CHILD DEVELOPMENT

Child Development, September/October 2020, Volume 91, Number 5, Pages 1491–1508

Young Children's Mathematical Learning From Intelligent Characters

Sandra L. Calvert, Marisa M. Putnam, Naomi R. Aguiar, Rebecca M. Ryan, Charlotte A. Wright, Yi Hui Angella Liu, and Evan Barba

Georgetown University

Children's math learning (N = 217; M_{age} = 4.87 years; 63% European American, 96% college-educated families) from an intelligent character game was examined via social meaningfulness (parasocial relationships [PSRs]) and social contingency (parasocial interactions, e.g., math talk). In three studies (data collected in the DC area: 12/2015–10/2017), children's parasocial relationships and math talk with the intelligent character predicted quicker, more accurate math responses during virtual game play. Children performed better on a math transfer task with physical objects when exposed to an embodied character (Study 2), and when the character used socially contingent replies, which was mediated by math talk (Study 3). Results suggest that children's parasocial relationships and parasocial interactions with intelligent characters provide new frontiers for 21st century learning.

Early childhood is a period of rapid change, one in which new social relationships are forming and cognitive development is expanding. Media provide a sociocultural context in which these skills develop, with U.S. 2- to 8-year-old children averaging 2 hr per day with screen media (Common Sense Media, 2017). These digitized environments offer a wide range of imaginary social partners for children to interact with through movies, television programs, and videogames (Calvert & Richards, 2014). Children can treat these imaginary media characters as social partners, similar to their real friends and teachers (Richert, Robb, & Smith, 2011).

While media have traditionally been a one-way transmission to children, the characters who breathe life into observational media have become increasingly interactive, and hence, increasingly life-like, integrating content and lessons across diverse platforms and environments (Calvert & Richards, 2014). In this digital world, young children form close emotionally-tinged *parasocial relationships* with characters that can now interact with them through socially contingent *parasocial interactions*, a technique in which characters are programmed to create pseudo conversations with children through comments, questions, and pauses (Lauricella, Gola, & Calvert, 2011). Rapid developments in artificial intelligence are making those conversations increasingly accessible and realistic, as interfaces are emerging that respond and interact with children through spoken language (Brunick, Putnam, Richards, McGarry, & Calvert, 2016).

The purpose of these studies was to examine young children's learning from an intelligent media character, focusing on children's parasocial relationships and parasocial interactions with the character. The targeted learning activity was a key math concept, the add-1 rule: knowing that adding one to a number increases the total sum by a single unit (Baroody, Eiland, Purpura, & Reid, 2012). In three studies, the following questions were asked (a) Can

Naomi R. Aguiar is currently affiliated with University of Wisconsin Whitewater.

Charlotte A. Wright is currently affiliated with George Washington University.

Yi Hui Angella Liu is currently affiliated with University of Sydney.

This research was funded by a grant from the National Science Foundation (DRL Grant #1252113) to Sandra L. Calvert and a National Science Foundation Graduate Research Fellowship Program Grant (#DGE-1444316) to Marisa M. Putnam. We thank the children, parents, and schools who made this research possible, as well as Nickelodeon at Viacom, Inc., especially Mariana Diaz-Wionczek, for giving us permission to use the *Dora the Explorer* characters in our Intelligent Character prototype. We also thank our National Science Foundation team and Advisory Board and the many Children's Digital Media Center members who contributed to this research, particularly Melissa Richards, Kaitlin Brunick, Stevie Chancellor, Marie Frolich, Zita De Zamaroczy, Jaclyn Horowitz, Elena Richmond, Victoria Scully, Fran Blumberg, Brigid McCaffery, Miranda Nadeo, Elizabeth Mah, Emily Zuckerman, Christina Duval, Molly Biedermann, and Anna Hoffman.

Correspondence concerning this article should be addressed to Sandra L. Calvert, Children's Digital Media Center, Department of Psychology, 306-G White Gravenor Hall, 37th & O Streets NW, Washington, DC 20057. Electronic mail may be sent to calverts@georgetown.edu.

© 2019 Society for Research in Child Development
All rights reserved. 0009-3920/2020/9105-0006
DOI: 10.1111/cdev.13341

young children learn the add-1 rule from an intelligent character prototype? (b) Is children's learning influenced by a parasocial relationship with an intelligent media character that provides socially contingent feedback through parasocial interaction techniques? and (c) Will children's learning in a screen-based context transfer to an add-1 task with physical objects?

Social Meaningfulness, Parasocial Relationships, and Learning

Children live in a world filled with socially meaningful people. From the beginnings of life, mutual, reciprocal attachment bonds with parents develop, which are the foundation of social development (Bowlby, 1969). Secure attachments provide a web of safety, security, and trust to learn about and from others. By early childhood, these attachments include other close relationships, such as teachers (Corriveau & Harris, 2009) and friends (Park & Waters, 1989).

Parents and teachers comprise a particularly important group of socially meaningful partners that children trust as credible sources of information. For example, toddlers imitated more actions performed by their socially meaningful mother than by a socially nonmeaningful stranger, even though the video message was the same (Krcmar, 2010). Consistent with this thesis, 3- to 5-year-old children trusted a familiar more than an unfamiliar teacher's labels for novel objects (Corriveau & Harris, 2009). Taken together, these results suggest that a cache of emotional trust may build up over time for knowledge conveyed by significant others.

In the 20th century, the advent of movies, television, and personal computing facilitated a new kind of close relationship for children, one with media characters. These symbolically presented characters are now ubiquitous, occurring on various screens, on clothing, and on the very sheets in which children are tucked into at night—often holding soft toy embodiments of those same characters (Calvert & Richards, 2014). Through parasocial relationships, these transmedia characters, who cross numerous physical and virtual contexts, serve as social partners for children, as companions, friends, playmates, and teachers (Calvert & Richards, 2014; Lauricella et al., 2011; Richert et al., 2011).

In *Parasocial Relationship Theory*, parasocial relationships are defined as the perception of relationships that cross situations, ones that can endure over time (Liebers & Schramm, 2019). Young children perceive their parasocial relationships as strong mutual bonds with media characters (Richards & Calvert, 2017), just as they perceive reciprocal bonds with imaginary characters in other contexts (Gleason & Hohmann, 2006; Taylor, 1999). Children's parasocial relationships can cross situations, such as onscreen and physical experiences with embodied characters in amusement parks or as toys (Calvert & Richards, 2014).

Young children's parasocial relationships with media characters are often measured by assessing how children perceive their favorite characters (Hoffner, 1996). Using parent surveys to assess the attributes of their child's favorite character, parent responses yielded three factors: attachment and character personification, social realism, and human-like needs (Richards & Calvert, 2016). Factor analyses of 3-to-6-year-old children's reports about their favorite characters yielded similar dimensions as those of their parents (Richards & Calvert, 2016). For children, the only factor with acceptable levels of internal consistency was *attachment and friendship*, which consisted of a favorite character who was a *trustworthy, safe, cute, friend*, with *Dora the Explorer* emerging as the most frequent favorite character (Richards & Calvert, 2017).

Parasocial relationships with media characters influence toddlers' learning of academic content, specifically early math concepts like seriation in which objects are sequenced in canonical order by attributes like size. An onscreen seriation presentation by the meaningful character Elmo increased mathematical learning in seriating physical objects when compared to an onscreen presentation of the same material by a nonmeaningful character named DoDo (Lauricella et al., 2011). Meaningful parasocial relationships can also be built with unfamiliar characters. For instance, when compared to a no character exposure control group, toddlers who had played for 3 months with a previously unfamiliar character as a plush puppet (Gola, Richards, Lauricella, & Calvert, 2013) or with a previously unfamiliar personalized interactive toy character (Calvert, Richards, & Kent, 2014) learned math better after viewing those characters subsequently present a seriation task on a screen. In both studies, toddlers who formed the closest parasocial relationships with characters as toys, as measured by nurturing toys during play, subsequently learned the most from those characters (Calvert et al., 2014; Gola et al., 2013). Close, meaningful parasocial relationships developed with puppet and toy characters in play, then, can lead to learning that transfers between virtual and physical contexts.

Making successful characters, however, is not an easy task. There are visual challenges, such as the

uncanny valley in which artificial looking characters look creepy, not really looking like a human yet appear human looking enough to appear odd (Mori, MacDorman, & Kageki, 2012). Media characters have no such hurdle to overcome with their young audience. Rather, popular media characters are already viewed as friends by many children (Richards & Calvert, 2017), making them ideal social partners to teach young children (Brunick et al., 2016).

Socially Contingent Interactions, Parasocial Interactions, and Learning

Socially meaningful relationships with family members, teachers, and friends are formed in part through socially contingent interactions. It is through socially contingent interactions that language develops. For instance, children are more responsive and they learn language more quickly when their mothers' replies are socially contingent to their vocalizations (Goldstein, Schwade, & Bornstein, 2009). Social contingency is an essential part of interactivity, of the turn taking that takes place in conversations between children and others (Rafaeli, 1988), and in certain media experiences, such as video chat that allows young children to interact contingently with socially meaningful people (McClure, Chentsova-Dutton, Holochwost, Parrott, & Barr, 2018; Roseberry, Hirsh-Pasek, & Golinkoff, 2014).

In contrast to the perceived parasocial relationship that an audience member feels with a media persona across situations and over time, parasocial interactions are defined as a more limited, one-way exchange between an audience member and a media persona within a specific media experience (Liebers & Schramm, 2019). Contemporary televised media characters, particularly those in children's educational television programs, typically interact with their young audiences via pseudo parasocial interactions, in which a character makes a comment, pauses for a reply, and then responds as if they heard what a child said (Lauricella et al., 2011; O'Doherty et al., 2011). Children's engagement in these "conversations" suggests that children treat media characters that interact with them as social partners (Calvert, 2015).

Using educational prompts in young children's media, particularly television content, is now a common practice (Calvert, 2015). Parasocial interaction is used to elicit small talk to build rapport and educational replies to foster learning. Preschool children who respond to television prompts learn more of the targeted lessons (Anderson et al., 2000), understand the program plot better (Calvert, Strong, Jacobs, & Conger, 2007), and master more vocabulary (Neuman, Wong, Flynn, & Kaefer, 2018). A limitation of this approach is that the child can say anything to a character in a television program, whether it be correct or incorrect, on-topic or off-topic, and the character will continue as if they heard a meaningful reply, whether the child made one or not (Roseberry et al., 2014). Interactive media address this limitation.

Acting on information, which takes place during the use of interactive media, can improve learning via contingent replies. For instance, preschool-aged children successfully searched for hidden characters in a playroom after exposure to an interactive computer game that provided onscreen feedback about where the characters were hiding (Lauricella, Pempek, Barr, & Calvert, 2010), and they learned math problems better after playing a computer math game with contingent responses (Baroody, Eiland, & Thompson, 2009). Put simply, social contingency that targets task-relevant information can enhance children's learning in ways that facilitate transfer from virtual to physical contexts.

Young Children's Learning in the 21st Century: The Age of Intelligent Characters

A new dawn has arisen for children to learn from socially meaningful media characters in socially contingent ways that approximate face-to-face social interactions. Specifically, intelligent characters will be able to respond contingently to exactly what a child *says*, creating new opportunities for character-based educational learning (Brunick et al., 2016). Voice recognition and contingent responses from Internet of Things-enabled devices, such as Amazon Echo or Apple's Siri, are already acclimating children to the notion of interactive smart objects, including the use of smart objects as educational tools, such as *Alexa Skills: Math Tutor*.

The next generation of interaction with artificial agents has begun and can be approximated using a Wizard-of-Oz prototyping approach (Kelley, 1983). This research method gets its name from the wizard behind the curtain in the classic *Wizard of Oz* film. As an experimental procedure, a researcher plays the role of the wizard by staying away from view of the participant and supplying output that appears to be coming directly from an interactive system. As a *human in the loop*, the wizard is capable of understanding the nuances and intentions of the child's actions and reacting to them in real time

by supplying socially contingent responses that appear to be generated by the machine itself. Wizard of Oz prototyping is frequently employed to test interfaces and interactions when the technology to do so is either too fragile, too expensive, or simply beyond our current capabilities.

Using a Wizard of Oz approach, Finkelstein (2018) had second-and third- grade low-income African American children interact with a novel virtual peer to teach science. African American children's rapport and science reasoning increased after interacting with a virtual peer who used African American dialect for small talk to build repertoire and Standard American English for science talk, rather than Standard American English in both contexts. Small talk, which emphasized interpersonal goals over task-oriented ones, also predicted trust in autonomous conversational agents, as it allowed users to move from more superficial to deeper levels of conversational interaction (Bickmore & Cassell, 2001; Cassell et al., 1999). These findings are consistent with the literature on parasocial relationships and parasocial interactions, as children and adults develop trust in, and learn through interactions with digital characters. Parasocial interactions may also influence learning by eliciting on-topic interactions that include contingent feedback from a character about academic content, thereby scaffolding children's knowledge.

Young Children's Early Mathematical Skills: Learning the Add-1 Rule

U.S. children lag behind their international peers in science, technology, engineering, and mathematical (STEM) skills, leading to a call for an integrated math curriculum for 3- to 6-year-old children (National Research Council [NRC], 2009). During the preschool years, children are committed media users (Common Sense Media, 2017), including video and gaming experiences that provide a relatively untapped approach for learning math (NRC, 2009). Indeed, young children can learn math informally when they have stronger parasocial relationships with the character who teaches the lesson (Calvert et al., 2014). Children's parasocial relationships and parasocial interactions with media characters can provide a new pathway for 21st century education, with popular media characters bridging the traditional boundaries between home and school settings.

A major problem in math expertise is that many U.S. children begin school with inadequate knowledge of number systems (Baroody et al., 2009; NRC, 2009). Fluency in computing basic sums, such as the add-1 rule (e.g., 2 + 1 = 3), is widely recognized as an essential math skill for curricular focus (Baroody et al., 2012; NRC, 2009). The add-1 rule is one of the earliest strategies that children learn (Baroody et al., 2012). Performance on add-1 problems provides a knowledge base that predicts future math achievement (Jordan, Kaplan, Ramineni, & Locuniak, 2009), making its mastery a foundation for future math proficiency.

Computer technologies are one approach that has been used to teach the add-1 rule. Using Vygotsky's (1978) theory, scaffolds have been built into computer games for preschool- and kindergarten-aged children based on their zone of proximal development (i.e., knowledge that is just within their grasp), but this application was object focused and used a mouse to answer problems (Baroody et al., 2012; Baroody et al., 2009). Advances in technology will allow intelligent characters to provide scaffolds through a spoken interface using math talk.

The successor principle- that each successive number name is one unit higher than the previous one- is an educational goal for kindergarten-aged children (Council of Chief State School Officers, 2010), and may be the foundation of the add-1 rule (Baroody et al., 2012). Prior data indicated that *Dora the Explorer* was children's favorite character at ages 3- to 5 (Richards & Calvert, 2017). Children who feel a strong parasocial relationship for a media character can potentially transfer learning across situations (Calvert et al., 2014; Liebers & Schramm, 2019). For example, 3- to 6-year-old children who trusted a television character more learned science content and transferred that knowledge better (Schlesinger, Flynn, & Richert, 2016). The preschool years are also a time when children are highly imaginative, engaging in pretense (Lilliard, 2015; Taylor, 1999), in this case, having conversations (i.e., parasocial interactions) with imaginary beings that are media characters (Anderson et al., 2000). Given children's propensity to talk to television characters at this age (Anderson et al., 2000), parasocial interactions may provide another route to successful learning and transfer from virtual to physical contexts. In particular, beneficial math outcomes may occur when children's math talk receives a socially contingent reply from a character.

In sum, children who are approximately 4- through 6-years-old are likely to feel parasocial relationships for, and engage in, parasocial interactions with media characters. As this is the developmental time frame to learn the add-1 rule (Baroody et al., 2009), the trust that is built through parasocial relationships and the contingent feedback that occurs

via parasocial interactions with characters, particularly about targeted lessons, can both potentially enhance children's learning and transfer of the add-1 rule.

Overview of the Present Studies

In three studies, 4- to 6-year-old children's (one child was 3 years, 10 months) learning of the add-1 rule from an intelligent character prototype was examined as a function of socially meaningful parasocial relationships and socially contingent parasocial interactions. In Study 1, children's learning was evaluated based on their parasocial relationships and parasocial interactions with the character, focusing on how quickly they answered add-1 problems correctly during the game. In Study 2, children's parasocial relationships for learning were examined by comparing the intelligent character to an intelligent no character control version of the game, while keeping meaningful parasocial interaction prompts constant. In Study 3, children's parasocial relationship were held constant using the same character in both conditions, but children's parasocial interactions were manipulated using socially contingent or noncontingent character replies. Add-1 transfer problems were included to measure flexibility in moving from virtual to physical contexts in Studies 2 and 3. A robustness analysis was conducted on latency scores as a function of parasocial relationship and parasocial interaction scores by comparing the performance of children from Study 1 to a combined sample from Studies 2 and 3.

Study 1: The Feasibility Study

Study 1 tested if children could learn the add-1 rule from a meaningful, socially responsive intelligent character prototype. The hypotheses were H^1: children would interact with the intelligent character in the game via parasocial interactions involving math talk and small talk; H^2: children who had a stronger parasocial relationship with Dora would correctly solve add-1 problems more quickly; and H^3: children who had more math talk and small talk parasocial interactions with Dora would correctly solve add-1 problems more quickly.

Method

Participants

An initial sample of 55 children (data collection 12/2015–5/2016) yielded a final sample of 50 children who completed the game (M_{age} = 4.87 years, SD = 0.42). Children were recruited from child-care centers in the Washington, DC metropolitan area. Table 1 presents demographic information, as reported by parents (n = 48).

Child Parasocial Relationship (PSR) Measure: Emotional Closeness to Dora

Children initially answered a child PSR measure about the Dora character, using the attachment and friendship subscale (Richards & Calvert, 2017). These items were presented on a 5-point Likert scale with yellow smiley faces that varied in both face size (larger for more happiness) and size of smile (bigger smiles for more happiness). The child could touch the smiley face or provide verbal responses, which an experimenter recorded on an answer sheet.

The *attachment and friendship* questions measured children's perceptions of the character as a *trustworthy*, *cute*, *friend*, that made them feel *safe* (e.g., "Do you believe what Dora tells you . . . all of the time, a lot of the time, sometimes, a little bit of the time, or not at all?"). The 5-point responses for the four items were averaged to create a mean attachment and friendship score (Richards & Calvert, 2017). The internal consistency of this subscale is acceptable for 4- to 6-year-old children, Cronbach's α = .70 (Richards & Calvert, 2017) and was validated by a parent scale for the dimensions of their children's parasocial relationships (Richards & Calvert, 2016).

The Intelligent Character Prototype and Game

The socially contingent intelligent prototype was based on the popular Hispanic children's media character, *Dora the Explorer*. The character was embedded in a game that presented opportunities for parasocial interactions through a simple story. Children were asked to help Dora gather items for a birthday party for her cousin Diego by counting items that came down a conveyor belt at a grocery store. At the end of the game, children viewed a screen with a picture of Diego's birthday party.

The Dora prototype was displayed on a video screen and used speech as an interface to communicate with children. Dora spoke to children throughout the game with prompts to elicit small talk (e.g., "What is your favorite color balloon?") and math talk (e.g., "What does 4 and 1 make?"). The number of math talk and small talk prompts varied based on the number of scaffolds children required (see Appendix S1 for the script and all prompts).

Table 1
Participant Demographics

	Study 1		Study 2				Study 3			
			Full $N = 94$		Truncated $N = 64$		Full $N = 73$		Truncated $N = 51$	
	Full $N = 50$	Truncated $N = 38$	No character $N = 49$	Character $N = 45$	No character $N = 34$	Character $N = 30$	Non-contingent $N = 35$	Contingent $N = 38$	Non-contingent $N = 24$	Contingent $N = 27$
Child sex										
Girl/Boy	27/23	22/16	26/23	19/26	19/15	15/15	16/19	18/20	9/15	13/14
% Female	54.00	57.89	53.06	42.22	55.88	50.00	45.71	47.37	37.50	48.15
Child age										
M_{years} (*SD*)	4.87 (.42)	4.84 (.45)	4.88 (.60)	4.87 (.60)	4.67 (.38)	4.81 (.60)	4.84 (.49)	4.90 (.48)	4.63 (.43)	4.80 (.48)
Range	3.81–5.51	3.81–5.51	4.02–6.64	4.08–6.66	4.02–5.46	4.08–6.66	4.13–5.70	4.08–5.68	4.13–5.61	4.08–5.68
Child race										
White/non-White	29/19	20/16	28/12	23/14	18/11	14/9	20/12	23/14	12/10	14/12
% White	60.42	55.56	70.00	62.16	62.07	60.87	62.50	62.16	54.55	53.85
Parent education										
≥college/<college	43/5	31/5	39/1	35/0	28/1	22/0	33/0	35/1	23/0	24/1
% college	89.58	86.11	97.50	100	96.55	100	100	97.22	100	96.00

For each add-1 math problem, a group of items came down the conveyor belt together (e.g., 1, 2, 3, or 4 balloons). Dora would say, for example, "Here comes 3 balloons." Once the group of items dropped into a grocery bag, one additional item came down the conveyor belt alone. Dora then said, "Oh, here comes one more balloon! What does 3 and 1 make?" At this point, Dora paused to allow the child to answer, a parasocial interaction technique (Lauricella et al., 2011). The child had to count the items correctly before they fell into a grocery bag. If they did not succeed in time, Swiper, the fox from the Dora television program, grabbed them. If the child missed the problem, Dora encouraged them to try again, and scaffolds were introduced to assist them. After each round, the bag disappeared, and a new bag appeared for the next problem.

The initial game had four rounds and four add-1 problems in each round. The party items—balloons, party hats, birthday candles, and goodie bags—were presented based on a story script in four rounds of game play, with each round increasing in difficulty. The objects within rounds initially moved down a grocery store conveyor belt at either a slow (2.5 s) or fast (5.5 s) speed, and items were presented in either sequential or random numerical order. The rounds occurred as follows: Round 1—sequential numerical order, slow presentation (item: balloons); Round 2—sequential numerical order, fast presentation (item: party hats); Round 3—random numerical order, slow presentation (item: birthday candles), and Round 4—random numerical order, fast presentation (item: goodie bags). Within each round, there were four add-1 math problems. These were "What does 1 and 1 make?" with comparable language used for 2+1; 3+1; and 4+1. The total number of trials was fixed (n = 16). Each child answered all four add-1 problems in each round, regardless of accuracy on the prior trial.

Scaffolds (Vygotsky, 1978) were built into the game to assist children who missed a problem. There were three possible scaffold levels for each problem. In the first scaffold level, the items for the problems that had been missed would slow down in their progression along the conveyor belt and would flash to highlight that they were a group. Those items fell into the bag as a group, followed by the next single item, which came down the conveyor belt at the same slower speed. If the problem was still missed, children entered a second scaffold level in which the items for the same problem came down the conveyor belt one by one and fell into the bag. In this level, Dora prompted children to count with her, pausing as each item appeared onscreen so that children could say the answer before she did. In the third scaffold level, Boots, who is Dora's animated monkey friend who joins her on educational adventures, told children the answer to the math problem so that children could answer correctly and move forward.

The program was developed in C#. Assets, such as the animated characters Dora, Diego, Swiper, and Boots, the voice of Swiper, and the Dora theme song, were provided by the Nickelodeon Dora the Explorer team. The conveyor belt, store scene, and party items were drawn by a member of our research team, and the voices of the Dora and Boots characters were provided by team members. Figure 1 depicts the Intelligent Character in the main program scene.

Procedure

In a room at their child-care center, a trained experimenter administered the attachment and friendship Child PSR Scale (Richards & Calvert, 2017) with Dora as the character. Next, the child played the intelligent character game while the same experimenter sat beside the child to assist if needed. Another experimenter sat in the back of the room, operating a video camera to record the session. The third experimenter was the game Wizard, who sat behind a screen where she was invisible to the child. The Wizard had a computer that controlled the intelligent character through a preset menu of keys that provided socially contingent responses to the child based on the child's replies to Dora during game play. At the end of the 25-to-30-min session, each child received a small gift.

Coding for Parasocial Interactions and Latency in Children's Responses

Parasocial interactions were scored by research assistants for children's small talk and math talk as children played the virtual game. *Small talk* involved meaningful replies to Dora that could take place in a conversation. For instance, one point was awarded for any color a child said when asked what their favorite color balloon was. No point was awarded for answers that did not involve a color. Other small talk prompts included "How old are you?"; "What else do we need for Diego's birthday party?'; "What should we wear on our heads?"; "Say it with me, Swiper, No Swiping!" There was a maximum of 30 small talk prompts, which varied depending on how many scaffolds children needed

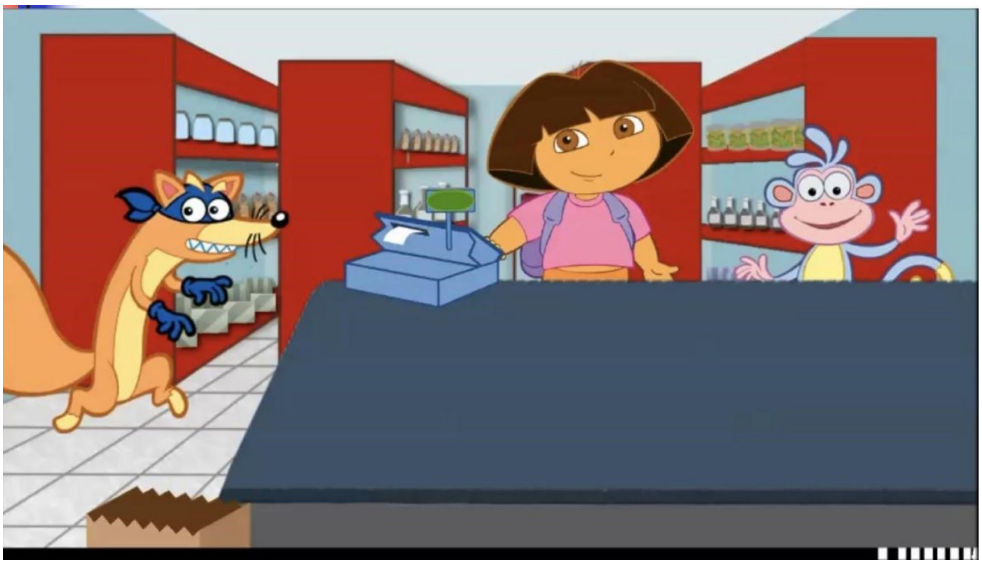

Figure 1. Dora the Explorer characters were used in our intelligent character prototype with permission from Nickelodeon at Viacom, Inc.

(see Appendix S1). To measure the proportion of small talk, the number of small talk replies were divided by the number of small talk prompt opportunities each child had. Reliability was computed from session videos on 20% of the sample, Cronbach's $\alpha = .96$.

For *math talk*, one point was awarded for a numerical reply. When Dora asked, for instance, "What does 3 and 1 make?," an answer such as 4 or 5 received one point. Children could respond verbally or by holding up their fingers to represent a number. If a nonmath reply was given, no point was received. The number of math talk prompts and replies varied (possible range = 16–64), depending on how many scaffolds children needed. Proportion scores were calculated by dividing the number of math replies by the number of math prompt opportunities each child had. Reliability was computed on 20% of the sample, Cronbach's $\alpha = .94$.

Latency. Latency scores were computed from session videos as the average amount of time in seconds between the math questions being asked and when a child solved the math problems correctly, including the time in scaffolds, for each problem. To simulate a natural conversation with the character, there was no specific cut off time for each trial. When children did not respond, time was allowed for children to think, including pauses and vocalizations like "hmm."

Reliability was computed on 20% of the sample, Cronbach's $\alpha = 1.0$.

In Study 2, potential condition differences in Wizard latency scores when children did not respond to prompts were analyzed. There were no significant differences. Studies 1 and 3 did not analyze condition differences in latency scores. The overall Wizard latency when children did not respond to prompts was about 7 s in Study 1, 9 s in Study 2, and 10 s in Study 3.

Results

The 91% of the children who completed the game took an average of 13.15 min (SD = 4.63 min). The video camera malfunctioned for one participant and the data collection session was not captured in its entirety. This child was excluded from the game time and latency analysis.

In preliminary analyses, possible gender and age effects were considered. Because gender did not significantly predict latency nor did boys or girls differ in getting all problems correct on the first trial, gender was not controlled in any subsequent analyses. Because age significantly predicted latency, it was included in models.

Parasocial Interactions and Parasocial Relationships

H^1 asked if children would interact with the character in the game. On average, children responded meaningfully to 79.60% (SD = 19.85%) of small talk prompts and to 92.54% (SD = 10.59%) of math talk prompts.

The strength of children's parasocial relationships was assessed as their attachment and friendship to Dora. On a scale of 1 to 5 for each of the four items, children reported an average attachment and friendship score of 3.63 (SD = 1.02; range = 1.5–5.0). No parent reported Dora as their child's favorite character in this study. Parents' reports of their children liking Dora on a 5-point Likert scale (*not at all* to *very much*; M = 2.91, SD = 1.02, N = 47) was significantly correlated with their children's reports of parasocial relationships with Dora, r = .32, p = .03, N = 47, thereby further validating the Child PSR subscale.

Latency Scores for Add-1 Problems During Game Play

Parasocial relationships (feelings of attachment and friendship) and meaningful parasocial interactions (small talk and math talk) were predicted to influence children's math learning. If children answered all problems correctly on the first trial, they already knew the add-1 rule. Therefore, 12 children were excluded from the analysis because they demonstrated ceiling level accuracy.

An ordinary least square (OLS) regression analysis with average attachment and friendship scores, small talk with the character, math talk with the character, and child age significantly predicted children's average latency scores during game play, n = 37, adjusted R^2 = .60, $F(4, 32)$ = 9.09, p = .0001. As predicted by H^2, average attachment and friendship scores significantly predicted faster latency scores, $B = -5.66$, SE = 2.15, p = .01. For each average point higher on attachment and friendship, children answered add-1 math problems almost six seconds *faster*. As predicted by H^3, math talk significantly predicted latency scores ($B = -136.27$, SE = 27.41, $p < .001$). The math talk variable ranged from 0 to 1: for each percentage point higher in children's math talk with the agent, children answered add-1 math problems 1.36 s *faster* on average. Small talk did not significantly predict latency scores. Therefore, H^3 was only partially supported. Age in months also significantly predicted latency scores: older children correctly answered add-1 problems more quickly than younger children did ($B = -0.16$, SE = 0.08, p = .048).

Figure 2 displays average latency scores on the y-axis and attachment and friendship scores on the x-axis, controlling for math talk, small talk, and children's age. The confidence intervals indicated that children who reported the highest level of attachment and friendship (i.e., 5) answered math problems significantly faster (95% CI [4.31, 15.26]) compared to children who reported lower levels of attachment and friendship (i.e., 1.5, 2, 3; 95% CI for 1.5 [17.96, 41.26]; 95% CI for 2 [17.19, 36.36]; 95% CI for 3 [15.37, 26.86]).

Summary

Children who had higher parasocial relationship scores, who engaged in more socially contingent math talk with the character, and who were older, correctly answered add-1 problems more quickly than those with lower scores or who were younger. Replies to small talk prompts had no significant effects on response times, perhaps because children already knew the character and small talk was not directly relevant to math performance. The findings suggest that children can learn the add-1 rule as a function of their parasocial relationships and parasocial math interactions with the character. Next, properties of the intelligent agent that made it successful in teaching math skills were manipulated.

Study 2: Intelligent Character Versus Intelligent No Character Control

Many interactive children's games provide no character, instead relying on the game objects to carry the experience (Baroody et al., 2012). On the one hand, the absence of a character could reduce processing demands, freeing up cognitive resources to understand the math problems (Lauricella et al., 2011). On the other hand, a trusted character could increase children's learning (Schlesinger et al., 2016). Social meaningfulness was varied in Study 2 by comparing children's learning from the intelligent character game as an embodied character or as an intelligent no character voiceover speaking to children. Both versions of the game used social contingency, the essential ingredient of being intelligent in this prototype.

Because young children have difficulty transferring virtual learning to physical objects (Barr, 2010), an add-1 transfer task was included. Children in the intelligent character condition were expected to transfer the add-1 rule from virtual to physical objects because parasocial relationships cross different situations (Liebers & Schramm, 2019). Many media characters, including Dora, appear as physical toys and as digital characters in children's everyday experiences (Calvert, 2015). Prior play with characters as toys before viewing those characters present onscreen math tasks increased children's transfer of onscreen learning to physical objects (Calvert et al., 2014; Gola et al., 2013).

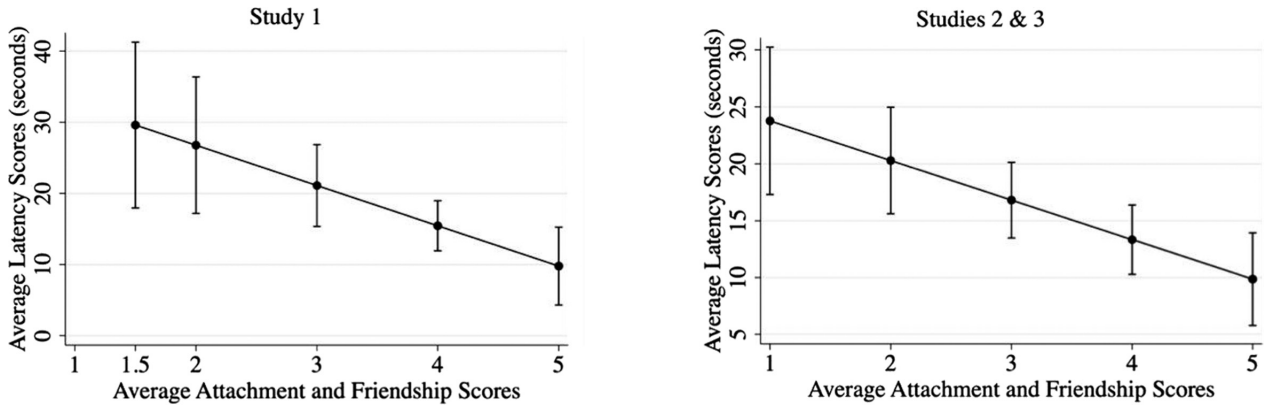

Figure 2. Children's attachment and friendship to character as a predictor of add-1 latency scores.
Note. Lower latency scores indicate faster response times. Bars above and below means indicate confidence intervals.

Preschool-aged children also transferred problem solving strategies from a media character to a different task when they trusted the character more (Schlesinger et al., 2016). Similar beneficial transfer outcomes were expected for the add-1 rule.

The hypotheses were that H^1: children in the intelligent character condition would solve add-1 problems faster than those in the intelligent no character control group; H^2: children with stronger rather than weaker parasocial relationships with Dora in the intelligent character condition would solve add-1 problems faster. This hypothesis was tested with a robustness analysis at the end of Study 3 with intelligent character data from both studies 2 and 3; H^3: children who responded with more math replies in either condition would answer add-1 problems faster; H^4: children who responded with more small talk replies in either condition would answer add-1 problems faster; and H^5: children in the intelligent character condition would perform better on a transfer task with physical objects than those in the intelligent no character group.

Method

Participants

An initial sample of 107 children (data collection: 6/2016–3/2017) yielded a final sample of 94 (M_{age} = 4.88 years, SD = 0.60, 49 males) who completed the game. Children were recruited from child-care centers in the Washington, DC metropolitan area. See parents' (n = 77) reports of demographic information in Table 1. Within gender groups, children were randomly assigned to one of two conditions: intelligent character or intelligent no character.

The Intelligent No Character Prototype

The intelligent character game was modified to create an intelligent no character prototype, which used an offscreen adult female narrator to deliver spoken content. The voice did not sound like Dora, as her voice is part of her character, just as her body is. All characters were eliminated, retaining the grocery store scene with the conveyor belt and the objects, plus the birthday scene. The script was changed somewhat from, for example, "We're having a birthday party for Diego" to "We're having a birthday party!" In both conditions, the game was condensed to three rounds: sequential numerical order, slow presentation; sequential numerical order, fast presentation; and random numerical order, fast presentation. The total number of trials was fixed (n = 12). Each child answered all four add-1 problems in each round, regardless of accuracy on the prior trial. The maximum number of small talk prompts was 30, and the maximum number of add-1 prompts was 48.

Procedure

The procedure was the same as in Study 1, except for the add-1 transfer task with physical objects. After completing the game, an experimenter told the child that they were going to play one more game. In this transfer task, the experimenter held up notepads, markers, stickers, and crayons that paralleled the game problems. For instance, she showed the child three stickers and said, "I have three stickers," and she put those stickers in a small goodie bag. Next she held up one more sticker and said, "I have one more sticker. How many stickers do we have?" The child then

answered the problem. Problems were presented sequentially from 1 + 1 through 4 + 1. No corrections were made for a child's performance. The correct number of add-1 problems solved was averaged to create a mean composite transfer score. At the end of the 20- to 25-min session, each child received a small gift.

Results

Of the 94 children who completed the game (88% of the sample; intelligent no character, $n = 49$ and intelligent character, $n = 45$), the average duration of game play was 8.72 min ($SD = 2.72$ min). For the full sample, condition differences occurred in the duration of game play, $t(92) = -2.22$, $p = .03$ (intelligent no character condition: $M = 8.14$ min, $SD = 2.76$ versus intelligent character condition: $M = 9.36$ min, $SD = 2.55$). There were no condition differences in the duration of game play in the truncated sample, $p > .05$. Preliminary analyses indicated that there were no significant age or gender differences across conditions, nor did either variable predict latency or transfer scores. Therefore, these variables were not controlled in any subsequent analyses.

Parasocial Interactions and Parasocial Relationships

Children responded meaningfully to 93.61% ($SD = 10.24\%$) of math prompts and to 67.16% ($SD = 19.90\%$) of small talk prompts. There were no significant condition differences in either math talk ($p = .14$) or small talk ($p = .28$). Children's reports of their attachment and friendship with Dora ($M = 3.45$, $SD = 1.15$; range = 1.0–5.0) were similar to the first study. Only 3.8% of parents reported Dora as their child's favorite character. Parents' reports of how much their children liked Dora ($M = 2.53$, $SD = 1.19$, $N = 76$) were significantly correlated with their children's reports of parasocial relationships with Dora, $r = .23$, $p = .04$, $N = 76$, thereby validating the child scale.

Latency Scores in Add-1 Problems During Game Play

To examine the impact of character presence on average latency scores during game play, an OLS regression was conducted predicting latency by condition as the only independent variable. Contrary to prediction, condition did not significantly predict latency scores, $p = .73$. Then an OLS regression analysis was conducted with condition, meaningful math talk to the character, meaningful small talk to the character, and average attachment and friendship scores as independent variables. Thirty children (15 in each condition) who answered all math questions correctly on their first try were excluded from both analyses, as they already knew the add-1 rule.

The regression results indicated that the predictors for the full model explained a significant proportion of the variance in average latency scores, $n = 64$, adjusted $R^2 = .15$, $F(4, 59) = 3.87$, $p = .007$. Math talk significantly predicted average latency scores, $B = -49.63$, $SE = 16.21$, $p = .003$, and there was a marginally significant effect for average attachment and friendship scores, $B = -2.59$, $SE = 1.31$, $p = .052$. For each percentage point higher in children's math talk, children answered add-1 problems approximately 0.5 s faster on average, controlling for condition, small talk, and parasocial relationships with Dora. For each point higher in average attachment and friendship scores, children answered add-1 problems 2.59 s faster on average, controlling for condition, math talk, and small talk. Contrary to prediction, there were no significant effects of condition or of small talk on latency scores.

Transfer Task Scores

The number of add-1 problems answered correctly on the transfer task with physical objects was analyzed by condition (0 = intelligent no character, 1 = intelligent character) in an OLS regression analysis, excluding those children who answered all problems correctly on the first trial during game play, as they already knew the add-1 rule. As predicted, condition significantly predicted the number of transfer problems children answered correctly, $n = 64$, $R^2 = .07$, $F(1, 62) = 4.43$, $p = .04$, thereby supporting H^5. Children in the Intelligent Character condition answered 0.49 ($SE = 0.23$) more transfer task problems correctly compared to the Intelligent No Character Control group. Condition remained a significant predictor of transfer scores after controlling for math talk and small talk in an OLS regression, $B = 0.53$, $SE = 0.24$, $p = .031$; math talk and small talk did not significantly predict transfer scores.

Summary

The findings from Study 2 indicated that children's math talk with socially contingent feedback was important in answering add-1 rule problems faster, with a marginally significant effect favoring attachment and friendship with the character. The character was most important for transferring the add-1 rule to physical objects. The intelligent

character may have aided transfer because children see transmedia characters like Dora in multiple settings and forms (screens and toys), which may provide links across virtual and physical settings (Liebers & Schramm, 2019). The finding suggests that a socially meaningful character that can provide feedback to children can assist them with transfer challenges from virtual to physical objects.

Study 3: Contingent Intelligent Character Versus Noncontingent Character

In Study 3, the character was kept constant and the social responsiveness of the Dora character was manipulated by contingent or no feedback to children's small talk and math talk. Because contingency provided children with corrective feedback, the main hypothesis was H^1: children in the contingent condition would answer more transfer questions correctly than those in the noncontingent group. Possible condition differences in latency scores could not be examined, as children in the noncontingent condition had only one opportunity to answer math problems before the game moved to the next problem.

Method

Participants

An initial sample of 79 children (data collection: 3/2017–10/2017) yielded a final sample of 73 children (M_{age} = 4.84 years, SD = 0.49) who completed the game. One child who completed the game did not complete the transfer task. Participants were recruited from child-care centers in the Washington, DC metropolitan area. See Table 1 for parents' (n = 69) reports of demographic information. Within gender groups, children were randomly assigned to one of two conditions: contingent intelligent character or noncontingent character.

The Intelligent Character Prototype and Procedure

The contingent intelligent character was the same prototype used in Study 2 in which Dora responded to children in socially contingent ways for small talk and math talk. The noncontingent character version gave no feedback during game play and moved on regardless of what children did, as is true in a television program. For instance, if a child said nothing in the noncontingent condition after Dora asked, "What does 3 and 1 make?," the game moved forward as Dora said, "Let's get a new bag." Other game components and the procedure were the same as in Study 2.

Results

Of the 73 children (92% of the full sample; n = 35 noncontingent character and n = 38 contingent intelligent character) who completed the game, the average game duration was 8.10 min (SD = 2.41 min). One child did not consent to be video-recorded so those data were not included in the average game duration (N = 72). Not surprisingly, the game duration time for the full sample was shorter in the noncontingent (M = 6.93 min, SD = 0.62) than in the contingent character condition (M = 9.14 min, SD = 2.91), $t(70) = -0.435$, $p < .001$, as the noncontingent game moved forward irrespective of the accuracy of children's responses. The game duration was also shorter in the truncated sample for the noncontingent (M = 7.17 min, SD = 0.61) than the contingent condition (M = 9.73 min, SD = 3.28), $t(48) = -3.68$, $p < .001$. Preliminary analyses indicated that there were no significant age differences across conditions, nor did age predict transfer scores. Therefore, age was not controlled in any subsequent analyses.

Parasocial Relationships and Parasocial Interactions With Dora

Children's average levels of attachment and friendship with Dora (M = 3.51, SD = 1.16, range = 1.00–5.00) were similar to attachment and friendship scores in Studies 1 and 2. Girls, however, reported significantly higher feelings of attachment and friendship with Dora than boys did (M = 3.88, SD = 1.00 vs. M = 3.19, SD = 1.21, respectively), $t(71) = -2.60$, $p = .01$. There were no initial differences in the strength of attachment and friendship by condition, $p = .45$. Parents reported that 6.8% viewed Dora as their child's favorite character. Parents' reports of how much their children liked Dora (M = 2.82, SD = 1.24, N = 67) were significantly correlated with their children's reports of parasocial relationships with Dora, $r = .27$, $p = .04$, N = 76.

For math parasocial interactions, the difference between conditions was statistically significant, favoring more math talk by children in the contingent intelligent character (M = 0.92, SD = 0.02) over the noncontingent character conditions (M = 0.70, SD = 0.38), $t(49) = -3.01$, $p = .004$. There were no significant condition differences in small talk, M = 0.61 (SD = 0.22).

Transfer Task Score Performance

Analysis of the number of physical object problems that children answered correctly about the add-1 rule was conducted by condition (0 = noncontingent character; 1 = contingent character) in an OLS regression. Only children who did not get all answers correct on the first try during game play were included in the analysis, as they knew the add-1 rule (truncated $n = 51$; 22 dropped, 11 from each condition).

As predicted by H^1, children in the contingent condition answered more transfer questions correctly than those in the noncontingent condition, $B = 0.68$ ($SE = 0.25$), $t(48) = 2.76$, $p = .008$. Children in the contingent character condition answered, on average, .68 more transfer task problems correctly than those in the noncontingent character condition. Math talk and small talk were added to the model; only math talk was significant in this model, $B = 1.31$, $SE = 0.47$, $t(46) = 2.79$, $p = .008$, and condition became nonsignificant, $p = .12$. Gender was initially examined in this analysis and was not significant so it was not included in the model presented here.

A mediation analysis was then conducted to test formally whether math talk explained the effect of condition on outcomes. In model 1, the regression of condition on the number of transfer task problems answered correctly was significant, controlling for small talk, $B = 0.65$, $t(47) = 2.57$, $p < .05$. This finding means that children in the contingent character condition answered, on average, 0.65 more problems correctly than children in the noncontingent character control group. In Model 2, when condition was regressed on math talk, condition significantly predicted more math talk, controlling for small talk, $B = 0.19$, $t(47) = 2.62$, $p < .05$. This finding means that children who were in the contingent character condition engaged in more math talk compared to children in the noncontingent character control group. Finally, when math talk was entered into the model predicting the number of transfer problems answered correctly from condition, condition became nonsignificant whereas math talk was significant, suggesting that higher levels of math talk in the contingent character condition partially explained their higher rate of transfer, $B = 1.32$, $t(46) = 2.79$, $p < .01$. Formal tests of mediation support this interpretation. The indirect effect of condition on transfer, through math talk, was 0.25, a significant indirect effect according to a Sobel Goodman-2 test ($z = 1.98$, $p < .05$; see Figure 3).

Therefore, H^1 was partially supported, but math talk was important in this outcome.

Robustness Analysis: Latency Score Analysis in Add One Problems for Studies 2 and 3

To examine the impact of parasocial relationships and social contingency on average latency scores for the game, the data from the samples in Studies 2 and 3 who had the exact same game experience (i.e., a socially contingent intelligent character) were collapsed and compared to the findings from Study 1. The hypotheses were as follows: H^1: children from the combined samples of Studies 2 and 3 would solve add-1 problems faster when they had a stronger rather than a weaker parasocial relationship with the character; H^2: children with higher rather than lower math talk scores would correctly solve add-1 problems faster; and H^3: children with higher rather than lower small talk scores would correctly solve add-1 problems faster.

In this analysis, participants in the socially contingent intelligent character conditions in Study 2 and Study 3 were pooled together ($n = 83$ children; 45 from Study 2 and 38 from Study 3). Twenty-six children were excluded (15 from Study 2 and 11 from Study 3) because they answered all math questions in the game correctly on their first try, which meant that they knew the add-1 rule. This exclusion yielded a final sample of 57 children ($M_{age} = 4.81$ years, $SD = 0.64$, 28 girls). Preliminary analyses revealed no significant age or gender effects on latency scores, and these variables were not controlled for in subsequent analyses.

Results

An OLS regression analysis was conducted with average attachment and friendship scores with Dora, small talk with the character, and math talk with the character as predictors of average latency scores in correctly answering add-1 math problems. The model was significant, $F(3, 53) = 7.12$, $p < .0004$, adjusted $R^2 = .29$. For each additional point higher children reported on attachment and friendship scores, they answered math problems correctly almost 3.5 s faster ($B = -3.48$, $SE = 1.06$, $p = .002$). For every percentage point higher on children's math talk, children replied correctly to math problems an average of 0.57 s faster, $B = -57.27$, $SE = 17.41$, $p = .002$. Small talk did not significantly predict latency scores. The findings were consistent with those reported in Study 1.

Figure 2 displays average latency scores on the y-axis and attachment and friendship scores on the x-axis, controlling for math talk and small talk. The

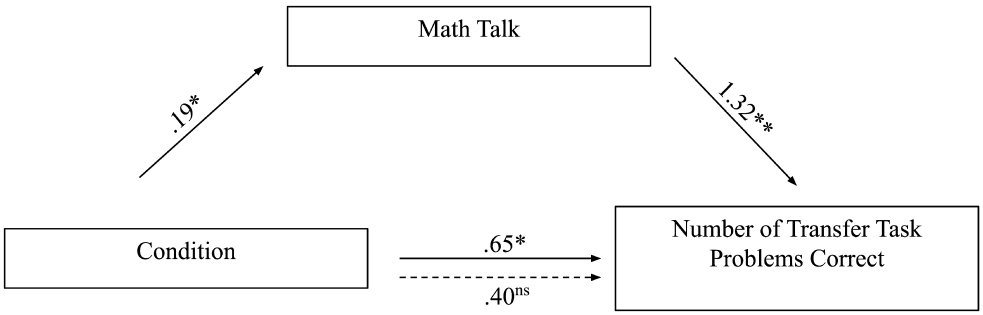

Figure 3. Number of transfer problems correct by condition, mediated by math talk.
Note. Covariate is small talk. *$p < .05$; **$p < .01$; *ns* = nonsignificant.

confidence intervals indicated that children who reported the highest level of attachment and friendship (i.e., 5) answered math problems significantly faster (95% CI [5.77, 13.94]) compared to children who reported low levels of attachment and friendship (i.e., 1 or 2; 95% CI for 1 [17.30, 30.23]; 95% CI for 2 [15.61, 24.97]). Children who reported the second highest level of attachment and friendship (i.e., 4) also answered math problems significantly faster (95% CI [10.29, 16.39]) than children who reported the lowest level of attachment and friendship (i.e., 1).

Summary

The results of Study 3 revealed that children's transfer scores were higher in the contingent condition, with mediation analysis demonstrating that contingency impacted transfer by increasing math parasocial interactions. The robustness analysis, which collapsed the add-1 latency data from Studies 2 and 3, demonstrated a pattern of quicker response times in correctly answering add-1 problems when children in the intelligent character condition had stronger parasocial relationship scores with the character, after controlling for math talk and small talk interaction scores. This pattern was consistent with the faster, accurate add-1 latency findings for children who had stronger parasocial relationships with the character in Study 1.

Discussion

The purpose of these studies was to examine children's learning of the add-1 rule as a function of their parasocial relationships and parasocial interactions with an intelligent character. The add-1 rule is key for young children to move forward to more complex math skills, as being able to add basic sums in your head frees up cognitive resources to compute higher order math problems (Baroody et al., 2012). Both latency and transfer scores were measured. These kinds of skills are essential for children's math success in the 21st century (Clements & Sarama, 2016).

In the current studies, an intelligent character prototype was built using a popular children's television character, *Dora the Explorer*, to determine if young children could learn the add-1 rule from this kind of interface. The interface was not expected to fall prey to the uncanny valley, in which characters look somewhat creepy when straddling the divide between a real and an animated being (Brunick et al., 2016). This thesis was supported. Children in these studies rated Dora in the middle of a five-point Likert scale on their feelings of attachment and friendship with her. Consistent with prior research (Richards & Calvert, 2016), girls in the third study had stronger parasocial relationships with her than boys did. The strength of boys' parasocial relationships with Dora in the other two studies did not differ from those of girls. No other gender differences were found, making this approach one that can get both girls and boys off to an early start in foundational math skills.

The strength of children's parasocial relationships with a meaningful character who responded contingently to their responses led to better learning in both the digital game and the transfer task with physical objects. Specifically, children performed faster in the latency analyses when they felt stronger parasocial relationships with Dora, and they transferred what they had learned better when the Dora character had been present in the game. The beneficial impact on speed of response may be due in part to reduced processing demands as well as enhanced motivation when children feel emotionally close to a character (see Lauricella et al., 2011).

The beneficial transfer outcomes from exposure to an intelligent character are consistent with prior findings in which an emotionally close relationship with an interactive toy and puppet characters yielded better transfer skills (Calvert et al., 2014; Gola et al., 2013). The transmedia experiences that children have with characters across virtual and physical contexts may well have contributed to this beneficial transfer outcome (Liebers & Schramm, 2019). The caveat to these findings, and it is an important one, is that children performed just as quickly on add-1 problems during the game (though transfer scores demonstrated a different pattern) in an intelligent no character voiceover as in the intelligent character condition. This finding points to the important role of social contingency in early learning, in this case for math skills.

Children's parasocial interactions with an intelligent character prototype received more contingent replies to math responses and scaffolds to improve their performance when they missed a problem than is possible in observational media experiences. Contingency, a key aspect of interactivity, enables conversations to take place between children and others (Rafaeli, 1988). Contingent interactions result in better learning by children from onscreen adults (Roseberry et al., 2014) and onscreen media characters (Lauricella et al., 2010). In the current studies, enhanced virtual learning emerged through children's parasocial interactions with Dora during game play or from the intelligent voiceover. When holding the Dora character constant as an intelligent agent, children produced more math talk with the socially contingent than noncontingent character. Social contingency, however, was only effective for transfer in the contingent condition when children used math talk. That is, it was children's math talk with the character that led to better transfer skills in the contingent condition, possibly because children were mastering problems about the add-1 rule that were necessary for subsequent transfer from virtual to physical settings. Although children's latency scores benefited from a no character intelligent voiceover condition, transfer was poorer when an embodied character was absent, suggesting that transmedia characters drive learning across situations while no characters constrain learning to a specific situation (Liebers & Schramm, 2019).

In contrast to the beneficial outcomes of small talk with intelligent prototypes reported by other scholars (Finkelstein, 2018), children's contingent replies to small talk prompts yielded no significant outcomes on virtual learning or transfer to physical objects in any of the current studies. The small talk used here involved responses when prompted to speak about everyday experiences, such as how old children were and what their favorite color was. Small talk might be more important when establishing an initial relationship to develop trust (Bickmore & Cassell, 2001) than when children interact with a popular character that they already know, or perhaps small talk was just not directly relevant to math performance.

The attachment and friendship subscale of the Child Parasocial Relationship (PSR) survey demonstrated promise as a measure. While this measure was created based on children's reports about favorite characters (Richards & Calvert, 2017), children's scores on this subscale about a popular media character predicted latency and transfer scores. Parent reports of how much their children liked the Dora character were also correlated with their children's attachment and friendship scores with that character.

At a basic level, the current research expands the computer science literature on intelligent agents and virtual peers where Vygotsky (1978) is often used to describe scaffolding processes (e.g., Ryokai, Vaucelle, & Cassell, 2003). The current findings explicate how children's feelings about and interactions with popular media characters, who are ubiquitous in children's lives, can scaffold those processes as intelligent characters through socially contingent interactions, thereby integrating the developmental, communication, education, and computer science literature. Consistent with the findings reported here on the value of emotionally tinged parasocial relationships, students who were exposed to artificial agents that displayed emotion were also more motivated to interact with the agent (Woolf et al., 2009). Perhaps agents who convey emotion elicit emotion (Kahn et al., 2012).

The findings reported here point to strong parallels between children's learning in human and artificial relationships. More specifically, the results of these studies indicate that children interact with humans and intelligent characters in similar ways (Finkelstein, 2018), that children have feelings for humans and for robots (Kahn et al., 2012), that they learn from humans and intelligent agents (Finkelstein, 2018), that children can use scaffolds to create logical bridges to build knowledge whether it be from humans or artificial agents, and that children can transfer information learned from personified artificial agents from one setting to another, just as they can from real people. Because children treat agents like people (Finkelstein, 2018; Kahn et al., 2012), human computer applications that draw

links between real and virtual beings may provide children with an optimal social and learning interface.

In these kinds of interactive applications, social contingency may further blur the lines between what is real and what is pretend (Kahn et al., 2012), which may make future characters potentially even more believable to children (Richards & Calvert, 2017). One child in our study, for example, excitedly exclaimed, "She's [Dora's] talking to me!" after the character responded contingently to her math talk reply.

At an applied level, the current findings suggest that intelligent character applications are part of the educational horizon as children's trusted peers and teachers. Voice assistants like Alexa and Google Home are already in children's homes, and better voice recognition systems are being developed. As these systems come to understand children's speech better, children can create an ongoing conversation with agents through small talk and academic areas through, for example, math talk, with the agent replying contingently to what children say. Lip syncing is more forgiving with animated characters than with human actors, making animated characters a viable interface. Eye tracking software can be used to pinpoint exactly what children are looking at onscreen, and motion sensors can be used to ensure that children are sitting in the middle of their seats, an indicator of engagement (Woolf et al., 2009). If children look or move away for a certain amount of time, the program can trigger the character to elicit an orienting response through speech or a sound effect.

A limitation of this research is that only one character, Dora the Explorer, was examined in this Wizard of Oz approach. However, this program is designed so that characters can easily be replaced with other ones. In future research, the sample should be expanded to include more ethnic minority and low-income children to prepare them for school entry. The use of a Hispanic character, as was the case here, could be fruitful, as could the use of other popular characters that appeal to different children. Future research could also examine if children's affinity for the character and fluency with the add-1 rule increases with repeated exposure, if novel versus familiar characters influence learning, how visual looks are allocated to characters versus objects being counted via eye-tracking approaches, and the role of parents in the learning process. Future research could also examine the influence of children's parasocial relationships and parasocial interactions on learning in virtual reality, robotic, and other intelligent agent experiences, particularly for children of different ages, genders, and ethnicities.

Conclusion

In conclusion, media characters are children's friends, playmates, and potential teachers. The current studies shed light on how children's parasocial relationships and parasocial interactions, in the form of math talk, increase learning of basic early math skills, a lesson that can potentially be extended to other academic and social areas. This interactive dimension will pave the way for children to embrace and trust media characters as effective intelligent social partners and teachers in the 21st century, as well as push the boundaries of what children will perceive to be alive.

References

Anderson, D. R., Bryant, J., Wilder, A., Santomero, A., Williams, M., & Crawley, A. (2000). Researching *Blue's Clues*: Viewing behavior and impact. *Media Psychology*, *2*, 179–194. https://doi.org/10.1207/S1532785XMEP0202_4

Baroody, A. J., Eiland, M. D., Purpura, D. J., & Reid, E. E. (2012). Fostering at-risk kindergarten children's number sense. *Cognition and Instruction*, *30*, 435–470. https://doi.org/10.1080/07370008.2012.720152

Baroody, A. J., Eiland, M. D., & Thompson, B. (2009). Fostering at-risk preschoolers' number sense. *Early Education and Development*, *20*, 80–128. https://doi.org/10.1080/10409280802206619

Barr, R. (2010). Transfer of learning between 2D and 3D sources during infancy: Informing theory and practice. *Developmental Review*, *30*, 128–154. https://doi.org/10.1016/j.dr.2010.03.001

Bickmore, T., & Cassell, J. (2001). Relational agents: A model and implementation of building user trust. In *Proceedings of the SIGCHI conference on human computer interaction* (pp. 393–403). Seattle, WA: Association for Computing Machinery, Inc. Retrieved from http://www.ccs.neu.edu/home/bickmore/publications/CHI2001.pdf

Bowlby, J. (1969). *Attachment and loss*. New York, NY: Basic Books.

Brunick, K. L., Putnam, M., Richards, M. N., McGarry, L., & Calvert, S. L. (2016). Children's future parasocial relationships with media characters: The age of intelligent characters. *Journal of Children and Media*, *10*, 181–190. https://doi.org/10.1080/17482798.2015.1127839

Calvert, S. L. (2015). Children and digital media. In M. Bornstein, T. Leventhal (Vol. Eds.), & R. Lerner (Ed.), *Ecological settings and processes in developmental systems. Handbook of child psychology and developmental science* (7th ed., pp. 375–415). Hoboken, NJ: Wiley.

Calvert, S. L., & Richards, M. N. (2014). Children's parasocial relationships with media characters. In J.

Bossert (Oxford Ed.), A. Jordan, & D. Romer (Eds.), *Media and the well being of children and adolescents* (pp. 187–200). Oxford, UK: Oxford University Press.

Calvert, S. L., Richards, M. N., & Kent, C. (2014). Personalized interactive characters for toddlers' learning of seriation from a video presentation. *Journal of Applied Developmental Psychology*, *35*, 148–155. https://doi.org/10.1016/j.appdev.2014.03.004

Calvert, S. L., Strong, B. L., Jacobs, E. L., & Conger, E. E. (2007). Interaction and participation for young Hispanic and Caucasian children's learning of media content. *Media Psychology*, *9*, 431–445. https://doi.org/10.1080/15213260701291379

Cassell, J., Bickmore, T., Billinghurst, M., Campbell, L., Chang, K., Vilhjalmsson, H., & Yan, H. (1999). Embodiment in conversational interfaces: Rea. In *Proceedings of CHI '99* (pp. 520–527). Pittsburgh, PA: Association for Computing Machinery, Inc. Retrieved from http://www.justinecassell.com/publications/CHI99.pdf

Clements, D., & Sarama, J. (2016). Math, science, and technology in the early grades. *The Future of Children*, *26*, 75–94. https://doi.org/10.1353/foc.2016.0013

Common Sense Media. (2017). *The common sense census: Media use by kids age zero to eight*. San Francisco, CA: Author.

Corriveau, K., & Harris, P. L. (2009). Choosing your informant: Weighing familiarity and recent accuracy. *Developmental Science*, *12*, 426–437. https://doi.org/10.1111/j.14677687.2008.00792.x

Council of Chief State School Officers. (2010). *Common core state standards initiative: Preparing America's students for college and career*. Retrieved from http://www.corestandards.org/Math/Content/K/CC/

Finkelstein, S. (2018). *"Alex speaks with my voice!": Promoting science discourse with bidialectal virtual peers*. Unpublished doctoral dissertation, Carnegie Mellon University.

Gleason, T. R., & Hohmann, L. M. (2006). Concepts of real and imaginary friendships in early childhood. *Social Development*, *15*, 128–144. https://doi.org/10.1111/j.1467-9507.2006.00333.x

Gola, A. A., Richards, M. N., Lauricella, A. R., & Calvert, S. L. (2013). Building meaningful relationships between toddlers and media characters to teach early mathematical skills. *Media Psychology*, *16*, 390–411. https://doi.org/10.1080/15213269.2013.783774

Goldstein, M. H., Schwade, J. A., & Bornstein, M. H. (2009). The value of vocalizing: Five-month-old infants associate their own noncry vocalizations with responses from caregivers. *Child Development*, *80*, 636–644. https://doi.org/10.1111/j.1467-8624.2009.01287.x

Hoffner, C. (1996). Children's wishful identification and parasocial interaction with favorite television characters. *Journal of Broadcasting & Electronic Media*, *40*, 389–402. https://doi.org/10.1080/08838159609364360

Jordan, N. C., Kaplan, D., Ramineni, C., & Locuniak, M. N. (2009). Early math matters: Kindergarten number competence and later mathematics outcomes. *Developmental Psychology*, *45*, 850–867. https://doi.org/10.1037/a0014939

Kahn, P. H., Kanda, T., Ishiguro, H., Freier, N. G., Severson, R. L., Gill, B. T., . . . Shen, S. (2012). "Robovie, You'll have to go into the closet now": Children's social and moral relationships with a humanoid robot. *Developmental Psychology*, *48*, 303–314. https://doi.org/10.1037/a0027033

Kelley, J. F. (1983). An empirical methodology for writing user-friendly natural language computer applications. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '83)* (193–196). Boston, MA: Association for Computing Machinery, Inc. Retrieved from https://dl.acm.org/citation.cfm?xml:id=801609

Krcmar, M. (2010). Can social meaningfulness and repeat exposure help infants and toddler overcome the video deficit. *Media Psychology*, *13*, 31–53. https://doi.org/10.1080/15213260903562917

Lauricella, A., Gola, A. A., & Calvert, S. L. (2011). Meaningful characters for toddlers learning from video. *Media Psychology*, *14*, 216–232. https://doi.org/10.1080/15213269.2013.783774

Lauricella, A., Pempek, T., Barr, R., & Calvert, S. L. (2010). Contingent interactions for young children's object retrieval success. *Journal of Applied Developmental Psychology*, *31*, 362–369. https://doi.org/10.1016/j.appdev.2010.06.002

Liebers, N., & Schramm, H. (2019). Parasocial interactions and relationships with media characters- An inventory of 60 years of research. *Communication Research Trends*, *38*, 4–31. ISSN: 0144-4646. Retrieved from https://www.researchgate.net/publication/333748971_Parasocial_Interactions_and_Relationships_with_Media_Characters_-_An_Inventory_of_60_Years_of_Research

Lilliard, A. (2015). The development of play. In L. Liben, U. Mueller (Vol. Eds.), & R. Lerner (Ed.), *Cognitive processes. Handbook of child psychology and developmental science* (7th ed., pp. 425–468). Hoboken, NJ: Wiley.

McClure, E., Chentsova-Dutton, Y., Holochwost, S., Parrott, W. G., & Barr, R. (2018). Look at that! Video chat and joint visual attention development among babies and toddlers. *Child Development*, *89*, 27–36. https://doi.org/10.3389/fpsyg.2018.02195

Mori, M., MacDorman, K. F., & Kageki, N. (2012). The uncanny valley [from the field]. *IEEE Robotics & Automation Magazine*, *19*, 98–100. https://doi.org/10.1109/MRA.2012.2192811

National Research Council (NRC). (2009). *Mathematics in early childhood: Learning paths toward excellence and equity*. Washington, DC: National Academy Press.

Neuman, S. B., Wong, K. M., Flynn, R., & Kaefer, T. (2018). Learning vocabulary from educational media: The role of pedagogical supports for low-income preschoolers. *Journal of Educational Psychology*, *111*, 32–44. https://doi.org/10.1037/edu0000278

O'Doherty, K., Troseth, G. L., Shimpi, P. M., Goldenberg, E., Akhtar, N., & Saylor, M. M. (2011). Third-party social interaction and word learning from video. *Child Development*, *82*, 902–915. https://doi.org/10.1111/j.1467-8624.2011.01579.x

Park, K. A., & Waters, E. (1989). Security of attachment and preschool friendships. *Child Development*, *60*, 1076–1081. https://doi.org/10.2307/1130781

Rafaeli, S. (1988). From new media to communication. *Sage Annual Review of Communication Research: Advancing Communication Science*, *16*, 110–134.

Richards, M. L., & Calvert, S. L. (2016). Parent versus child report of young children's parasocial relationships. *Journal of Children and Media*, *10*, 462–480. https://doi.org/10.1080/17482798.2016.1157502

Richards, M. L., & Calvert, S. L. (2017). Measuring young children's parasocial relationships: Creating a child self-report survey. *Journal of Children and Media*, *11*, 229–240. https://doi.org/10.1080/17482798.2017.1304969

Richert, R. A., Robb, M. B., & Smith, E. I. (2011). Media as social partners: The social nature of young children's learning from screen media. *Child Development*, *82*, 82–95. https://doi.org/10.1111/j.1467-8624.2010.01542.x

Roseberry, S., Hirsh-Pasek, K., & Golinkoff, R. (2014). Skype me! Socially contingent interactions help toddlers learn language. *Child Development*, *85*, 956–970. https://doi.org/10.1111/cdev.12166

Ryokai, K., Vaucelle, C., & Cassell, J. (2003). Virtual peers as partners in storytelling and literacy learning. *Journal of Computer Assisted Learning*, *19*, 195–208. https://doi.org/10.1046/j.0266-4909.2003.00020.x

Schlesinger, M. A., Flynn, R. M., & Richert, R. A. (2016). U.S. preschoolers' trust of and learning from media characters. *Journal of Children and Media*, *10*, 321–340. https://doi.org/10.1080/17482798.2016.1162184

Taylor, M. (1999). *Imaginary companions and the children who create them*. New York, NY: Oxford University Press.

Vygotsky, L. (1978). *Mind and society: The development of psychological processes*. Cambridge, MA: Harvard University Press.

Woolf, B., Burleson, W., Arroyo, I., Dragon, T., Cooper, D., & Picard, R. (2009). Affect-aware tutors: Recognizing and responding to student affect. *International Journal of Learning Technology*, *4*, 129–164. https://doi.org/10.1504/IJLT.2009.028804

Supporting Information

Additional supporting information may be found in the online version of this article at the publisher's website:

Appendix S1. Game Script: Dora Intelligent Character Condition, 3 Rounds (Studies 2 and 3)