DOI: 10.1111/cdev.14094

CHILD DEVELOPMENT

EMPIRICAL ARTICLE

"You gotta tell the camera": Advancing children's engineering learning opportunities through tinkering and digital storytelling

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Funding information
Division of Research on Learning in Formal and Informal Settings, Grant/Award Number: #1906808, #1906839 and #1906940

Abstract
This study addressed whether combining tinkering with digital storytelling (i.e., narrating and reflecting about experiences to an imagined audience) can engender engineering learning opportunities. Eighty-four families with 5- to 10-year-old (M=7.69) children (48% female children; 57% White, 11% Asian, 6% Black) watched a video introducing a tinkering activity and were randomly assigned either to a digital storytelling condition or a no digital storytelling condition during tinkering. After tinkering, families reflected on their tinkering experience and were randomly assigned to either engage in digital storytelling or not. Children in the digital storytelling condition during tinkering spoke most to an imagined audience during tinkering, talked most about engineering at reflection, and remembered the most information about the experience weeks later.

Over the past several decades, science, technology, engineering, and mathematics (STEM) educational opportunities have expanded dramatically in the United States (NGSS Lead States, 2013; NRC, 2009). As part of this effort, researchers, educators, and policymakers have advanced programs and activities both in schools and in informal educational settings, such as museums, zoos, libraries, parks, and families' homes, to foster children's STEM interest and learning (NRC, 2009). Informal STEM educational programs for early childhood often involve hands-on activities and interactions with caregivers (Marcus et al., 2018; Rogoff et al., 2016). An example is *tinkering*, a form of playful hands-on problem-solving with familiar materials (Bevan, 2017). Tinkering attracts attention because of its potential to offer engineering learning opportunities to children, specifically chances to engage in authentic engineering practices including planning, making, testing, and redesigning to solve problems (NGSS Lead States, 2013; Simpson et al., 2017). Tinkering is also frequently social, and research grounded in sociocultural theories (Rogoff, 1990; Vygotsky, 1978) indicates that adult-child socio-communicative interactions during and after tinkering can impact their engineering engagement and learning (Marcus et al., 2021; Pagano et al., 2020). Furthermore, tinkering can broaden participation in engineering (Acosta & Haden, 2023; Bevan, 2017; Simpson et al., 2017) because it draws on families' funds of knowledge—practices, skills, and experiences central to children's learning at home and in their cultural communities (Bermudez et al., 2023; Moll et al., 1992).

Importantly, not all tinkering activities are designed for engineering learning. Whereas some tinkering activities involve problem-solving goals that engender testing and iterating a design (e.g., make something that can do X), others focus on tool use or building models (Bevan, 2017; Pagano et al., 2019, 2020). Whether a tinkering program or activity encourages making to solve a problem, testing, and redesigning can determine how much families talk about and engage in engineering, as well as what engineering-related information children retain about these experiences (Marcus et al., 2021; Pagano et al., 2019, 2020). However, museum-based tinkering activities can pose barriers to participation for families,

Abbreviation: STEM science, technology, engineering, and mathematics including costs, transportation, and lack of connection to cultural and day-to-day practices. Tinkering does not require specialized tools, so tinkering at home with day-to-day materials (cardboard, tape) may offer unique opportunities for accessible family learning. Moreover, instead of focusing on children's learning of engineering content knowledge, the current study explores children's engineering learning *processes* during and after tinkering at home. Informal learning environments aim to introduce children to scientific processes (NRC, 2009), and engagement in scientific processes offers benefits such as increased STEM interest and the development of critical thinking and problem-solving skills (NGSS Lead States, 2013; NRC, 2009).

Story-based tinkering

In the context of an engineering-focused tinkering program, we explored how opportunities for oral storytelling during tinkering could support children's engineering talk and memory. Storytelling, whether through books or traditional oral narratives, may promote learning through both cognitive and socioemotional processes. Regarding cognitive processes, narrative stories often use an organizational structure—a logically connected beginning, middle, and end—which can aid children's understanding of causal relations and retention of information (Bruner, 1991; Egan, 1989). When children organize events using a narrative structure, their experiences may be easier to comprehend and remember later (Bower & Clark, 1969; Reese, Haden, et al., 2011). As for socioemotional processes, stories ground factual concepts in situations that are personally relevant or interesting to children, thereby making new information more meaningful (Bruner, 1996). Indeed, most stories involve characters and emotionally salient problems that can foster children's investment in the story (Egan, 1989).

Stories may be especially beneficial for STEM learning because they can make complex STEM information more familiar and comprehensible (Casey et al., 2008; Haden et al., 2023; NRC, 2009). Stories and STEM processes share complementary forms: articulating problems, establishing goals, brainstorming, planning, and trying solutions to solve a problem (Klassen, 2010). Presenting engineering and math concepts to children through stories supports retention of information and transfer of STEM knowledge to new contexts (Casey et al., 2008). Stories also have the capacity to illustrate challenging scientific information and expose children to scientific concepts and processes they do not often encounter in daily life (Haden et al., 2023). Stories can highlight how scientific concepts affect children's lives and how real people use scientific processes, which helps children value science and motivates continued interest and participation in science (Cunningham et al., 2020; Klassen, 2010).

In educational contexts, there have been efforts to combine storybooks with hands-on STEM activities, and these programs have resulted in increased STEM interest and knowledge for children (Cunningham et al., 2020; Haden et al., 2023; Pattison et al., 2020). As with storybooks, oral storytelling practices have been combined with hands-on STEM activities in informal settings, and these programs have been linked to increased persistence, interest, and engagement in STEM practices (Haden et al., 2023). Moreover, strength-based approaches advocate for valuing practices from diverse cultural communities (Rogoff et al., 2017), and storytelling is a common day-to-day cultural practice for many groups (Acosta & Haden, 2023; Kelly et al., 2024). Therefore, story-based tinkering activities may support STEM learning processes among children who are underrepresented in STEM. We investigated families' engineering learning processes during and after a story-based tinkering activity in which families were asked to build a ramp to move something 6 feet and create an oral story about what or who needed to be moved down the ramp from “Here to There.”

Narrative reflection after tinkering

After tinkering, families in this study were asked to reflect on their tinkering experiences. Narrative reflection—or telling stories about the past—can support children's understanding and long-term retention of their experiences, as well as more general cognitive and memory skills (Fivush et al., 2006; Jant et al., 2014). The memory process consists of encoding, consolidation, storage, and retrieval (Bauer, 2015). How an event was experienced—for example, whether storytelling occurred—can affect what information is initially encoded. But narrative reflection immediately after an experience can facilitate consolidation of information (Bauer, 2015). During reflection, children and families can organize events into memorable narrative structures, which makes information easier to store and recall later (Bower & Clark, 1969; Bruner, 1996; Klassen, 2010). When reflecting, families can evaluate their activities, express their emotions, and connect to prior knowledge, which makes the experience personally meaningful and aids understanding (Fivush et al., 2006). After stimulating, hands-on STEM learning experiences, narrative reflection allows children and their families to step back and digest the complex, novel STEM information encountered (Haden et al., 2016). Parents can support children by highlighting what was most important to remember, and families are more likely to remember the specific content discussed when refelecting, compared to content that was not discussed (Hedrick et al., 2009; Reese et al., 1993). In informal learning settings, children who discuss more STEM-related information during family narrative reflections tend to remember more STEM information later and are more likely transfer knowledge learned to new contexts (see Alexandre et al., 2022 for review). In this study, we examined families' engineering talk and narrative quality in reflections after tinkering to understand what was initially remembered and learned from the home tinkering activity. We also explored the tinkering and reflection conditions that would promote engineering talk and narrative quality in families' reflections.

Digital storytelling and children's learning

In addition to engaging families in a story-based tinkering activity and inviting post-tinkering narrative reflection, we considered another type of storytelling activity that is familiar and popular among many children today: digital storytelling, which uses audio, photographs, and videos to create shareable stories (Robin, 2008). Digital platforms, such as YouTube, TikTok, Snapchat, and Instagram, and technologies, such as computers and cellphones, have made children experienced with the process of using technology to create digital stories (Anderson & Subrahmanyam, 2017). Moreover, video creation using programs such as Flipgrid, Microsoft Photo Story, and Windows Moviemaker is becoming a common way to encourage storytelling and reflection in formal educational settings (Sadik, 2008), and some museums are integrating digital technologies into their exhibits (Hillman et al., 2015; Pagano et al., 2019). However, as digital technology use has become more common, researchers, educators, and caregivers have expressed concerns about whether digital technology is helpful or harmful for children's learning and development (Anderson & Subrahmanyam, 2017; Kelly et al., 2023) and some work has shown that parents' use of digital technology can displace conversational interactions about STEM and interrupt children's learning processes (Kelly et al., 2023).

Nonetheless, theory and research suggest ways that digital technology can support children's learning. Positive Technological Development Theory (Bers, 2012) acknowledges that some digital tools and practices can distract children and limit their learning. But digital experiences that foster creative content creation (not just consumption) and communication and collaboration with others can promote exploration, self-reflection, and learning (Bers, 2012). Likewise, Joint Media Engagement Theory posits that when children and caregivers interact with digital media together and collaboratively co-create new media (e.g., video stories) they may make sense of new information and make meaning from their experiences (Takeuchi & Stevens, 2011). Because digital technology practices are common in families' day-to-day lives, strengths-based approaches suggest that digital storytelling may draw on families' existing skills and foster learning across different environments (Kelly et al., 2024). Digital storytelling often involves children creatively producing new media content (e.g., video recordings, web posts) as they narrate activities or reflect on past experiences. Digital stories, like the ones in our study, can be co-created with caregivers and shared with others, and therefore may support children's learning.

Although there is less work considering digital storytelling in informal settings, studies in schools have shown that digital storytelling can foster development of essential digital literacy skills (Marty et al., 2013) and learning of specific content like math (Niemi et al., 2018). The combination of digital storytelling with project-based learning activities can support children's development of critical thinking and problem-solving skills (Hung et al., 2012). Therefore, we invited some families to create digital stories during tinkering and reflection to advance engineering learning opportunities.

Current study

The current study involved observing families via Zoom as they watched a museum-produced video invitation for tinkering at home and engaged in the story-based tinkering activity featured in the video. We further incorporated digital storytelling activities into families' tinkering experiences and their reflections after tinkering. Specifically, we asked families in the *digital storytelling* conditions to narrate their activities during tinkering and reflect together afterward as if they were creating a video story they could share with an audience, such as YouTube viewers. We felt that digital storytelling *during* the tinkering experience would encourage communication between children and caregivers and would require children to narrate the important elements of their experiences in a way that others could understand. Likewise, we thought that digital storytelling when reflecting would encourage families to summarize, organize, and make meaning of their tinkering experience. Therefore, we put forth the following hypotheses:

1. Parents and children who are asked to create digital stories during tinkering will: (a) talk more to their imagined audience as they work and (b) talk more about engineering during tinkering and reflection, compared to parents and children who are not asked to create digital stories.
2. Parents and children who are asked to create digital stories during tinkering and when reflecting after will: (a) talk more about engineering in their reflections and (b) use more narrative elements in their reflections, compared to parents and children who are not asked to create digital stories.
3. Children who are asked to create digital stories during tinkering and reflection will remember more about

their engineering activities in their follow-up memory interviews than children who do not create digital stories.

METHODS

Participants

The sample included 84 English-speaking parents and their 5- to 10-year-old children (M = 7.69 years, SD = 1.60). All families resided in the United States and Canada and participated between the dates of January to September 2021. We focused on 5- to 10-year-old children because the elementary years are a crucial period for advancing children's STEM learning and interest and because tinkering activities are typically targeted toward this age group (NRC, 2009). We also recorded follow-up memory interviews with 82 (98%) of the original 84 participants 11–27 days later. A breakdown of participant characteristics (i.e., child age, gender, ethnicity, parent education) by condition can be found in Table 1. Families were recruited via online advertisement on social media platforms and Children Helping Science, and through our database of past research participants.

Power analysis

A power analysis was conducted using the G*Power 3.1 program for linear multiple regression with 2 tested predictors and 4 total predictors (Faul et al., 2009). In the analysis, α = .05, power $(1-\beta)$ = .80, and medium effect size f = 0.15, revealing that a sample of 68 participants would be necessary. We collected data on 84 families, giving power of 0.89 with alpha set at .05. The 84 families were randomly assigned to four groups in our experimental design: (1) digital storytelling both during and after tinkering, (2) digital storytelling during tinkering, (3) digital storytelling after tinkering, and (4) no digital storytelling.

Procedure

The study procedures (see Figure 1 for the order of events) were approved under Loyola University Chicago IRB protocol #2992, *Tinkering with Digital Storytelling*.

Online story-based tinkering activity

A researcher met with each family individually on Zoom and video-recorded the session. Before the

TABLE 1 Participant demographics by conditions.

Tinkering condition	**No digital storytelling**	**No digital storytelling**	**Digital storytelling**	**Digital storytelling**			
Reflection condition	**No digital storytelling**	**Digital storytelling**	**No digital storytelling**	**Digital storytelling**	**Total**		
	M (SD)	***M (SD)***	***M (SD)***	***M (SD)***	***M (SD)***	***F***	***p***
Child age (in years)	7.67 (1.72)	8.02 (1.27)	7.34 (1.69)	7.97 (1.61)	7.69 (1.60)	0.333	.801
Parent's years of education	18.87 (2.83)	19.19 (3.17)	18.42 (3.71)	18.39 (3.21)	18.80 (3.32)	0.538	.657
Time tinkering (min)	29.05 (6.42)	26.92 (9.54)	23.77 (8.83)	28.43 (8.19)	27.00 (8.48)	1.64	.187
	***N* (%)**	***N* (%)**	***N* (%)**	***N* (%)**	***N* (%)**		
	21	**22**	**21**	**20**	**84**	χ^2	***p***
Child gender						0.29	.962
Male	11 (52%)	12 (54%)	10 (48%)	11 (55%)	44 (52%)		
Female	10 (48%)	10 (46%)	11 (52%)	9 (45%)	40 (48%)		
Parent gender						0.64	.887
Male	4 (19%)	6 (27%)	4 (19%)	5 (25%)	19 (23%)		
Female	17 (81%)	16 (73%)	17 (81%)	15 (75%)	65 (77%)		
Child ethnicity						10.72	.295
Caucasian/White	11 (52%)	13 (59%)	14 (67%)	10 (50%)	48 (57%)		
African American/Black	0 (0%)	1 (5%)	1 (5%)	3 (15%)	5 (6%)		
Asian	1 (5%)	2 (9%)	2 (9%)	4 (20%)	9 (11%)		
More than one	9 (43%)	6 (27%)	4 (19%)	3 (15%)	22 (26%)		

Note: This table outlines participants' key demographic information collected via the background questionnaire (see the Supporting Information) per condition assignment. Participants that indicated "More than one ethnicity" reported the following: 10 identified as White and Asian, 5 as White and Hispanic/Latine, 2 as White and Middle Eastern, 2 as White and African American/Black, and 3 participants reported as "Mixed."

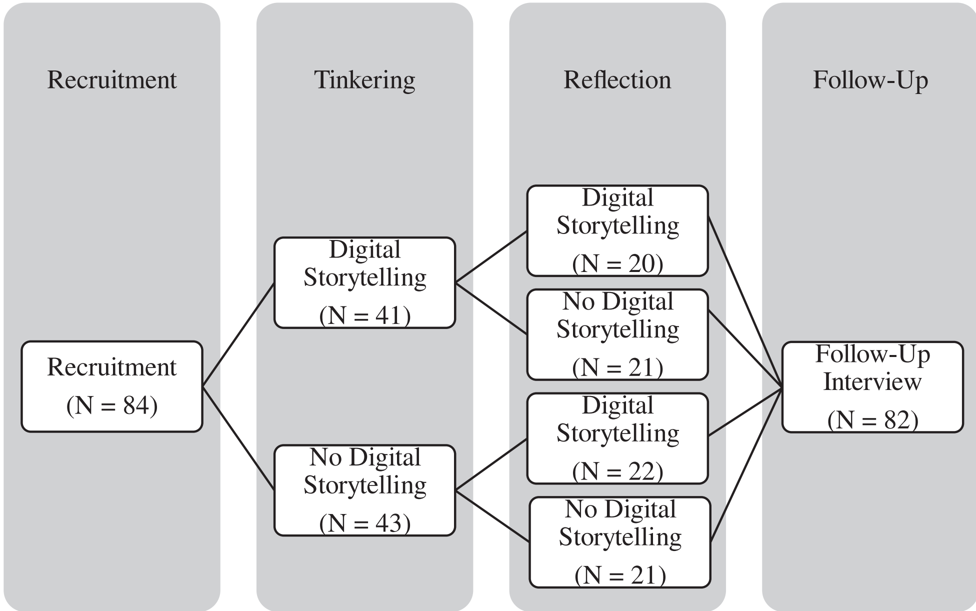

FIGURE 1 Study procedure and condition assignment.

session, researchers asked the parents and children to gather materials they would use while tinkering (e.g., recyclables such as cardboard and plastic; stick-like things such as plastic cutlery and chopsticks; connectors like tape, string, and rubber bands; scissors; and a ruler or tape measure). The sessions began with the parents and children watching a 3.5-min video produced by Chicago Children's Museum that introduced the "Here to There" engineering activity: https://youtu.be/nYYFi1oh7T0?si=apNUx7N-BaSBZaBw. In the video, a museum educator (1) explains the tinkering activity—to build a ramp to move something important from "here" to "there," (2) tells families they should try to make the ramp 6 feet long and that the object being moved should not fall off the ramp, (3) invites families to decide the story of their ramp—such as what the important object being moved was, who was sending or receiving the object, and where "here" and "there" were, and (4) briefly explains the simplified engineering design process of "making, testing, and fixing." The video concludes with three museum staffers sharing the ramps and stories they created, including one about delivering a gift to a turtle's birthday party, and another about sending a ball down a ramp to a pet cat. After the video concluded, the researcher told the parents and children that they would have 30 min for the tinkering activity and that they would have some questions for them at the end.

Digital storytelling during tinkering

Before they started tinkering, parents and children were randomly assigned to either the digital storytelling during tinkering group or the no digital storytelling during tinkering group. Immediately after watching the video introduction to the tinkering activity, the researcher asked the parents and children in the digital storytelling during tinkering condition to create a digital story as they worked. Specifically, they were instructed to talk aloud about their tinkering activities and their story as they worked together, as if they were creating a YouTube video that an audience would later watch. We emphasized to the participants that they should talk about their thoughts and actions in a way that others would understand their story and their tinkering project. In contrast, we instructed parents and children in the no digital storytelling group to simply work together and talk as they normally would. As all the families engaged in tinkering, the researcher turned off their Zoom video and microphone so as not to be a distraction. After 30 min of tinkering, the researcher asked all parents and children if they wanted another 5 min to finish.

Digital storytelling in post-tinkering reflections

After tinkering, parents and children recorded reflections together about their tinkering activities and stories. We randomly assigned parents and children to either a digital storytelling at reflection group or a no digital storytelling at reflection group. We asked those in the digital storytelling group to create a digital story as they reflected on their tinkering experience. The researcher took six screenshot photographs of the family as they were tinkering (one screenshot photograph was taken every 5 min during the activity), which were shared on the screen. The researcher asked the parents and children to create a digital story about their tinkering experience and "Here to There" story, using the tinkering photographs to guide their conversation. We asked the parents and children in the no digital storytelling group to sit together and talk about their tinkering experience and "Here to There" story with no prompt for digital storytelling or access to screenshot photographs.

Background questionnaire

After finishing their reflections, parents completed a background questionnaire about their family's demographic information and their child's previous digital storytelling experiences (see the Supporting Information for questionnaire). Because of the study's focus on digital storytelling, we asked parents three separate questions about how often their child (1) watched videos on YouTube or social media, (2) recorded videos on cellphones or other devices, and (3) uploaded video recordings to YouTube or social media. Parents responded on a scale of 1 (never) to 7 (daily).

Follow-up child memory interview

We aimed to schedule families' follow-up Zoom calls for 2 weeks after their tinkering and reflection session. The delay interval was selected to be in keeping with prior studies assessing memory for museum-based experiences, which indicate that a two-week delay is sufficient to reveal effects of learning and memory interventions on children's retention and forgetting of information (Benjamin et al., 2010; Jant et al., 2014). During the follow-up call, a different researcher met with families on Zoom to interview the children and assess what they remembered and learned from their tinkering experience (see the Supporting Information for follow-up questions). The researcher asked children several general, open-ended questions to elicit their memory reports: "What did you do during your tinkering session on Zoom?" "What did you make?" "How did you make it?" "What did you learn?".

Measures

The Zoom video recordings of the parent–child tinkering interactions, reflections, and child follow-up memory interviews were transcribed verbatim by a researcher using CHAT formatting (MacWhinney, 2000), and checked by a second researcher. For each coding system, two researchers independently coded at least 20% of the transcripts.

Family engineering talk during tinkering and reflection

To determine if there were differences among digital storytelling groups in their engineering-related talk, we coded transcripts of the tinkering conversations and the post-tinkering reflections for the frequency of parents' and children's talk about engineering-related practices (κ = .83 for tinkering conversations, κ = .86 for reflections). The engineering talk coding system was adapted from prior work grounded in the engineering design process from Next Generation Science Standards (NGSS Lead States, 2013; Pagano et al., 2019, 2020; Simpson et al., 2017). We coded for frequency of talk about setting goals for the size/design of the ramp ("How tall do you want to make our ramp?"), brainstorming ideas by referring to other ramps they've seen ("It could be like the ramp in the video that moved a toy to the cat"), planning ("How do you want to start?"), testing their ramp ("Let's try the car on the ramp"), identifying problems ("It's going way too fast and crashing"), and redesigning to solve problems ("Let's make it lower to slow it down"). The codes were mutually exclusive, meaning that a single piece of information could only receive one code. The coding system was not exhaustive, so not every utterance received a code.

Child engineering talk during follow-up memory interviews

We coded transcripts of children's follow-up memory interviews for the frequency of engineering memory elaborations that provided unique pieces of information about their engineering process during tinkering (e.g., "We decided to make a tube ramp," "We tested it," "The car kept falling off," "We added borders to the sides"), κ = .71.

Audience talk during tinkering

To determine if there were differences in families' digital storytelling behaviors between conditions during tinkering, we coded transcripts of families' tinkering sessions for frequency of talk to an imagined audience (κ = .80). "Audience talk" included directly addressing an imagined audience ("Alright everybody, I'm gonna test and see what happens"), prompting their partner to address the audience ("Make sure you're telling your viewers what you're doing"), referring to their partner in the third person ("As you can see, my mom has no idea what she's doing"), and using social media catchphrases ("Remember to like, comment, and subscribe"). Because all families, regardless of condition, were being recorded on Zoom by the researcher, we did not include talk about adjusting the camera or computer in our analyses.

Narrative quality during reflection

We coded transcripts of families' reflections after tinkering for narrative quality (coding system was adapted from Haden et al., 1997). We coded the frequency with which parents and children provided information about agents/characters ("We made the ramp for *Olaf*"), locations ("The ramp was going from *heaven to Earth*"), physical or mental actions ("It *fell off* the ramp," "I had to *think* about what to do"), character dialogue ("What do you want to do, Crunch?"), evaluations of the experience ("Our ramp wasn't *very good*, but that was sorta *funny*"), or temporal ordering ("*First* we cut the cardboard," "It finally worked *at the end*"), $\kappa = .85$.

RESULTS

Participant characteristics

We first explored whether there were differences by tinkering or reflection digital storytelling conditions for any participant characteristics. One-way analyses of variance (ANOVAs) revealed that there were no significant differences by condition for children's age, parents' years of education, or time tinkering, $F\text{s} = 0.33$, 0.54, and 1.64, respectively, $ps \geq .19$ (see Table 1 for the mean and standard deviation values). Chi-square tests revealed that there were no statistically significant differences by condition for children's ethnicity, children's gender, and parents' gender, $\chi^2 = 0.29$–27.07, $ps > .08$ (see Table 1 for frequencies and percentages).

Pearson correlation tests explored whether child age or parents' level of education were significantly related to our dependent variables. Child age was significantly correlated with parents' audience talk, $r(80) = .22$, $p = .04$. Therefore, child age was included in our main regression analyses. Parents' level of education was not correlated with any of our dependent variables, $rs < .18$, $ps > .05$. Researchers told the families that they would have 30 min to tinker and create their "Here to There" project. Time spent tinkering was not significantly different across the digital storytelling conditions, $F(3, 80) = 1.64$, $p = .19$. Nonetheless, some families finished the project early and 20 families asked for a 5-minute time extension. On average, families spent 27 min tinkering ($SD = 8.48$), with a range from 8 min to 51 min. Time spent tinkering was significantly correlated with parents' engineering talk during tinkering ($r(82) = .66$, $p < .001$), children's engineering talk during tinkering ($r(82) = .65$, $p < .001$), children's engineering talk ($r(82) = .32$, $p = .004$) and narrative quality ($r(82) = .37$, $p < .001$) at reflection, and children's follow-up memory elaborations ($r(80) = .23$, $p = .04$). Therefore, time spent tinkering was also included in our main regression analyses.

Independent-samples t-tests examined whether there were differences by child gender for our dependent variables, and we found that parents of girls ($M = 11.68$, $SD = 8.02$) used more engineering talk during reflection than parents of boys ($M = 8.18$, $SD = 6.03$), $t(82) = 2.27$, $p = .026$. However, gender was not a significant predictor in any of our regression analyses, so it was removed from our final regression models. There were no differences by child gender for any other variables. Similarly, independent-samples t-tests examined whether there were differences by parent gender for our dependent variables, and we found that female parents ($M = 2.74$, $SD = 2.62$) engaged in more audience talk during tinkering than male parents ($M = 1.\ 58$, $SD = 1.47$), $t(82) = 2.48$, $p = .015$. Again, this difference was no longer significant in our main analyses and was removed from the final regression models. There were no differences by parent gender for any other variables. Using ANOVAs, we found no differences by cethnicity for any of our dependent variables, $F\text{s} < 2.16$, $ps > .05$ (see the Supporting Information for complete analyses).

Finally, we examined whether children's prior experiences with digital storytelling were linked to our dependent variables. We found that 90% of children had watched videos on social media sites like YouTube, with 36% of children watching videos on social media daily. Further, 83% of children used devices like cellphones and tablets to record their own videos, and 10% of the children in our study uploaded videos to their own social media channels online. Children's experience watching videos online was not correlated with any of our dependent variables, $rs < .16$, $ps > .15$; nor was children's experience recording videos, $rs < .16$, $ps > .17$. Eight children had social media channels and uploaded videos online, so we used t-tests to compare children who did and did not upload videos online. Only parents' engineering talk during tinkering differed by whether children had experience uploading videos online, $t(82) = 2.40$, $p = .018$. Therefore, children's experience uploading videos online was included in our regression model for parents' engineering talk during tinkering.

Parents' and children's talk during tinkering

We predicted that parents and children in the digital storytelling condition during tinkering would talk more about engineering and would talk more to their imagined audience during tinkering than families who were not in the digital storytelling condition. In the four confirmatory regressions testing these hypotheses, child age and time spent tinkering were entered in the first block; children's experience uploading videos was also included in the regression for parents' engineering talk during tinkering. The second block included digital storytelling condition during tinkering (0 = no digital storytelling condition, 1 = digital storytelling condition). The means and standard deviations by condition for families' talk by digital storytelling condition during tinkering are shown in Table 2. Overall, parents and children in the no digital storytelling condition talked more about engineering during tinkering than parents and children in the digital storytelling condition, but parents and children in the digital storytelling condition engaged in more audience talk than parents and children in the no digital storytelling condition.

Neither regression for engineering talk during tinkering was significant, for children's engineering talk: $F(1, 80) = 0.09$, $p = .769$, $Adj.\ R^2 = .415$, for parents' engineering talk: $F(1, 79) = 0.24$, $p = .626$, $Adj.\ R^2 = .434$ (see the Supporting Information for coefficients). Nonetheless, as shown in Table 4, there was evidence that the manipulation of encouraging digital storytelling during tinkering was effective: being in the digital storytelling condition positively predicted children's audience talk during tinkering, $F(1, 80) = 5.47$, $p = .022$, $Adj.\ R^2 = .044$. Likewise, the regression predicting parents' audience talk during tinkering was significant, $F(1, 80) = 5.36$, $p = .023$, $Adj.\ R^2 = .096$, with digital storytelling condition as a significant positive predictor.

Parents' and children's talk at reflection

Our second hypothesis predicted that parents and children in the digital storytelling conditions during tinkering and at reflection would talk more about engineering and use more narrative elements when reflecting on their tinkering experience, compared to families in the no digital storytelling condition. Child age and time spent tinkering were again entered in the first block of the confirmatory regressions, with digital storytelling during tinkering (0 = no digital storytelling condition, 1 = digital storytelling condition) and digital storytelling at reflection (0 = no digital storytelling condition, 1 = digital storytelling condition), entered in the second block. Means and standard deviations for families' talk by digital storytelling condition at reflection are shown in Table 3. Parents and children who were in the digital storytelling condition during both tinkering and reflection talked more about engineering at reflection, used more narrative elements, and offered more unique memory elaborations than parents and children in the other three conditions.

As shown in Table 4, the regression model for children's engineering talk was significant, with digital storytelling condition during tinkering as a significant positive predictor of children's engineering talk in their reflections, $F(2, 79) = 3.59$, $p = .032$, $Adj.\ R^2 = .135$. Neither the model for parents' engineering talk during reflection, $F(2, 79) = 1.97$, $p = .146$, $Adj.\ R^2 = .001$, nor the models for children's and parents' narrative quality were significant, for children: $F(2, 79) = 2.56$, $p = .084$, $Adj.\ R^2 = .159$, for parents: $F(2, 79) = 2.03$, $p = .138$, $Adj.\ R^2 = .001$ (see the Supporting Information).

TABLE 2 Parent and child talk during tinkering by digital storytelling during tinkering conditions.

	Digital storytelling during tinkering		No digital storytelling during tinkering	
Talk during tinkering	***M***	***SD***	***M***	***SD***
Child engineering talk	23.54	14.69	26.65	15.26
Parent engineering talk	39.00	21.70	44.40	23.06
Child audience talk	1.71	2.45	0.72	1.55
Parent audience talk	3.00	2.67	1.98	2.13

Children's follow-up memory interviews

Our third hypothesis predicted that compared to children in the no digital storytelling conditions, children prompted to engage in digital storytelling during tinkering and in the reflections would recall more engineering-related information weeks later. The number of days between the tinkering session and follow-up ranged from 11 to 27 days ($M = 15.24$, $SD = 2.64$) but was not related to children's engineering memory, $rs < .16$, $ps > .15$. Therefore, the number of days between tinkering and follow-up was not included as a variable in our regression analyses. In our confirmatory regression analysis, child age and time spent tinkering were entered in the first block, and digital storytelling during tinkering (0 = no digital storytelling condition, 1 = digital storytelling condition) and digital storytelling in the reflections (0 = no digital storytelling condition, 1 = digital storytelling

TABLE 3 Parent and child talk at reflection and follow-up by condition.

	No digital storytelling during tinkering				Digital storytelling during tinkering			
	No digital storytelling at reflection		Digital storytelling at reflection		No digital storytelling at reflection		Digital storytelling at reflection	
Parent and child talk	***M***	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***
Reflections								
Child engineering talk	8.76	4.12	6.59	4.58	9.52	8.06	12.75	10.55
Parent engineering talk	9.33	6.84	7.68	8.34	11.33	8.12	11.20	4.71
Child narrative quality	23.76	11.79	23.41	13.95	24.14	15.98	33.50	24.38
Parent narrative quality	33.19	19.15	29.36	23.89	38.95	23.42	43.20	23.38
Follow-up								
Child engineering elaborations	13.33	6.26	16.71	8.90	17.25	7.55	22.65	17.55

TABLE 4 Significant regression models for the parent and child talk.

Variable	Unstandardized coefficients B	SE	Standardized coefficients β	t	p
Summary for children's audience talk during tinkering					
Constant	−1.219	1.455		−0.838	.404
Child age	0.180	0.142	.138	1.272	.207
Time tinkering	0.019	0.027	.077	0.706	.482
Digital storytelling condition (Tinkering)	1.054	0.451	.253	2.339	.022
Summary for parents' audience talk during tinkering					
Constant	−2.530	1.657		−1.527	.131
Child age	0.398	0.162	.260	2.463	.016
Time tinkering	0.050	0.031	.173	1.633	.106
Digital storytelling condition (Tinkering)	1.188	0.513	.244	2.315	.023
Summary for children's engineering talk at reflection					
Constant	−3.483	4.927		−0.707	.533
Child age	0.303	0.483	.065	0.627	.533
Time tinkering	0.310	0.091	.353	3.392	.001
Digital storytelling condition (Tinkering)	4.090	1.526	.276	2.680	.009
Digital storytelling condition (Reflection)	0.206	1.527	.014	0.135	.893
Summary for children's follow-up engineering memory					
Constant	−4.286	7.828		−0.547	.586
Child age	0.980	0.763	.138	1.285	.203
Time tinkering	0.355	0.141	.270	2.509	.014
Digital storytelling condition (Tinkering)	6.033	2.368	.270	2.548	.013
Digital storytelling condition (Reflection)	3.090	2.372	.138	1.303	.197

condition) were entered in the second block. The means and standard deviations by condition for children's engineering memory in the follow-ups are shown in Table 3. As shown in Table 4, the model was significant, with children's total engineering memory elaborations positively predicted by time spent tinkering and digital storytelling condition during tinkering, $F(2, 77)=4.11$, $p=.020$, *Adj.* $R^2=.114$.

DISCUSSION

In this study, we examined how digital storytelling would affect children's and parents' talk during and after tinkering. As we predicted, the families who engaged in digital storytelling during tinkering used more "audience talk" during the activity, suggesting that the manipulation was successful in encouraging this sort of talk. Moreover, children who were in the digital storytelling during tinkering condition talked more about engineering in their reflections and remembered more about their engineering experience weeks later. We did not find support for our hypotheses regarding effects of digital storytelling during the reflections. We discuss our findings in relation to existing research on children's memory and learning, suggest future directions for research on digital storytelling, and share implications of our results for educational practice.

Parents' and children's talk during tinkering

In contrast to our hypotheses, we found no effects of digital storytelling condition on parents' or children's engineering talk during tinkering. Although there were no differences in *how much* families talked about engineering during tinkering, there were differences in how the engineering talk was framed. Both parents and children engaged in more talk with their imagined audience during tinkering if they were in the digital storytelling condition, compared to those who were not. Parents encouraged their children to "talk to the camera," "show the audience what you're doing," or "pretend you're a YouTuber." Likewise, children narrated their actions and explained their thoughts and ideas in a way that others could understand (see the Supporting Information for examples). Therefore, although families across conditions talked about engineering the same amount, those who were in the digital storytelling condition framed their engineering engagement in ways that might support learning and retention of information. In keeping with Positive Technological Development Theory (Bers, 2012) and Joint Media Engagement Theory (Takeuchi & Stevens, 2011), engaging in digital storytelling and intending to share information with others may have supported engineering learning processes.

In retrospect, it is perhaps not surprising that families talked about engineering to a similar degree across conditions. All families heard about the engineering design process of "making, testing, fixing" and saw examples of testing and redesigning ramps in the "Here to There" introduction video. The activity posed an engineering challenge and opportunities for testing, which prior work has shown facilitates conversations about engineering (Pagano et al., 2020). Our findings are consistent with museum studies from several labs demonstrating that families who receive STEM-related information prior to engaging in a tinkering or building activity talk more about STEM than those who do not receive STEM-related information (see Alexandre et al., 2022 for review). Instead of manipulating whether families received STEM-related information prior to tinkering, we manipulated whether families were encouraged to talk with an imagined audience during the tinkering activity. Consistent with many studies in informal environments, families followed researchers' instructions by adjusting their conversational style, not the STEM content of their conversations (Degotardi et al., 2019; Jant et al., 2014). For example, Eberbach and Crowley (2017) prompted families to engage in elaborative talk during a visit to a botanic garden. Parents who were provided with elaborative talk instructions engaged in elaborative-style conversations with their children, but the STEM talk during the activities did not vary across families in the elaborative or nonelaborative style groups.

Parents' and children's talk in post-tinkering reflections

We further predicted that parents and children who were asked to create digital stories during tinkering and when reflecting after would talk more about engineering in their reflections and would use more narrative elements in their reflections, compared to parents and children who were not asked to create digital stories. When looking at children's reflections, we found that children in the digital storytelling condition *during tinkering* talked more about engineering in their reflections than children who were in the no digital storytelling condition during tinkering (see the Supporting Information for examples). Framing the tinkering activity as a digital story may have helped children to organize the experience and make it more understandable and reportable, leading to more engineering-rich reflections.

Research on children's memory supports the notion that when events are encoded in a way that is more comprehensible and meaningful, they may also be more retrievable and memorable (Fivush et al., 2006; Ornstein et al., 2004). In our study, families in the digital storytelling condition during tinkering used effective digital practices like co-creation of narratives and audience-directed explanation of their activities (Bers, 2012; Takeuchi & Stevens, 2011). These digital storytelling practices may have supported initial encoding of information (Niemi et al., 2018; Pagano et al., 2019; Wu et al., 2021), which in turn promoted engineering talk in family reflections and children's follow-up memory conversations. In line with this, other informal STEM learning studies demonstrate differences in families' STEM talk weeks after an activity because of differences in activity instructions, despite not finding differences in families' STEM talk during the activity (Marcus et al., 2018).

Consolidation, which occurs after the initially experienced event, is defined by re-organizing and storing key information for future retrieval and plays a key part in children's memory (Bauer, 2015). Reflections after informal learning experiences present valuable opportunities for consolidation, and social and environmental factors during reflection can impact what children remember (Fivush et al., 2006). For this reason, we expected to see differences in children's learning and memory by digital storytelling condition during reflection. However, there were no differences between parents or children in the digital storytelling and no digital storytelling during reflection groups on engineering talk or narrative quality at reflection. This may be because our conditions were too similar—in a way, both groups engaged in digital storytelling. During tinkering, families had to step away from the computer to work on their "Here to There" projects, and families in the digital storytelling condition needed to intentionally approach the computer to communicate with their imagined audience. During reflection, on the other hand, all families were seated directly in front of the computer. Researchers invited families in the experimental group to "make a digital story" and provided photographs of their tinkering activities that they used to support their storytelling. Families in the no digital storytelling group were simply told to "talk together about what you did." Nevertheless, all families saw themselves on a computer screen and had recently spoken with the researcher on Zoom. Building on Positive Technological Development Theory (Bers, 2012) and Joint Media Engagement Theory (Takeuchi & Stevens, 2011), we instructed all families to co-create digital reflective content—the only distinguishing difference between the digital storytelling conditions was whether they had access to photographs and whether researchers primed them to speak as though they were talking to an imagined audience.

Regarding the lack of differences by digital storytelling condition during tinkering or reflection on children's narrative quality, it is possible that children's narrative abilities are more affected by personal factors like age (Reese, Haden, et al., 2011), family socioeconomic status

(Peterson, 1994), culture (Melzi et al., 2019), prior storytelling experiences, or parents' use of elaborative conversation styles (Fivush et al., 2006). Moreover, our measure of narrative quality may have been limited—we assessed the frequency of families' talk about agents, locations, physical and mental actions, dialogue, evaluations, and temporal ordering. Other research has examined narrative styles, used rating scales, or considered other narrative elements (Peterson & McCabe, 1983; Reese, Sparks, & Suggate, 2011). Future work should draw on a variety of narrative measures to uncover the impact digital storytelling may have on children's narrative development.

It is intriguing that we never found any impact of digital storytelling condition during tinkering or reflection on parents' engineering talk or narrative quality—we only found effects for children. One possibility is that parents did not view the digital stories as their own. Instead, they were a “side character” in their child's story. Parents' audience talk often included reminders to their child to tell their story to the camera. They were supporting their child through the process of creating a child-centered digital story instead of creating their own. In line with the idea of a “digital divide” between generations who did and did not grow up with digital technology, it is possible that parents are less comfortable or familiar with digital technology than their children (Aarsand, 2007), and therefore did not benefit from digital storytelling.

Children's follow-up memory

Our third hypothesis predicted that children in the digital storytelling during tinkering and reflection conditions would remember more about their engineering activities in their follow-up memory interviews than children in the no digital storytelling conditions. Although there were no differences by digital storytelling condition at reflection, we found that children in the digital storytelling condition during tinkering remembered significantly more about their engineering activities in their follow-up interviews than children in the no digital storytelling condition during tinkering (see the Supporting Information for examples). As we saw in the reflections, digital storytelling may have encouraged children to verbalize their thoughts and feelings to their imagined audience throughout the tinkering process (Niemi et al., 2018; Wu et al., 2021). Ultimately, this may have supported encoding of new information, which was better remembered at retrieval during the follow-up interviews (Ornstein et al., 2004; Pagano et al., 2019).

Limitations and future directions

We recruited our participants online during the COVID-19 pandemic, so families were self-selected, not randomly sampled. Parents in our study may have prioritized STEM learning for their children or knew that their children would enjoy doing a tinkering activity. This recruitment strategy yielded a sample of 57% white participants and highly educated parents. In ongoing work, our team is developing strategies to include more ethnically and socioeconomically diverse families (e.g., by designing Spanish-language tinkering videos and materials, recruiting families in-person in informal learning spaces, and collaborating with community organizations). Nonetheless, we believe the tinkering and storytelling activities described in this study can create broad impacts regarding informal STEM learning opportunities for children. Tinkering has been described as having “low floors, wide walls, and high ceilings” (Resnick, 2011), meaning that it is accessible to learners who are diverse in age, experience, education, and cultural background and has the potential for a great deal of creativity, exploration, and learning. Storytelling is also a practice that is relevant to many cultural communities and has been found to be especially beneficial for girls' STEM interest and learning (Casey et al., 2008; Haden et al., 2023; Robinson et al., 2018; Rogoff et al., 2016). Moreover, many existing studies examining the effects of digital storytelling on learning were conducted outside of the United States (e.g., Hung et al., 2012; Laine et al., 2016; Niemi et al., 2018; Sadik, 2008), suggesting that digital storytelling may offer benefits for a wide range of children and families.

All parents and children in our study participated from their homes and met with a researcher via Zoom. During tinkering and reflection, our participants were seated in front of the computer, regardless of condition. In future work it would be beneficial to compare how interactions that involve digital storytelling (i.e., with computers, tablets, smartphones) differ from day-to-day parent–child interactions that do not involve any recording with digital technologies. Prior experience with digital storytelling and interest in digital media may affect the impact of digital storytelling on children's learning and memory. In this study, children's experience watching YouTube videos and recording personal videos was not associated with any memory or engineering talk. However, eight children in our sample reported that they had social media channels and uploaded videos online. This limited sample size prevents us from drawing conclusions about the interaction between digital storytelling activities and prior social media experience on children's memory and learning, but it will be important to continue investigating how children's interest and experience with digital media relates to their learning processes.

Additionally, this study only used verbal measures to assess families' engagement in the engineering design process, memory, and learning. Parents' and children's talk during informal learning activities and reflection are essential for memory and learning (Jant et al., 2014;

Marcus et al., 2021; Pagano et al., 2020), but existing research also highlights the benefits of gesture, hands-on engagement with objects, and physical movement for children's STEM learning (Degotardi et al., 2019; Jant et al., 2014). Future studies should explore other methods for assessing children's conceptual learning from informal activities.

Conclusions and implications for practice

Overall, families that researchers invited to create digital stories during tinkering talked more to their imagined audience, and the children in these families talked more about engineering at reflection and remembered more about their engineering activities weeks later. These findings provide support for the idea that digital storytelling, in which children and caregivers co-construct creative, shareable video narratives and reflections, can support children's communication, memory, and learning processes (Hillman et al., 2015; Niemi et al., 2018; Wu et al., 2021). We believe that digital storytelling during learning activities may provide a familiar framework for children to verbalize their thoughts and ideas in a way that is understandable to others, thereby facilitating their own learning. Our findings extend existing theories and research demonstrating that the style of parents' and children's conversations during learning activities—in this case, whether they communicated to an imagined audience—may relate to children's memory and learning (Haden et al., 2014; Jant et al., 2014; Pagano et al., 2020; Vygotsky, 1978). Our study focused on digital storytelling because the use of photo, video, and audio technologies has become prevalent in children's daily lives (Coyne et al., 2014; Kelly et al., 2023; Robin, 2008), but parents, educators, and practitioners express concerns over whether and how children's use of technology may affect their learning (Anderson & Subrahmanyam, 2017; Coyne et al., 2014; Kelly et al., 2023). Our study builds upon Joint Media Engagement Theory (Takeuchi & Stevens, 2011) and Positive Technological Development Theory (Bers, 2012), as we find that children's and caregivers' active co-construction of creative, shareable digital stories may support, not hinder, children's memory and learning. However, some work has shown that the use of digital technology during informal learning activities can distract families and interrupt parent–child interactions (Kelly et al., 2023), so research is needed to understand how factors like prior experience with digital media, learning context, and adult-child interactions moderate the impact of digital storytelling on children's learning.

Digital storytelling is being integrated into educational activities both in and out of school. The current study took place in families' homes, and parents may find it useful to allow children to video-record their play and learning activities if they wish, as such opportunities for regular documentation may foster children's encoding and consolidation of new information (Wu et al., 2021). In the context of schools, many teachers are now utilizing digital learning spaces and games and asking students to share their learning with their classmates online (Laine et al., 2016). Existing studies in schools indicate that inquiry-based projects involving digital storytelling produce lasting learning (Hung et al., 2012; Niemi et al., 2018). We posit that digital storytelling—as long as it involves productive elements like creativity, collaboration, and communication—may aid students in expressing their complex inner thoughts and reflecting on their observations as they work through new challenges in the classroom (Wu et al., 2021). Finally, many families bring smartphones with them when visiting informal learning spaces, so museums may provide stations for taking photographs and prompts to start reflective conversations (Hillman et al., 2015; Kelly et al., 2023). Some museums have even constructed video- and audio-recording spaces where visitors can sit together and record reflections about their activities (Haden et al., 2014; Pagano et al., 2019). These kinds of digital storytelling opportunities may help children to extend and transfer their learning across contexts, such as from the museum to home (Marcus et al., 2021). In sum, encouraging children to create and share stories may foster remembering of informal STEM learning experiences and even lead to lasting impacts.

FUNDING INFORMATION

This research was supported by the National Science Foundation under collaborative grant #1906940/#1906808/#1906839.

CONFLICT OF INTEREST STATEMENT

We have no known conflicts of interest to disclose.

DATA AVAILABILITY STATEMENT

For participants' privacy and confidentiality, the data necessary to reproduce the analyses presented here are not publicly accessible. The analytic code necessary to reproduce the analyses presented in this paper is not publicly accessible, and the analyses presented here were not preregistered. The materials necessary to attempt to replicate the findings presented here are publicly accessible—many are available in the Supporting Information, and others are available from the first author upon request.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Pagano, L. C., George, R. E., Uttal, D. H., & Haden, C. A. (2024). "You gotta tell the camera": Advancing children's engineering learning opportunities through tinkering and digital storytelling. *Child Development*, *00*, 1–14. https://doi.org/10.1111/cdev.14094