-2.49	1.63	-1.53	.131	[-5.76, 0.77]
Pretest numeracy × Math non-DR	0.12	0.08	1.54	.130	[-0.04, 0.28]
Pretest numeracy × Non-math DR	**0.18**†	0.09	1.97	.054	[-0.00, 0.37]

Note. $N = 66$; Numeracy pretest scores, mathematical language pretest scores, and general vocabulary pretest scores are centered at their minimum; CI = Confidence Interval; $^{\dagger}p < .10$. $^{*}p < .05$. $^{***}p < .001$.

Core Mathematical Language. Next, the second regression model (Model 2) was fitted to predict children's core mathematical language learning specifically, which is presented in Table 4. In Model 2, the results indicated that children's core mathematical language posttest performance was not significantly predicted by children's general vocabulary ($b = 0.02$, $p = .086$). Children's core mathematical language pretest scores significantly predicted their posttest core mathematical language scores (*b* = 0.48, *p* < .001). Importantly, the Pretest Numeracy × Math non-DR interaction effect was significant (*b* = 0.13, *p* = .016) whereas Pretest Numeracy × Non-math DR interaction effect was not, suggesting that the effect of reading condition, particularly the difference between the Math DR and Math non-DR conditions on children's learning of core mathematical language, varied by children's initial numeracy skills.

Table 4

Regression Model Predicting Posttest Core Mathematical Language

Variables	*b*	*SE*	*t*	*p*	95% CI
Intercept	**4.46*****	1.13	3.94	< .001	[2.19, 6.73]
Child age	-0.01	0.02	-0.48	.636	[-0.05, 0.03]
Female	-0.29	0.30	-0.96	.343	[-0.89, 0.32]
General vocabulary	**0.02**†	0.01	1.75	.086	[-0.00, 0.05]
Numeracy pretest	-0.02	0.04	-0.42	.673	[-0.10, 0.06]
Core mathematical language pretest	**0.48*****	0.11	4.32	< .001	[0.26, 0.70]
Math non-DR condition	**-1.75**†	0.90	-1.95	.056	[-3.55, 0.05]
Non-math DR condition	-1.42	1.08	-1.32	.193	[-3.59, 0.74]
Numeracy pretest × Math non-DR	**0.13***	0.05	2.48	.016	[0.02, 0.24]
Numeracy pretest × Non-math DR	0.09	0.06	1.40	.168	[-0.04, 0.21]

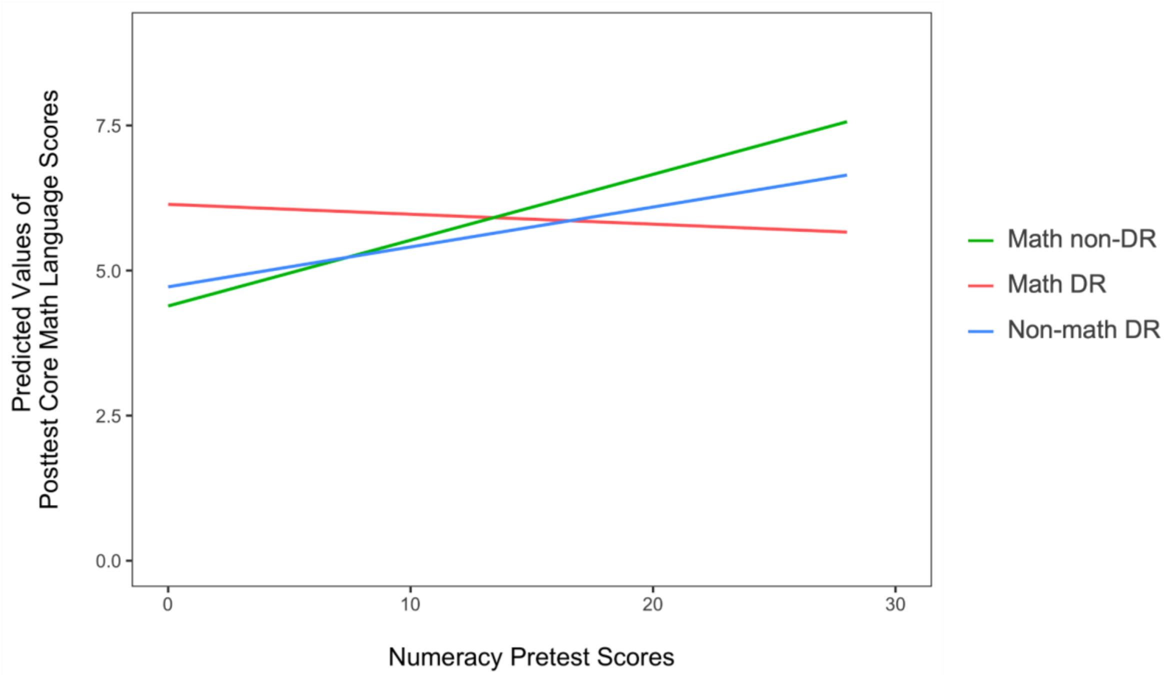
Note. N = 66; Numeracy pretest scores, mathematical language pretest scores, and general vocabulary pretest scores are centered at their minimum; CI = Confidence Interval; † *p* < .10. **p* < .05. ****p* < .001.

To understand the numeracy × Math non-DR interaction effect, simple effect analyses were conducted with children's pretest numeracy scores centered at their minimum and maximum, respectively (Figure 5). As Model 2 centered children's pretest numeracy at its minimum with Math DR condition as a reference group, the effect of the Math non-DR condition indicated the difference between the Math DR and Math non-DR conditions. In Model 2, the effect of Math non-DR was marginally significant (b = -1.75, p = .056) in predicting children's posttest core mathematical language scores, suggesting that posttest core mathematical language was higher in the Math DR condition compared to Math non-DR condition, with marginal significance. Thus, children with relatively lower levels of numeracy skills showed a tendency to learn better when they read the math storybook with dialogic reading questions than when they read the math storybook without dialogic reading questions, although the significance level was marginal (Figure 5).

Another regression model (not shown in Table 3), fitted with pretest numeracy centered at its maximum, revealed a significant effect of the Math non-DR condition (b = 1.90, p = .012) with Math DR condition as a reference group, indicating that that posttest core mathematical language scores were higher in the Math non-DR condition compared to Math DR condition. That is, children with relatively higher levels of numeracy understanding learned core mathematical language better when reading a math storybook without questions than when reading a math storybook with questions.

Figure 5

Children's Core Mathematical Language Post Performance as Function of Condition and Numeracy



Reading Interests. Children's reading interest per session was first calculated for each reading group and for the overall sample, as presented in Table 5. Overall, children reported they enjoyed the reading sessions a medium amount to a lot across sessions. We fitted two multiple regression models for each reading, one with total mathematical language and the other one with core mathematical language, to examine whether children's reading interests varied by reading condition for each reading session after controlling for children's age and sex, general vocabulary, (core) mathematical language pretest scores, and numeracy pretest scores. The results indicated that children's reading interests did not differ by reading condition for all reading sessions (*ps* > .170). Other regression models including interaction terms between reading condition and numeracy pretest scores were not significant for all reading sessions (*p*s > .217).

Table 5

Children's Reading Interest by Session and Reading Condition

Variable	Math DR			Math non-DR			Non-Math DR			All		
	n	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*	*N*	*M*	*SD*
First reading	25	2.76	0.60	22	2.86	0.47	17	2.82	0.39	64	2.81	0.50
Second reading	23	2.74	0.54	21	2.62	0.74	17	2.41	0.80	61	2.61	0.69
Third reading	24	2.46	0.72	19	2.53	0.77	17	2.41	0.87	60	2.47	0.77

Chapter 6: Discussion

With the advent of new technology, finding ways to utilize technology in educational settings has become an important agenda for teachers, parents, and educators. The current study was designed to examine how an AI-powered voice agent could support children's learning of mathematical language, which plays an important role in developing children's numeracy skills (Purpura, Napoli, et al., 2017; Purpura & Logan, 2015; Purpura & Reid, 2016). In the current study using a randomized pretest-posttest experimental design, children read either a math storybook with and without dialogic questions or a general storybook not incorporating any mathematical language three times. Children's mathematical language, numeracy skills, and general vocabulary skills were measured before and after reading sessions and reading comprehension was additionally measured after reading sessions. The results showed that the effect of dialogic reading of the math storybook with the AI voice agent on children's mathematical language learning varied by children's initial understanding of numeracy, a fundamental skill that is closely correlated to mathematical language development and literacy development. A detailed discussion of each finding is followed below.

Dialogic Reading Effect on Preschoolers' Mathematical Language Learning

Our second research aim was to examine whether dialogic math storybook reading with an AI voice agent better supports children's learning of mathematical language than non-dialogic math storybook reading. To answer this research question, children's performance on mathematical language tests after three book readings was compared between two reading conditions: math storybook reading with and without dialogic questions. We found that dialogic reading with an AI voice agent was helpful for children's learning of the mathematical language that the book intended to teach; however, the benefits were only valid when children initially had lower levels of numeracy skills.

For children who initially had a lower understanding of numeracy skills, hence in need of more support to grasp the target information, the dialogic reading framework including using prompts and expanding questions, evaluating children's responses, and repeating children's answers (Whitehurst, 1992; Whitehurst et al., 1988) were likely to benefit them. In our study, when children provided a correct answer, the AI voice agent confirmed their answer and repeated the correct answer as in "You are right. Lucy and Bear have fewer peanuts than Benjamin." In case children provided wrong answers or no answers, the AI voice agent repeated the questions once again while giving hints as in "Look at the plates and basket on the mat. Are there more things on the plates or in the basket?". This type of contingent feedback, along with the story and the illustration that was closely connected, would have helped children focus on the key information and process it, which replicated prior research reporting the effectiveness of the storybook intervention on improving children’s mathematical language learning (Hassinger-Das et al., 2015; Purpura, Napoli, et al., 2017; Wijns et al., 2023). In another previous study where the AI voice agent was used in preschoolers’ book reading (Xu & Warschauer, 2020), the use of follow-up prompts, one component of dialogic reading, helped young children produce more relevant responses compared to older children. Similarly in our study, the children with lower levels of numeracy skills who need more support to grasp the intended mathematical language were more likely than their peers with higher levels of numeracy skills to benefit from hearing additional prompts and relevant feedback. Importantly, this pattern was detected for the core mathematical language that was specifically targeted by the math storybook we used (Purpura et al., 2021), not for the overall mathematical language, suggesting that the condition effects were specific to the target words.

It should be noted, however, that the advantage of dialogic reading over non-dialogic reading for children with lower levels of numeracy skills was marginally significant. One potential explanation for this result is the sample size. Compared to other studies that found a benefit of dialogic reading for children within the same age range (Purpura et al., 2021; Xu et al., 2022), our sample size is relatively small. A larger sample size may demonstrate more robust benefits of dialogic reading over non-dialogic reading. Another potential explanation may be related to the study design. In our study, children who read the math storybook without dialogic reading questions also had the opportunity to interact with the AI voice agent as part of establishing rapport. All children, regardless of the reading conditions, engaged in brief conversations with the AI voice agent to share their personal favorites and interests. Additionally, the AI voice agent prompted the children to recall the names of the main characters or key objects in each session. This kind of interaction may have served as pedagogical cues, which may have caused a relatively small effect of dialogic reading on children's learning outcomes compared to non-dialogic reading. Through the contingent interaction with the AI voice agent at the outset of each reading session, children in the Math non-DR condition would have perceived the AI voice agent as a reliable reading partner and have received the message that they were the intended listener, which may have facilitated their subsequent engagement with the learning material (Csibra & Gergely, 2009).

We also found that children who initially had higher levels of numeracy skills benefited more from reading a math storybook without being asked dialogic reading questions or hearing feedback. Earlier research that found the benefits of dialogic reading of the AI agent focused on single reading with a goal to improve children's general comprehension and engagement with a novel story (Xu et al., 2 022), whereas the current study conducted three readings of the same book and aimed to teach domain-specific language for which children's prior knowledge played a critical role. The findings from this study may be interpreted in relation to the expertise reversal effect (Kalyuga, 2014). According to the information processing theory, children's prior knowledge makes it available for young learners to integrate new information more easily into their current knowledge system, and this in turn decreases demands on limited working memory resources (Miller, 2011; Shiffrin & Schneider, 1977). However, higher levels of prior knowledge make learners benefit less from the learning activities because processing unnecessary information that they already know could also cause extraneous cognitive load, which in turn decreases learning (Plass et al., 2010). It is likely that to children who had better numeracy skills in our study, answering many questions would be unnecessary for them, thus, would have benefited less from dialogic reading compared to their peers with lower levels of numeracy.

Together, our research findings highlight the importance of considering individual differences in educational settings using technology. In particular, children's numeracy played an important moderating role. We have also explored the moderating roles of children's other cognitive characteristics (i.e., mathematical language, general vocabulary) and found that only children's numeracy significantly moderated the impact of reading conditions on mathematical language learning. Early numeracy skills concern children's ability to work with exact quantities and numbers whereas mathematical language focuses more on understanding keywords and conceptual knowledge, which makes them two distinct constructs (Hornburg et al., 2018). In our study, children needed to link the story they heard from the AI voice agent with illustrations at appropriate moments. For example, when children hear, "Lucy took a few apples. Benjamin took fewer apples. Bear got the fewest.", they ideally should look at the different amounts of peanuts and follow each character's plate of peanuts to learn what "a few", "fewer", and "fewest" mean in the context of book reading while listening to the AI voice agent. This process of engaging in book reading requires multiple skills including comparing sets of objects and connecting quantities to words (e.g., a few, fewer, fewest), which largely consists of early numeracy skills.

Numeracy skills have been reported to have several distinct constructs. Some numeracy skills are related to general language only, some are related to mathematical language, and some are unrelated to both general language and mathematical language (Hornburg et al., 2018, 2024). Therefore, it is likely that prior knowledge of numeracy skills played a bigger role than prior knowledge of mathematical language in moderating the effect of reading conditions on subsequent mathematical language learning. One mathematical language intervention study (Purpura et al., 2021) found that children's storybook reading with their caregivers not only improved their mathematical language but also improved their numeracy skills. Furthermore, it was numeracy, not the mathematical language, on which the effect remained valid at the 8-week delayed posttest, suggesting that the math-specific storybook used in the current study, albeit aiming to improve mathematical language learning, deeply involves children's broader range of skills to understand numbers and numerical concepts.

On the other hand, in our study, children's general vocabulary skills marginally predicted their mathematical language learning beyond and above other variables including mathematical language and numeracy. In previous storybook intervention studies, general vocabulary has been observed to predict preschoolers' mathematical language learning after controlling for conditions (Wijns et al., 2023). However, in other instances, this same variable has been found not to predict mathematical language learning after accounting for conditions (Purpura et al., 2021). It has been also reported that oral vocabulary skills are more strongly associated with early numeracy skills than receptive vocabulary skills (Purpura et al., 2011). Mathematical language skills were more closely linked to preschoolers' early numeracy skills than general vocabulary (Hornburg et al., 2018; Purpura & Reid, 2016). In the current study, children's ability to comprehend AI voice agents' questions and verbally produce answers is needed to engage in dialogic storybook reading. The measure of receptive vocabulary skills, not oral or productive vocabulary skills, is used as a proxy of general vocabulary skills in our study, which is assumed to make the general vocabulary skills not a unique and strong predictor of children's mathematical language learning above and beyond the numeracy and mathematical language.

Math Storybook Intervention Effect on Preschoolers' Mathematical Language Learning

Our first research aim was to examine whether math storybook reading with an AI voice agent would support children's learning of mathematical language. To answer this research question, children's performance on the mathematical language measure was compared between two reading conditions (i.e., math storybook reading with dialogic questions condition and general storybook reading with dialogic questions). Inconsistent with our hypothesis, children who read a math storybook three times with an AI voice agent did not outperform their peers who read a general story not including mathematical words. This result contrasts earlier studies that found storybook reading intervention effects in teaching children mathematical language (Purpura, Napoli, et al., 2017; Purpura et al., 2021) and spatial language (Wijns et al., 2023). One potential reason for not finding significant intervention effects may be related to the different logistics of storybook intervention. Earlier studies used at least two different storybooks for the intervention groups and the total reading sessions ranged from ten to 24 sessions (Hassinger-Das et al., 2015; Purpura, Napoli, et al., 2017, Purpura et al., 2021; Wijns et al., 2023).

Our study only used one storybook and had three reading sessions within a relatively short period, which may have caused immediate posttest differences not being significant between these two groups. In fact, in Hassinger-Das et al.'s (2015) study, children's performance on the intervention words posttests did not differ between the intervention group and control groups, however, it did differ on the delayed posttest in favor of the intervention group. In our study, we only measured the immediate intervention effect, so it may show up over time. Using multiple storybooks over a long period may support children's better learning.

Implications for AI Voice Agents as Children's New Reading Partners

The current study provides important discussion points that will be beneficial for the future use of AI voice agents in educational settings. Critically, the findings from our study highlight the importance of considering individual differences in educational settings using technology, evidenced by the significant moderating effect of children's initial understanding of numeracy on the impact of dialogic reading of the math storybook with the AI voice agent on children's mathematical language learning of target (core) words. Overall, children in our sample appeared to enjoy reading the storybook with the AI voice agent we developed. They were able to respond to the AI voice agent's questions in a reasonable amount of time and understood its feedback in our study. Unlike a human reading partner, the disembodied AI voice agent could not provide additional cues such as facial expression and gestures, which are important components in supporting young children's learning (Barnes et al., 2023; Csibra & Gergely, 2009; Kuhl, 2007). Despite these limitations, contingent interaction with the AI voice agent including pedagogical prompts and verbal communicative cues (e.g., calling children's names, child-directed speech), which is considered critical in sociocultural theory (Vygotsky, 1978), played an important role in children's book reading involving domain-specific mathematical language. However, the findings from our study emphasized a nuanced approach to integrating such technologies for children's learning of mathematical language that can benefit from repeated exposures and relies on children's prior knowledge. These results extend the earlier studies that introduced the AI voice agent to children or used it to support children's learning of novel information for limited exposure (Xu, Aubele, et al., 2022; Xu, Vigil, et al., 2022; Xu & Warschauer, 2020; Zhang et al., 2022). The significant moderating role of children's prior numeracy skills also underscores the need to understand children's specific cognitive characteristics, which can be further utilized to tailor the difficulty of questions or the number of questions being asked to children depending on their prior knowledge.

In order to make the best use of the advanced technology, several aspects to be considered for future studies have been observed during the data collection. First, different strategies may be needed when introducing the AI voice agent to children depending on children's individual differences such as age and cognitive characteristics. Overall, the older children understood that they needed to wait for a small beep to signal their turns so that the AI voice agent could hear what they were saying, however, some young children seemed to lack this understanding. They would answer the question immediately, causing the AI voice assistant to miss the answers and ask the question again with prompts. Different ways of signaling when it is the child's turn to answer (e.g., use of light, automatic recording) can be introduced to make the interaction easier and more engaging for young children. On the other hand, we also observed that young children tended to ask personalized questions, perceiving the AI voice agent as friendlike (e.g., why Toma's name is Toma?, how did you know its name is Toma?, Toma, what's your favorite color?), whereas older children asked questions more relevant to features and appearance (e.g., how come Toma has multiple voices?, are you controlling Toma from your laptop?, I want to see what Toma's back look like). Given that previous studies have reported that children's interactions with voice assistants differ based on their age and familiarity with the AI technology (Oranç & Ruggeri, 2021) or based on their parasocial relationship with the agent (Gampe et al., 2023), a properly designed dialogic system that takes developmental stages into account is needed.

Another point of interest concerns the capability of AI voice agents. AI-powered technology has made significant progress in recent years, drawing attention from researchers and early development professionals across disciplines. However, it was discussed that it still exhibits limitations in capturing children's voices and human voices speaking English as a second language (Garg et al., 2022; Song et al., 2022). Our study also revealed that the system was unable to accurately capture or recognize the vocalizations of children in some instances. However, the addition of training phrases based on pronunciation similarities (e.g., "bear" vs. "pair") resolved some instances, although it did not cover all possible cases. This technical error resulted in the AI voice agent asking the questions once again or providing general feedback. To enhance the engagement of children with the AI voice agent, it is necessary to improve the accuracy of the AI voice agent's capability to capture children's vocalizations as intended, while incorporating additional hint phrases.

Limitations and Future Directions

This study has several limitations to be addressed. Firstly, this study solely focused on the quantitative aspect of mathematical language, with no consideration of spatial language. In consideration of other intervention studies that have employed both quantitative and spatial mathematical language learning approaches (Purpura et al., 2021) or solely spatial language learning approaches (Wijns et al., 2023), future research could examine whether the effectiveness of dialogic reading in conjunction with the AI voice agent technology in fostering spatial language learning still exhibits variation based on the initial levels of numeracy skills or other individual characteristics. Future studies could also employ the use of multiple storybooks, as utilized in previous studies (Purpura et al., 2021; Hassinger-Das et al. 2015), in order to comprehensively encompass a wide range of mathematical language. This new direction will facilitate a deeper understanding of the role of advanced technology in teaching domain-specific language to young children.

Secondly, our designed study did not exhaustively examine the relative benefits of different types of questions in promoting children's improvement in mathematical language learning. The dialogic reading questions that were used in the current study encompass a range of difficulty levels. Some questions are more proximal to the target words (e.g., who has more peanuts?), and some questions are more focused on making connections between the story and the children's real lives (e.g., what would you bring on your picnic?). Additionally, it was observed that some children perceived the reading sessions to be a little lengthy, or attention levels decreased toward the end of sessions, particularly among 3-year-old children. Reducing the number of questions per reading and making the reading sessions slightly shorter may prove to be more effective. Furthermore, it also remains unclear whether the effect of dialogic reading was primarily due to the use of questions, contingent feedback, or a combination of both. Future studies could investigate the components of dialogic book reading in order to identify the most effective approaches.

Thirdly, the current study primarily focused on children's performance on learning outcomes, rather than on their engagement during the book reading. Previous studies have indicated that children's book reading with an AI voice agent differs from reading with a human partner in terms of intelligibility, productivity, diversity of language, and relatedness to the topics (Xu et al., 2021). Additionally, it was reported that how children's vocalizations were relevant to the storybook narration played a mediating role between reading condition and story comprehension when reading a storybook with an AI voice agent (Xu et al., 2022). Consequently, an analysis of children's engagement during a book reading in terms of vocal responses, their relatedness to the questions, and visual attention may provide detailed explanations as to why no differences in children's performance were observed on the mathematical language learning outcome between the Math-DR group and the Non-math DR group.

Finally, our sample size is slightly smaller than other studies that used a similar experimental design (Purpura et al., 2021, Xu et al., 2022), which may have resulted in underpower to detect the benefits of dialogic reading over non-dialogic reading in improving children's mathematical language learning. In addition, while our sample is representative of children's experience with AI voice agents, the majority of children had highly educated parents. Including a more heterogeneous sample will increase the validity and generalizability of our findings.

Conclusion

In the current study, we designed and conducted storybook reading activities to teach mathematical language to young children aged 3 to 5 using an AI-powered voice agent. The research findings, which focus on the effect of math storybook reading and dialogic questions, indicate that shared math storybook reading supports children's target mathematical language learning differently based on their initial understanding of numeracy, a critical component in early math development. Children with higher levels of numeracy skills demonstrated greater benefits from simply listening to the story, whereas children with lower levels of numeracy skills showed a tendency to learn better when hearing questions and feedback from the AI voice agent. This study provides implications for considering individual differences in key cognitive skills in the use of advanced technology involving social interaction to support children's learning of mathematical language that can be supported by repeated reading.

The findings provide important and practical implications for families, educators, and developers on how to utilize advanced technology in educational settings while drawing attention to the use of educational questions in domain-specific language learning.

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Appendix A

Parent Permission Form

Title of research study: 22-357 AI Storybook Reading
Principal Investigator: Koeun Choi, Human Development and Family Science, (540) 231-5720, koeun@vt.edu
Other study contact(s): Jisun Kim, Human Development and Family Science, jisunk@vt.edu
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Shannon Mury, Child Development Center for Learning and Research, smarsha@vt.edu

Key Information: The following is a short summary of this study to help you decide whether or not to provide permission for your child be a part of this study. More detailed information is listed later on in this form.

Why is my child being invited to take part in a research study? We invite your child to take part in a Virginia Tech research study because your child enrolled in a preschool or child care center that has given permission to use their site for this project. This study includes **children** between ages of 3-5 years who speak English and have not yet started kindergarten.

What should I know about my child being in a research study?

- Someone will explain this research study to you and your child.
- Whether or not you provide permission is up to you.
- You can choose not to provide permission.
- You can provide permission and later change your mind.
- Your decision will not be held against your child.
- You can ask all the questions you want before you decide.

What should I know about this research study?

- We are interested in understanding how children learn from shared book reading with an Artificial Intelligent (AI) reading partner.
- We expect that your child's participation in this research study will take approximately 100 minutes in total. There will be 5 sessions, which take 20 min each.
- During the first and last sessions, your child will meet with researchers to play word and math games and answer questions. For the three sessions in between, your child will read a storybook with an AI reading partner and answer questions while wearing a wristband. All of children's sessions will be conducted on-site at their school at a time and place coordinated with the school. More detailed information about the study procedures can be found under "What happens if I say yes, I want my child to be in this research?"
- There is only minimal risk associated with this research project. It is not more than what is experienced in a typical preschool/childcare center classroom. More detailed information about the risks of this study can be found under "Is there any way being in this study could be bad for my child? (Detailed Risks)".

- There are no benefits to your child from their taking part in this research. We cannot promise any benefits to others from their taking part in this research. However, possible benefits to others include gaining a better understanding of the effective design and use of AI voice assistant technology to promote early learning.
- Providing your permission for your child to take part in research is completely up to you and your child. You can decide to provide permission or not provide permission to participate. The decision whether to participate or not in this research will have no effect on your child's relationship with your child's school or Virginia Tech.

Detailed Information: The following is detailed information about this study in addition to the information above.

Who can I talk to? If you have questions, concerns, or complaints, or think the research has hurt your child, talk to the research team at koeun@vt.edu or jisunk@vt.edu.

This research has been reviewed and approved by the Virginia Tech Institutional Review Board (IRB). You may communicate with them at 540-231-3732 or irb@vt.edu if:

- You have questions about your child's rights as a research subject
- Your questions, concerns, or complaints are not being answered by the research team
- You cannot reach the research team
- You want to talk to someone besides the research team to provide feedback about this research

How many people will be studied? We plan to include about 140 children in this research study.

What happens if I say yes, I want my child to be in this research? The entire procedure of this study will take approximately 100 minutes for your child. This study consists of 5 sessions (20 min each; total 100 min). If you provide your permission for your child to join this study, your child will be asked to do the following.

- ***Child sessions (5 sessions, 20 min each)***: During the first and last sessions, your child will meet with researchers to play math and word games and answer questions. For the three sessions in between, your child will read a storybook with an AI reading partner and answer questions. While reading the storybook, you child will wear a wristband to measure their physiological engagement in reading.
- ***Audio/video recording of the child sessions***: We will video and audio record all sessions. Recordings will be used for research purposes. Digital copies will be kept in the lab. Identifiable videos will be viewed for purposes of data analysis and training. Only authorized research personnel may view these recordings. Identifiable recordings will not be shown, either publicly or as part of the presentation of data, unless you give your permission on the form below. The results will be reported as group response patterns. Your child's responses do not make them identifiable. The data we collect are confidential, and we do not disclose results from any individual participant to parents, subjects, or the university.

What happens if I say yes, but I change my mind later? You can withdraw your permission for your child's participation in this research at any time, for any reason, and it will not be held against you. If you decide you no longer want your child to participate in this research, contact the investigator so that the investigator can cancel scheduled sessions. Your child can leave this research at any time for any reason. If your child decides to stop, he/she can tell the researcher and the researcher will end the task immediately. If you wish to withdraw your child, you will be asked for permission to use data collected up to the point of withdrawal. Data collected to the point of withdrawal will be used for the study, it is requested to be destroyed by you or your child.

Is there any way being in this study could be bad for my child? (Detailed Risks). There are no known risks to participating in this study. There is only minimal risk associated with this research project. It is not more than what is experienced in a typical preschool/childcare center classroom.

Can my child be removed from the research without my OK? Your child will not be removed from the research study without your approval.

What happens to the information collected for the research? We will make every effort to limit the use and disclosure of your child's personal information, including research study and medical records, only to people who have a need to review this information. We cannot promise complete confidentiality. Organizations that may inspect and copy your child's information include the IRB, Human Research Protection Program, and other authorized representatives of Virginia Tech. Any suspicions of child abuse, neglect, or other concerning circumstances will be reported by researchers to the PI, Dr. Koeun Choi, who will report to the appropriate channels. Specifically, Dr. Choi, after informing the parent, will be obligated to contact the Department of Social Services, in compliance with the mandatory reporting laws of the state of Virginia. If identifiers are removed from your private information or samples that are collected during this research, that information or those samples could be used for future research studies or distributed to another investigator for future research studies without your additional informed consent. The results of this research study may be presented in summary form at conferences, in presentations, reports to the sponsor, academic papers, and as part of a thesis/dissertation.

What else do I need to know? This project is being funded by the Institute of Creativity, Arts, and Technology and the College of Liberal Arts and Human Sciences at Virginia Tech. If you want your child to take part in this research study, your child will receive small prizes (i.e., stickers) after each session and a certificate of completion at the end upon approval of your child's school. The stickers will be placed on child's certificate at the end of each session. For the first four sessions, the certificate will be retrieved by the researcher to minimize disruptions in your child's classroom. Upon completion of the final session, the certificate will be handed to directors or staff so that the child can pick it up during pick-up time. Your child's classroom will be compensated with storybooks. We will not offer to share your child's individual task results with you.

Signature Block for Capable Adult

Your signature documents your permission for your child to take part in this research. We will provide you with a signed copy of this form for your records.

Printed Name of Child

Printed Name of Parent (Legal Guardian/Legally Authorized Representative)	**Email Address of Parent** (Only for sending study updates)
Signature of Parent	**Today's Date**
Printed Name of Person Obtaining Permission	
Signature of Person Obtaining Permission	Today's Date

Optional: Check the items below if you agree to allow the current research team to use identifiable recordings of participation for the following purposes during the study period and beyond study completion.

☐ Presentations of data to academic audiences
☐ Publications

Optional: If you agree to allow the researchers included in this protocol to use identifiable recordings of participation for future non-research purposes, please sign the attached form titled Media and Interview Release.

Appendix B

Parent Consent Form

Title of research study: 22-357 AI Storybook Reading
Principal Investigator: Koeun Choi, Human Development and Family Science, (540) 231-5720, koeun@vt.edu
Other study contact(s): Jisun Kim, Human Development and Family Science, jisunk@vt.edu
Caroline Hornburg, Human Development and Family Science, (540) 231-2664, chornburg@vt.edu
Myounghoon Jeon, Industrial and Systems Engineering, (540) 231-3510, myounghoonjeon@vt.edu
Shannon Mury, Child Development Center for Learning and Research, smarsha@vt.edu

Key Information: The following is a short summary of this study to help you decide whether or not to be a part of this study. More detailed information is listed later on in this form.

Why am I being invited to take part in a research study? We invite you to take part in a Virginia Tech research study because your child is enrolled in a preschool or child care center that has given permission to use their site for this project. This study includes parents of children between ages of 3-5 years who speak English and have not yet started kindergarten.

What should I know about being in a research study?

- Someone will explain this research study to you.
- Whether or not you take part is up to you.
- You can choose not to take part.
- You can agree to take part and later change your mind.
- Your decision will not be held against you.
- You can ask all the questions you want before you decide.

What should I know about this research study?

- We are interested in understanding whether family factors influence how children learn from shared book reading with an Artificial Intelligent (AI) reading partner.
- We expect that your participation in this research study will take approximately 10 minutes in total.
- You will receive an email including a link to an online survey about your child's background and media use. Reminder emails will be sent to you up to two times in case you forget to complete the survey. A hard copy of the parent survey will be provided if needed. More detailed information about the study procedures can be found under "What happens if I say yes, I want to be in this research?"
- There are no known risks to participating in this study. More detailed information about the risks of this study can be found under "Is there any way being in this study could be bad for me? (Detailed Risks)"
- There are no benefits to you from your taking part in this research. We cannot promise any benefits to others from your taking part in this research. Possible benefits to others include

gaining a better understanding of the effective design and use of AI voice assistant technology to promote early learning.

- Taking part in research is completely up to you. You can decide to participate or not to participate. The decision whether to participate or not participate in this research will have no effect on your relationship with your child's school or Virginia Tech.

Detailed Information: The following is more detailed information about this study in addition to the information listed above.

Who can I talk to? If you have questions, concerns, or complaints, or think the research has hurt you, talk to the research team at koeun@vt.edu or jisunk@vt.edu.

This research has been reviewed and approved by the Virginia Tech Institutional Review Board (IRB). You may communicate with them at 540-231-3732 or irb@vt.edu if:

- You have questions about your rights as a research subject
- Your questions, concerns, or complaints are not being answered by the research team
- You cannot reach the research team
- You want to talk to someone besides the research team to provide feedback about this research

How many people will be studied? We plan to include about 140 parents in this research study.

What happens if I say yes, I want to be in this research? The entire procedure of this study will take approximately 10 minutes. If you agree to join this study, you will be asked to do the following:

- ***Parent survey (10 min)***: You will receive an email including a link to an online survey about your child's background and media use. Reminder emails will be sent to you up to two times in case you forget to complete the survey. A hard copy of the parent survey will be provided if needed.

What happens if I say yes, but I change my mind later? You can leave the research study at any time, for any reason, and it will not be held against you. You may stop participating at any time by closing the browser window or the program to withdraw from the study. Partial data will not be analyzed.

Is there any way being in this study could be bad for me? (Detailed Risks). There are no known risks to participating in this study.

Can I be removed from the research without my OK? You will not be removed from this study without your approval.

What happens to the information collected for the research? All of your responses will be kept strictly confidential. All materials will be stored on a password-protected computer in a locked office and by removing all identifiable information from the data. Any reports and presentations about the findings from this study will not include your name or any other information that could identify you. We may share the data we collect in this study with other researchers doing future studies. If we share data, we will not include information that could identify you. If identifiers are removed from your private information or samples that are collected during this research, that information or those samples could be used for future research studies or distributed to another investigator for future research studies without your additional informed consent.

What else do I need to know? This project is being funded by the Institute of Creativity, Arts, and Technology and the College of Liberal Arts and Human Sciences at Virginia Tech. There will be no compensation for participating in this study.

Signature Block for Capable Adult

Your signature documents your consent to take part in this research. We will provide you with a signed copy of this form for your records.

Printed Name of Parent (Legal Guardian/Legally Authorized Representative)	**Email Address of Parent** (Only for sending survey)
Signature of Parent	**Today's Date**
Printed Name of Person Obtaining Permission	
Signature of Person Obtaining Permission	Today's Date

Appendix C

Child Assent Form

Title of research study: 22-357 AI Storybook Reading
Principal Investigator: Koeun Choi, Human Development and Family Science, (540) 231-5720, koeun@vt.edu
Other study contact(s): Jisun Kim, Human Development and Family Science, jisunk@vt.edu
Caroline Hornburg, Human Development and Family Science, (540) 231-2664, chornburg@vt.edu
Myounghoon Jeon, Industrial and Systems Engineering, (540) 231-3510, myounghoonjeon@vt.edu
Shannon Mury, Child Development Center for Learning and Research, smarsha@vt.edu

Child Assent Form

What Is A Research Study? Hello, my name is (insert your name here). I work at Virginia Tech, and I want to tell you about a research study we are doing. A research study is a way to learn new things.

Why Are We Doing This Research? For this research study, we would like to learn more about how children learn.

Why Am I Being Asked to Join This Research? You are being asked to take part in this research study because you are between 3 and 5 years old and your parent has said it is okay.

What Would Happen If I Join This Research? You will be asked to meet with us five times. While we are meeting, you will be reading a storybook on some days and play some math and word games on other days.

Could Bad Things Happen If I Join This Research? You may get tired answering questions or may not want to read the storybook or play games. If you want to stop, you can tell me anytime by saying, "I would like to stop", okay?

What If I Have Questions About The Research? You can ask me questions at any time about anything in this study. You can also ask your parent any questions you might have about this study.

What If I Don't Want to Join This Research? You do not have to join this research study. It is up to you. You can change your mind or stop at any time. No one will be upset if you do not say yes or if you change your mind later.

If you say "yes", we will start activities that I prepared. Would you like to help me with this project?

Yes No

If the child says yes or nods his or her head: Great, Thank you.

If the child says no or shakes his or her head: That's okay.

Signature Block for Researcher Obtaining Assent

I witnessed the following child nod his or her head or otherwise signal positive intention, non-verbally, a sign I understood to signify agreement to participate in the AI Storybook Reading project; and/or I witnessed the child verbally agree to participate in the AI storybook Reading project.

____

Printed Name of Participant

____ ________________________

Signature of Person Obtaining Assent Today's Date

____

Printed Name of Person Obtaining Assent

Appendix D

Child Date of Birth Form

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

Child Date of Birth Form

Title of research study: AI Storybook Reading (IRB Protocol #22-357)
Principal Investigator: Koeun Choi, Human Development and Family Science,
(540) 231-5720, koeun@vt.edu
Other study contact(s): Jisun Kim, Human Development and Family Science, jisunk@vt.edu
Caroline Hornburg, Human Development and Family Science, (540) 231-2664, chornburg@vt.edu
Myounghoon Jeon, Industrial and Systems Engineering, (540) 231-3510, myounghoonjeon@vt.edu
Shannon Mury, Child Development Center for Learning and Research, smarsha@vt.edu

Child Date of Birth Form

Dear Parent/Guardian,

Please fill in the information below if you would like to provide permission for your child to participate in this research.

Child Date of Birth: ___________/___________/________________
MM DD YYYY

PLEASE DO NOT FILL OUT BELOW THIS LINE (FOR RESEARCHER USE ONLY)

Child ID:

Appendix E: Recruitment Materials

Recruitment Fliers

Virginia Tech
AI Storybook Reading Study
(Home Visit)

How do children read with conversational AI agents?

Who: Children ages **3 to 5 years** who speak English, have not yet started kindergarten, and live in New River Valley and surrounding areas of Virginia, USA, and their parents.

What: 5 home-visit sessions (20 min each)

- During two sessions, children will play math and word games.
- During three sessions, they will **read a storybook** with AI smart speaker.
- Parents will also complete a 10-minute online survey about their child's background and media use.

How: Scan the QR code to learn more about our study and fill out the **interest form**:

- Participants will be compensated with a $25 USD Amazon gift card.
- This is a Virginia Tech research study (IRB # 22-357).
- If you have any questions, please email us at jisunk@vt.edu

VIRGINIA TECH

CoDeS Lab
Cognitive Developmental Science Lab

INSTITUTE FOR CREATIVITY, ARTS, AND TECHNOLOGY
VIRGINIA TECH

Virginia Tech
AI Storybook Reading Study (School)

How do children read with conversational AI agents?

Who: Children ages **3 to 5 years** who speak English and have not yet started kindergarten and their parents.

What: 5 sessions at your child's school (20 min each)

- During two sessions, children will play math and word games.
- During three sessions, they will **read a storybook** with AI smart speaker.
- Parents will also complete a 10-minute online survey about their child's background and media use.

How: Scan the QR code to learn more about our study and fill out the **permission and consent forms**:

- This is a Virginia Tech research study (IRB # 22-357).
- If you have any questions, please email us at jisunk@vt.edu

VIRGINIA TECH

CoDeS Lab Cognitive Developmental Science Lab

INSTITUTE FOR CREATIVITY, ARTS, AND TECHNOLOGY VIRGINIA TECH

Director Recruitment Letter

Dear Director,

We are a research group at Virginia Tech that studies how to use technology to support children's learning. In our new Virginia Tech research study (IRB# 22-357) entitled, "AI Storybook Reading," we are studying children's learning from shared book reading with an Artificial Intelligence (AI) reading partner to better understand how to design and use AI voice assistant technology to promote early learning. We are contacting you now because we are currently looking for preschool partners to help us conduct this research. Your students' participation in this project would be invaluable in helping us to explore this question.

For this project, we are working with children between 3 and 5 years of age who have not yet started kindergarten. If you agree to participate, we will deliver recruitment packets for eligible families. These packets contain a parent letter, a brochure, a parent permission form, child date of birth form, and parent consent form. Parents who are interested in participating will sign the three forms (parent permission form, child date of birth form, parent consent form). They will return these materials to an envelope at your school. After a week or two, we will pick up any forms that were returned. We will then work with your staff to schedule blocks of time that are most convenient for your school.

This study consists of a total of 5 sessions for each child (2 test sessions and 3 reading sessions), and each session will last 20 minutes. Research assistants will meet with children in quiet places within your school during normal school hours to read a book and play word and math games. During reading, children will wear a wristband to detect children's physiological engagement. We video and audio record children's responses. Identifiable recordings such as your child's faces will not be shown, either publicly or as part of the presentation of data, unless parents give their permission on the form. Parents will be asked to complete a 10-minute online survey.

There are no discomforts or risks involved in this study, and children usually find our projects interesting and fun. All laboratory personnel undergo state background checks and training for conducting this project in a preschool setting. When this project is complete, we will send you a letter that summarizes our findings. We will also provide copies of this letter for each of the participating families. We would be happy to discuss with you the findings of this study as well as other studies of children's development and media use if you are interested. We would also be delighted to deliver a workshop for your staff or families regarding this topic.

Our study depends on the help and involvement of our community preschools, and we will be grateful if you are able to work with us. If you would like to be involved or have questions about the project, please contact me via email at koeun@vt.edu or phone at (540) 231-5720. If you choose to work with us, we will need a brief letter of support stating that you will allow us to conduct this project in your school (please see attached template). We will then work with you to contact parents in whatever way is most convenient for you and your families.

Thank you very much for your consideration of our project. We hope that you will be interested in helping us with this important research!

Sincerely,

Koeun Choi, Assistant Professor, Human Development and Family Science

On behalf of myself and my collaborators:
Caroline Hornburg, Assistant Professor, Human Development and Family Science
Myounghoon Jeon, Associate Professor, Industrial and Systems Engineering
Shannon Mury, Teacher, Child Development Center for Learning and Research

Brochure

Did you know..?

- Nearly all (98%) of U.S. families with children from birth to age 8 years have an interactive mobile device such as an iPad or smartphone.
- In 2017, only 9% of families with young children (0-8 years) owned a smart speaker or virtual assistant such as Amazon's Alexa or Apple's Siri. By 2020, that number has risen to 41%. Researchers do not know how much that has increased since 2020.
- Preschool-age children spend an average of 2.5 hours per day using screen media.
- Children use media in many different ways, such as watching television, playing with mobile apps, reading books, and chatting with family members.
- How children use technology matters as much (or perhaps more) than how much they use technology.
- Researchers know little about the impact of emerging technologies on early learning and long-term developmetal outcomes.
- At the Cognitive Developmental Science (CoDeS) Lab at Virginia Tech, we are beginning to answer these questions.

To learn more about how to choose and use media with your kids, visit:

1. Common Sense Media
https://www.commonsensemedia.org
2. Zero to Three
http://www.zerotothree.org
3. TEC Center
http://teccenter.erikson.edu
4. Joan Ganz Cooney Center
http://joanganzcooneycenter.org

VIRGINIA TECH

AI STORYBOOK READING
IRB# 22-357

AI STORYBOOK READING

Understanding the Impact of New Technology on Early Development

VIRGINIA TECH

Children's Learning & Media Technologies

Young children learn from the world around them. This learning can take place through a variety of activities, including talking, reading, and playing games.

Children are spending time with technology and learning from it more than ever before. Parents increasingly use technology to teach new words and read books to their children. Researchers like us are interested in whether and how children learn from various types of media technologies.

We are conducting a new study in order to investigate these questions. Your child's participation in this project will be invaluable in helping us to understand the impact of interactive technology on young children.

Thank you very much for your consideration of our project. We hope that you will be interested in participating in this important research!

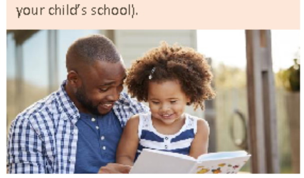
Our Study

What is this project about?
We are studying how children learn from shared book reading with an AI voice assistant reading partner.

What is involved?
Parents will complete one survey (10 min) about their child's background and experience with media. Children will interact with our team to read a storybook with a smart speaker and play word and math games for 5 sessions (20 min each), which will be scheduled within 2-4 weeks.

Who is eligible?
This project is for any children between the ages of 3 and 5 years who speak English and have not yet started kindergarten. Children usually have fun playing our games, and they receive a small gift for participating in our study upon approval of child's school.

Where will the study take place?
Researchers will meet with your child at the preschool or child care center during regular school hours. Parents will complete one survey online (or on paper and return it to your child's school).



To sign up:

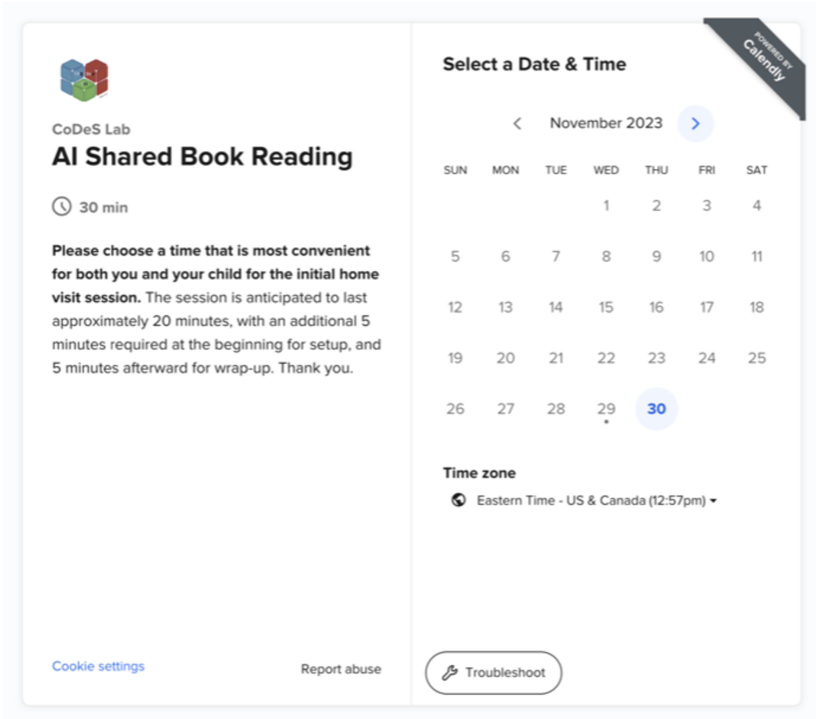
1. **Child Participation (On-Site Sessions at Your Child's School): Sign** the enclosed **parent permission form**, fill in the **child date of birth form**, and **return** them to your child's school.
2. **Parent Participation (Survey): Sign** the enclosed **parent consent form** and **return** them to your child's school. Then, **we will contact you over email** to ask you to complete the parent survey online.

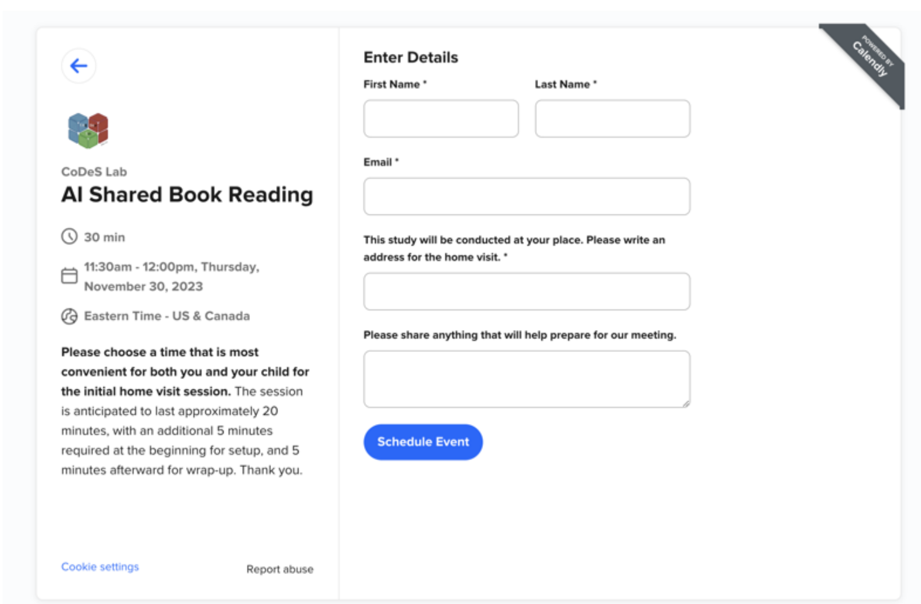
To get more information:

1. **Contact** Prof. Koeun Choi by:
   - Calling (540) 231-5720
   - Emailing koeun@vt.edu
2. **Visit** the Cognitive Developmental Science Lab (CoDeS) website: http://kchoi.org

CoDeS Lab Cognitive Developmental Science Lab

Scheduling Form





Appendix F

Parent Survey

Confidential

Demographics

Virginia Tech AI Storybook Reading Project (#22-357) - Parent Survey

Dear Parent(s)/Guardian(s):

Thank you for completing this questionnaire as part of a Virginia Tech research study (IRB #22-357) on storybook reading with an AI voice assistant. Please answer these questions to the best of your ability. Whenever a question asks about "your child," it is referring to the child who participated in this project.

To begin the questionnaire, please enter your participant code in the space above. Participant codes are used to ensure the confidentiality of your responses. You can find your code in the message that we sent you with the link to this questionnaire.

For additional questions about this research, please contact Koeun Choi at koeun@vt.edu or 540-231-5720.

Sincerely,

Koeun Choi, Assistant Professor
Human Development & Family Science, Virginia Tech
The CoDeS Team

Please enter your participant code.

What is your age (in years)? ______________________

What is your gender?
- ◯ Man
- ◯ Woman
- ◯ Transman
- ◯ Transwoman
- ◯ Gender expansive / gender nonconforming
- ◯ Prefer to self-describe
- ◯ Prefer not to say

Please describe: ______________________

What is your relation to your child who is participating in this research study?
- ◯ Child's mother or mother figure
- ◯ Child's father or father figure
- ◯ Other

Please describe: ______________________

Are you of Hispanic, Latino, or Spanish origin?

◯ Hispanic or Latino ◯ Not Hispanic or Latino ◯ Don't know ◯ Prefer not to answer

How would you describe your race? Please select all that apply.	☐ American Indian/Alaska Native ☐ Asian or Pacific Islander ☐ Black or African American ☐ White ☐ Other (Please Specify) ☐ Don't know ☐ Prefer not to answer
Please specify:	__________________________________
What is the highest level of education that you completed?	◯ No formal school ◯ Elementary/primary school ◯ Middle school ◯ High School or Equivalent (e.g., GED) ◯ Some College or Vocational Degree (e.g., AA) ◯ Bachelor's Degree (e.g., BA/BS) ◯ Master's Degree (e.g., MA, MFA) ◯ Doctoral or Professional Degree (e.g., MD, JD, EdD, DDS, PhD, VMD)
Are you currently employed?	◯ No job ◯ Part-time job ◯ Full-time job ◯ Maternity / parental leave ◯ Other
Please describe:	
In which of these ranges does your family's yearly income before taxes for last year?	◯ Less than $10,000 ◯ $10,000 to $19,999 ◯ $20,000 to $29,999 ◯ $30,000 to $39,999 ◯ $40,000 to $49,999 ◯ $50,000 to $59,999 ◯ $60,000 to $69,999 ◯ $70,000 to $79,999 ◯ $80,000 to $89,000 ◯ $90,000 to $99,000 ◯ $100,000 to $149,000 ◯ More than $150,000 ◯ Don't know ◯ Prefer not to answer
Please specify:	__________________________________
Do you receive public assistance (WIC, SNAP, etc.), or have you received public assistance in the last year?	◯ I receive public assistance currently. ◯ I have received public assistance in the last year, but I do not currently receive public assistance. ◯ I have received public assistance in the past (more than one year ago), but I have not received public assistance within the last year. ◯ I have never received public assistance.

Child Demographic

The following set of questions asks about your child that participated in this study.

In what month and year was your child born?

Month	◯ January ◯ February ◯ March ◯ April ◯ May ◯ June ◯ July ◯ August ◯ September ◯ October ◯ November ◯ December
Year	◯ 2022 ◯ 2021 ◯ 2020 ◯ 2019 ◯ 2018 ◯ 2017 ◯ 2016 ◯ 2015
What is your child's sex assigned at birth?	◯ Male ◯ Female ◯ Prefer not to answer ◯ Neutral / Other
Self describe:	
Is your child of Hispanic, Latino, or Spanish origin?	◯ Hispanic or Latino ◯ Not Hispanic or Latino ◯ Don't know ◯ Prefer not to answer
How would you describe your child's race? Please select all that apply.	☐ American Indian/Alaska Native ☐ Asian or Pacific Islander ☐ Black or African American ☐ White ☐ Other (Please Specify) ☐ Don't know ☐ Prefer not to answer
Please specify:	______________________________
Is a language other than English spoken to your child in your home?	◯ No ◯ Yes, some of the time ◯ Yes, most of the time

Which languages and what proportion of time does your child typically hear these languages in the home?

For instance, if a child hears English about half of the time and Spanish about half of the time, you can write "English 50%, Spanish 50%"

Language Proportion of time (%)
Language 1 (Primary)

_____ _____
Language 2 _____ _____
Language 3 _____ _____
Above 4, use this format: "English 50%, Spanish 50%, etc" _____ _____

Are there any other adults or children living in your home, besides you and your child?	◯ No, my child and I are the only people living in my home. ◯ Yes, there are other people living in my home.

How many adults (age 18 years or older) and children (age under 18 years) reside in your household, including you and the target child?

Please indicate the number of adult(s) or child(ren) living in your household for each item.

You (the person completing this survey) 1
Number of adults other than you ______
The target child participating in this study 1
Other children older than the target child ______
Other children the same age as the target child ______
Other children younger than the target child ______

What are the ages (in years) of all of your children currently residing in your home, including the child(ren) participating in this project? (Use this format: "Child 1:___, Child 2:____, etc")

Age (in years)
Child 1 (Participating in this study) ______
Child 2 ______
Child 3 ______
Child 4 ______
Child 5
Above 6, use this format:

"Child 6: , Child 7: , etc"

______

How would you describe your current parenting situation?	◯ Raising my child with a spouse or live-in partner ◯ Raising my child with with someone who lives in a different household ◯ Raising my child on my own

The following questions are about another adult (parent/guardian 2) in your home that cares for your child participating in this study.

What is the Parent/Guardian 2's gender?	◯ Man ◯ Woman ◯ Transman ◯ Transwoman ◯ Gender expansive / gender nonconforming ◯ Prefer to self-describe ◯ Prefer not to say
Please describe:	__________________________________
What is Parent/Guardian 2's relation to your child who is participating in this research study?	◯ Child's mother or mother figure ◯ Child's father or father figure ◯ Other
Please describe:	__________________________________

Is Parent/Guardian 2 of Hispanic, Latino, or Spanish origin?

○ Hispanic or Latino ○ Not Hispanic or Latino ○ Don't know ○ Prefer not to answer

How would you describe Parent/Guardian 2's race? Please select all that apply.

- ☐ American Indian/Alaska Native
- ☐ Asian or Pacific Islander
- ☐ Black or African American
- ☐ White
- ☐ Other (Please Specify)
- ☐ Don't know
- ☐ Prefer not to answer

Please specify: __________________________

What is the highest level of education that Parent/Guardian 2 completed?

- ○ No formal school
- ○ Elementary/primary school
- ○ Middle school
- ○ High School or Equivalent (e.g., GED)
- ○ Some College or Vocational Degree (e.g., AA)
- ○ Bachelor's Degree (e.g., BA/BS)
- ○ Master's Degree (e.g., MA, MFA)
- ○ Doctoral or Professional Degree (e.g., MD, JD, EdD, DDS, PhD, VMD)

What type of childcare do you use for your child?

- ○ In-home care with nanny or relative other than you (in your home or a nanny/relative's home)
- ○ Family-based home childcare (outside your home and with other children)
- ○ Childcare center, nursery school, preschool or other group program
- ○ Other
- ○ None of the above

Please describe: __________________________

Child Activities

Child Activities
The next several questions ask about different activities children often do.

How often does your child do each of the following activities?

	Has never done this	Less than once a month	Less than once a week	Once a week	Several times a week	Once a day	Severa times a day	Once an hour	Several times an hour	All the time
Watching videos, including movies, series, TV shows, home-videos or video clips. This includes watching videos on any device, for instance YouTube, TV, cellphone, or computer.	○	○	○	○	○	○	○	○	○	○
Playing digital games on any device, including computers, tablets, smartphones, or consoles (XBox, PlayStation, Switch etc). This could be any kind of game that is controlled directly on a screen or remote control. For example puzzles, gaming apps, online-games, strategy games, or touchscreen drawing.	○	○	○	○	○	○	○	○	○	○
Video-chatting on any device. This could be any kind of video chat on any device, including smartphones, tablets, and laptop computers.	○	○	○	○	○	○	○	○	○	○
Reading or listening to digital books. This includes e-books, fairy tale story apps, picture book apps, interactive stories, audiobooks, and podcasts	○	○	○	○	○	○	○	○	○	○
Reading or looking at print books such as traditional picture books or board books.	○	○	○	○	○	○	○	○	○	○
Playing without digital media or books, such as building with blocks, coloring with markers, or playing on a playground.	○	○	○	○	○	○	○	○	○	○

Asking questions or giving commands to the voice-activated assistant on a phone (e.g., Siri) or a smart speaker (e.g., Alexa, Google Assistant). Smart speakers include Amazon Echo Dot, Google Home, and Apple HomePod.	○	○	○	○	○	○	○	○	○	○
Using a virtual reality headset	○	○	○	○	○	○	○	○	○	○
Interacting with a programmable robot (e.g., Nao, Aibo)	○	○	○	○	○	○	○	○	○	○

WATCHING VIDEOS

This and the following questions are about WATCHING VIDEOS, including movies, series, TV shows, home-videos or video clips. This includes watching videos on any device, for instance YouTube, TV, cellphone, or computer.

Thinking about a typical weekday (Monday-Friday) and a typical weekend day (Saturday-Sunday) during the last two weeks, how much time did your child spend watching videos at home?

On a typical weekday (Monday - Friday) in the last two weeks, my child spent about [video_weekday_hour]

hour(s) [video_weekday_minute] minute(s) per day watching video content.

Hour(s) — 0 to 24

(Place a mark on the scale above)

Minute(s) — 0 to 59

(Place a mark on the scale above)

On a typical weekend day (Saturday - Sunday) in the last two weeks, my child spent about [video_weekend_hour]

hour(s) [video_weekend_minute] minute(s) per day watching video content.

Hour(s) — 0 to 24

(Place a mark on the scale above)

Minute(s) — 0 to 59

(Place a mark on the scale above)

When your child watches videos (movies, series, TV shows, home-videos or video clips), how often do you watch together with the child?

- ○ Never or almost never
- ○ Less than half the time
- ○ About half the time
- ○ More than half the time
- ○ Always or almost always

Why does your child watch TV programs or videos?

	Never	Rarely	Sometimes	Often	Always
to educate my child	○	○	○	○	○
to calm my child down when they are upset	○	○	○	○	○
to keep my child busy while I get things done or take a break	○	○	○	○	○
because my child enjoys doing it	○	○	○	○	○
to spend time together or connect with other people	○	○	○	○	○

PLAYING DIGITAL GAMES

This and the following questions are about PLAYING DIGITAL GAMES on any device, including computers, tablets, smartphones, or consoles (XBox, PlayStation, Switch etc). This could be any kind of game that is controlled directly on a screen or remote control. For example puzzles, gaming apps, online-games, strategy games, or touchscreen drawing.

Thinking about a typical weekday (Monday-Friday) and a typical weekend day (Saturday-Sunday) during the last two weeks, how much time did your child spend playing digital games at home?

On a typical weekday (Monday - Friday) in the last two weeks, my child spent about [games_weekday_hour]

hour(s) [games_weekday_minute] minute(s) per day playing digital games at home.

Hour(s) 0 24

(Place a mark on the scale above)

Minute(s) 0 59

(Place a mark on the scale above)

On a typical weekend day (Saturday - Sunday) in the last two weeks, my child spent about [games_weekend_hour]

hour(s) [games_weekend_minute] minute(s) per day playing digital games at home.

Hour(s) 0 24

(Place a mark on the scale above)

Minute(s) 0 59

(Place a mark on the scale above)

When your child digital games on any device, how often do you play together with the child?

- ○ Never or almost never
- ○ Less than half the time
- ○ About half the time
- ○ More than half the time
- ○ Always or almost always

Why does your child play digital games?

	Never	Rarely	Sometimes	Often	Always
to educate my child	○	○	○	○	○
to calm my child down when they are upset	○	○	○	○	○
to keep my child busy while I get things done or take a break	○	○	○	○	○
because my child enjoys doing it	○	○	○	○	○
to spend time together or connect with other people	○	○	○	○	○

VIDEO CHAT

This and the following questions are about VIDEO CHAT on any device, including computers, tablets, or smartphones.

Thinking about a typical weekday (Monday-Friday) and a typical weekend day (Saturday-Sunday) during the last two weeks, how much time did your child spend video chatting?

On a typical weekday (Monday - Friday) in the last two weeks, my child spent about [videochat_weekday_hour]

hour(s) [videochat_weekday_minute] minute(s) per day video chatting at home.

Hour(s) — 0 to 24

(Place a mark on the scale above)

Minute(s) — 0 to 59

(Place a mark on the scale above)

On a typical weekend day (Saturday - Sunday) in the last two weeks, my child spent about [videochat_weekend_hour] hour(s) [videochat_weekend_minute] minute(s) per day video chatting at home.

Hour(s) — 0 to 24

(Place a mark on the scale above)

Minute(s) — 0 to 59

(Place a mark on the scale above)

When your child video chats on any device, how often do you chat together with the child?

- ○ Never or almost never
- ○ Less than half the time
- ○ About half the time
- ○ More than half the time
- ○ Always or almost always

Why does your child use video chat?

	Never	Rarely	Sometimes	Often	Always
to educate my child	○	○	○	○	○

to calm my child down when they are upset	○	○	○	○	○
to keep my child busy while I get things done or take a break	○	○	○	○	○
because my child enjoys doing it	○	○	○	○	○
to spend time together or connect with other people	○	○	○	○	○

DIGITAL BOOKS

This and the following questions are about READING OR LISTENING TO DIGITAL BOOKS. This includes e-books, fairy tale story apps, picture book apps, interactive stories, audiobooks, and podcasts.

Thinking about a typical weekday (Monday-Friday) and a typical weekend day (Saturday-Sunday) during the last two weeks, how much time did your child spend reading or listening to digital books at home?

On a typical weekday (Monday - Friday) in the last two weeks, my child spent about [ebook_weekday_hour]

hour(s) [ebook_weekday_minute] minute(s) per day reading or listening to digital books at home.

Hour(s) 0 ———— 24

(Place a mark on the scale above)

Minute(s) 0 ———— 59

(Place a mark on the scale above)

On a typical weekend day (Saturday - Sunday) in the last two weeks, my child spent about [ebook_weekend_hour]

hour(s) [ebook_weekend_minute] minute(s) per day reading or listening to digital books at home.

Hour(s) 0 ———— 24

(Place a mark on the scale above)

Minute(s) 0 ———— 59

(Place a mark on the scale above)

When your child reads or listens to digital books, how often do you do that together with the child?

- ○ Never or almost never
- ○ Less than half the time
- ○ About half the time
- ○ More than half the time
- ○ Always or almost always

Why does your child read or listen to digital books?

	Never	Rarely	Sometimes	Often	Always
to educate my child	○	○	○	○	○

to calm my child down when they are upset	◯	◯	◯	◯	◯
to keep my child busy while I get things done or take a break	◯	◯	◯	◯	◯
because my child enjoys doing it	◯	◯	◯	◯	◯
to spend time together or connect with other people	◯	◯	◯	◯	◯

When your child reads or listens to digital books, how much of the time does your child listen to a voice, without any pictures or with only a few pictures?

◯ Never or almost never
◯ Less than half the time
◯ About half the time
◯ More than half the time
◯ Always or almost always

PRINT BOOKS

This and the following questions are about READING OR LOOKING AT PRINT BOOKS such as traditional picture books or board books.

Thinking about a typical weekday (Monday-Friday) and a typical weekend day (Saturday-Sunday) during the last two weeks, how much time did your child spend reading or looking at print books at home?

On a typical weekday (Monday - Friday) in the last two weeks, my child spent about [ebook_weekday_hour]

hour(s) [ebook_weekday_minute] minute(s) per day reading or looking at print books at home.

Hour(s) 0 —— 24

(Place a mark on the scale above)

Minute(s) 0 —— 59

(Place a mark on the scale above)

On a typical weekend day (Saturday - Sunday) in the last two weeks, my child spent about [ebook_weekend_hour]

hour(s) [ebook_weekend_minute] minute(s) per day reading or looking at print books at home.

Hour(s) 0 —— 24

(Place a mark on the scale above)

Minute(s) 0 —— 59

(Place a mark on the scale above)

When your child reads or looks at print books, how often do you do that together with the child?

◯ Never or almost never
◯ Less than half the time
◯ About half the time
◯ More than half the time
◯ Always or almost always

Why does your child read or look at print books?

	Never	Rarely	Sometimes	Often	Always
to educate my child	○	○	○	○	○
to calm my child down when they are upset	○	○	○	○	○
to keep my child busy while I get things done or take a break	○	○	○	○	○
because my child enjoys doing it	○	○	○	○	○
to spend time together or connect with other people	○	○	○	○	○

Voice-Activated Assistant

This and the following questions are about a Voice-Activated Assistant on a phone (such as Siri) or a smart speaker (such as Alexa, Google Assistant). Smart speakers include Amazon Echo, Google Home, and Apple HomePod.

Thinking about a typical weekday (Monday-Friday) and a typical weekend day (Saturday-Sunday) during the last two weeks, how much time did your child spend asking questions or giving commands to the voice-activated assistant on a phone or a smart speaker?

On a typical weekday (Monday - Friday) in the last two weeks, my child spent about [speaker_weekday_hour]

hour(s) [speaker_weekday_minute] minute(s) per day using the voice-activated assistant at home.

Hour(s) 0 ——— 24

(Place a mark on the scale above)

Minute(s) 0 ——— 59

(Place a mark on the scale above)

On a typical weekend day (Saturday - Sunday) in the last two weeks, my child spent about [speaker_weekend_hour] hour(s) [speaker_weekend_minute] minute(s) per day using the voice-activated assistant at home.

Hour(s) 0 ——— 24

(Place a mark on the scale above)

Minute(s) 0 ——— 59

(Place a mark on the scale above)

When your child uses a voice-activated assistant on a phone (such as Siri) or a smart speaker (such as Alexa, Google Assistant), how often do you do that together with the child?

- ○ Never or almost never
- ○ Less than half the time
- ○ About half the time
- ○ More than half the time
- ○ Always or almost always

Why does your child use a voice-activated assistant on a phone (such as Siri) or a smart speaker (such as Alexa, Google Assistant)?

	Never	Rarely	Sometimes	Often	Always
to educate my child	○	○	○	○	○
to calm my child down when they are upset	○	○	○	○	○
to keep my child busy while I get things done or take a break	○	○	○	○	○
because my child enjoys doing it	○	○	○	○	○
to spend time together or connect with other people	○	○	○	○	○

Overall, based on the content of the media your child uses and the amount of time your child spends using it, do you think watching videos helps, hurts, or makes no difference to your child's...

Watching videos, including movies, series, TV shows, home-videos or video clips. This includes watching videos on any device, for instance YouTube, TV, cellphone, or computer.

	Hurts a lot	Hurts a little	Makes no difference	Helps a little	Helps a lot
Reading skills	○	○	○	○	○
Speaking skills	○	○	○	○	○
Math skills	○	○	○	○	○
Social skills	○	○	○	○	○
Physical activity	○	○	○	○	○
Attention span	○	○	○	○	○
Creativity	○	○	○	○	○
Behavior	○	○	○	○	○
Sleep	○	○	○	○	○

Overall, do you think using the voice-activated assistant on a phone or a smart speaker helps, hurts, or makes no difference to your child's...

	Hurts a lot	Hurts a little	Makes no difference	Helps a little	Helps a lot
Reading skills	○	○	○	○	○
Speaking skills	○	○	○	○	○
Math skills	○	○	○	○	○
Social skills	○	○	○	○	○
Physical activity	○	○	○	○	○
Attention span	○	○	○	○	○
Creativity	○	○	○	○	○
Behavior	○	○	○	○	○
Sleep	○	○	○	○	○

About how many children's books do you have in your home? (choose one)	◯ None ◯ 1-5 ◯ 6-10 ◯ 11-20 ◯ 21-30 ◯ 31-50 ◯ 51-75 ◯ 76-100 ◯ 101-150 ◯ More than 150
About how many children's books that involve math in some way do you have in your home? (choose one)	◯ None ◯ 1-5 ◯ 6-10 ◯ 11-20 ◯ 21-30 ◯ 31-50 ◯ 51-75 ◯ 76-100 ◯ 101-150 ◯ More than 150

In the past month, how often did you and the target child engage in the following?

	Never	1-3 times a month	About once a week	2-5 times per week	daily	Multiple times a day
read any storybooks	◯	◯	◯	◯	◯	◯
read number storybooks	◯	◯	◯	◯	◯	◯
Read to your child at times other than bedtime	◯	◯	◯	◯	◯	◯
Play electronic games involving counting, numbers, addition/subtraction, or other math	◯	◯	◯	◯	◯	◯
Use the terms more/less to compare quantities	◯	◯	◯	◯	◯	◯
Watch TV shows or online videos together that involve counting or numbers	◯	◯	◯	◯	◯	◯

What rules do you have, if any, for your child's use of the voice-activated assistant on a phone (such as Siri) or a smart speaker (such as Alexa, Google Assistant)? Smart speakers include Amazon Echo, Google Home, and Apple HomePod.	__________________________________
Please share any final thoughts about a voice-activated assistant on a phone (such as Siri) or a smart speaker (such as Alexa, Google Assistant) or other media use by your child.	____________________________

Future Contact Information

Can we contact you in the future regarding:	☐ This study only? ☐ Future studies? ☐ Research/study news? ☐ Please do not contact
How did you hear about this study?	__________________________

End of Survey

Thank you so much for taking time to complete this survey. Your responses are important to our research!