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TangibleTale: Designing Tangible Child–Parent Interactive Storytelling for Promoting Eating Behaviors

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ABSTRACT

Tangible narrative allow children to interact with physical objects and provides an immersive storytelling approach to influence their cognition and behavior. However, research on using tangible narratives to encourage behaviors in children remains limited. To improve children's eating behaviors, we combined narrative transportation theory with behavior change principles to conduct a design study, called TangibleTale. Specifically, we conducted a formative user study ($N=12$ pairs) to identify the characteristics of children's engagement with tangible narrative and their interactions with parents, which were then incorporated into a design workshop ($N=12$) to develop an interactive product comprising tangible elements and an accompanying app. With the produced outcomes, we conducted a comparative experiment ($N=24$ pairs) in a home setting to verify and explore the role of tangible narrative in child–parent mealtime interaction. Finally, we formulated design guidelines for a tangible narrative that can serve as a reference to assist in creating more impactful products that foster positive behavioral growth in children.

KEYWORDS

Tangible interface;
interactive storytelling;
child-parent interaction

Early childhood experiences significantly influence long-term behavior, forming the foundation for future learning, health, and behavior (Caspi et al., 2005). Therefore, promoting healthy behavior during this critical period is essential. Various theories and tools have been developed to make behavioral interventions more engaging and enjoyable for children, encouraging their active participation in learning activities (Parker & Thomsen, 2019). Among these methods, using the power of narrative is particularly effective (Tayler, 2015; Whorrall & Cabell, 2016). Storytelling, grounded in narrative as a cognitive tool, is particularly effective for children, who often experience emotional changes in response to plot developments, guiding them through the progression of the story.

However, most contemporary interactive storytelling technologies focus on digital formats, resulting in screen-based interactions between children and parents. Although these digital interfaces can be engaging and user-friendly, their instructional power is limited due to the abstract nature of two-dimensional representations (Revelle et al., 2005). For cognitive developmental reasons, embedding interactivity into tangible elements can significantly benefit children by engaging embodied cognition. This approach provides a more intuitive way for children to understand

the world as they grow (Jensen et al., 2012; Kirsh, 2013). Furthermore, physical-sensory cognition helps children grasp abstract emotional and learning experiences (Hartson, 2003). Thus, the absence of a tangible narrative and associated interaction methods represents a missed opportunity for enhancing children's behavioral development.

To address the gap in promoting healthy eating behaviors in children, we proposed a tangible narrative method specifically designed for this purpose. This approach constructs tangible stories to foster healthy behavior development. We conducted a series of formative studies to develop comprehensive guidelines, aiding designers in implementing more effective design practices. These studies helped us progressively derive design principles by empathizing and defining tangible story representations ($N=12$ pairs), developing design strategies in workshops ($N=12$ designers), and creating prototypes for a case study to validate the TangibleTale system ($N=24$ pairs). This process provides insights into the potential impact of our system on promoting children's behaviors in daily life. Finally, we derived insights from the experiments into a set of easily accessible TangibleTale design principles and guidelines, including how to design software and hardware systems that support parent-child interaction and the implementation of narrative elements in

the design. This structured framework empowered designers to create interactive storytelling experiences that effectively engage children and encourage positive behavioral changes.

Our main contributions include:

- We introduce a theoretical pathway that connects tangible narrative elements with narrative transportation theory, rooted in practical formative studies. This framework encourages healthier eating behaviors in children by providing a basis for understanding how tangible interactions influence behavior.
- Through rigorous controlled experiments, we empirically validate the TangibleTale system's effectiveness in enhancing children's eating behaviors. The findings indicate that tangible narrative sustains children's engagement and exerts a more significant influence on behavior compared to traditional oral storytelling methods.
- We present a structured approach with detailed design guidelines for integrating narrative and tangible elements. These guidelines serve as a reference for designers, supporting the application of tangible narrative across various behavioral domains and enhancing the interactive storytelling experience.

1. Related work

1.1. The power of narrative techniques for children behavior development and change

The early years of a child's life are vital for their overall growth and development, with the implementation of healthy behavioral interventions during this critical period playing a central role in shaping their long-term outcomes (Baker et al., 2019). Various theories and approaches for promoting children's behavioral development and modification are introduced during the initiative versus guilt stage of psychosocial development, a phase characterized by children's assertion of autonomy and control through engagement in play and social interactions (Erikson, 1993).

Drawing on research on early childhood characteristics, numerous theories and techniques have been developed to modify children's behavior. Applied behavior analysis (ABA) is a widely adopted approach that focuses on teaching new skills, reducing problematic behaviors, and promoting positive behavioral changes through the principles of behavior (Cooper et al., 2007). The effectiveness of ABA has been extensively documented in child development studies. Concurrently, cognitive-behavioral therapy is commonly utilized to equip children with coping mechanisms, problem-solving skills, and cognitive restructuring techniques tailored to address diverse behavioral challenges (Butler et al., 2006; Hofmann et al., 2012). Social learning theory emphasizes the influence of observational learning on children's behavior (Bandura & Walters, 1977), while goal-setting theory highlights the importance of establishing attainable objectives (Locke & Latham, 2015). Furthermore, self-monitoring theory suggests that children can enhance their understanding of behavioral patterns and cultivate positive behaviors

through self-monitoring and recording (Gangestad & Snyder, 2000).

Narrative theory provides a unique and powerful approach to influencing behavior change in children. Narrative transportation theory suggests that narrative shapes emotions, beliefs, and intentions, thereby driving shifts in attitudes and behaviors (Green & Brock, 2000; Murphy et al., 2011; Van Laer et al., 2014). Similarly, "narrative engagement" indicates that individuals integrate narrative experiences into their own lives, further facilitating behavior change (Busselle & Bilandzic, 2008; Dahlstrom, 2010). Group storytelling has also emerged as a valuable tool for implementing caregiving interventions and improving mental well-being (Braga et al., 2011). Additionally, the Extended Elaboration Likelihood Model demonstrates that narrative can reduce cognitive resistance and increase receptivity to persuasive content, ultimately leading to positive behavioral outcomes (Slater & Rouner, 2002).

Narrative techniques have been widely explored and applied across various domains, including human-computer interaction, education, and entertainment (Gudmundsdottir, 1991; Zhou et al., 2004). Consequently, their versatility and effectiveness in promoting behavior change in children have been highlighted. Researchers have thus drawn on scholarly evidence to adopt the narrative approach in early childhood education, aiming to enhance children's receptivity to guidance and support behavior change (Griffith et al., 2016). While there are many technology-driven solutions to promote active lifestyles, these often fall short in engaging children, especially those who may lack self-discipline and common sense (Nelsen et al., 2011).

1.2. Tangible narrative in storytelling

Storytelling, whether in oral (Homaei et al., 2009), visual (Lugrin et al., 2010), or written forms (Harper, 2016), plays a central role in various types of media, including novels, movies, comics, and dramas. The prevalence of storytelling in culture can be explained by using narrative as a cognitive tool for contextual understanding (Gerrig, 2018). This cognitive tool is not only essential in media but also in everyday interactions, such as understanding a child's non-verbal language. Decoding a child's non-verbal cues means being able to enter their world and understand its multifaceted details, even when facing the discomforts they may experience (Evangelista et al., 2009).

To make stories vivid and engaging, tangible interfaces have been combined with storytelling, a practice known as tangible narrative. Here, it is worth noting that in existing literature, tangible narrative is typically framed as hybrid interactive experiences that digitally map narrative content to physical artifacts and environments (Echeverri & Wei, 2023). However, in this paper, we extend this concept to include tangible narrative that do not necessarily rely on digital methods for the mapping process. For example, pop-up books exemplify tangible narrative that does not rely on digital methods, offering three-dimensional and tactile elements in the storytelling process. These books engage readers more tangibly than traditional methods through interactive features such as moving pieces (e.g., pull tabs, volvelles, or rotating

mechanisms) (Phillips & Montanaro, 2014), making the story more dynamic and immersive (Newell, 2017).

Further, tangible narrative enhance user immersion by leveraging embodied interaction, a concept explored by Dourish (2001), which examines the interplay between the environment, human behavior, and cognition. Embodied interaction is closely related to embodied cognition, both emphasizing the significance of the body and its surrounding environment in shaping cognitive processes and interactions. Embodied cognition posits that cognitive processes do not solely occur within the brain but are influenced by the interactions between the body and the environment (Gee, 2023). This means that our physical interactions and experiences with the world shape our understanding and cognition.

Therefore, embodied cognition offers a theoretical basis for understanding the value of tangible narrative (Fishkin, 2004). Tangible narrative provides embodied information through physical interaction, creating opportunities for deeper engagement. By connecting abstract concepts with specific physical actions or figures (Jensen et al., 2012), tangible narrative enrich the learning experience and open new avenues for design (Kirsh, 2013). Despite this, the potential of tangible narratives to influence children's behavior remains largely untapped (Figure 1).

1.3. Children-parent interactive storytelling

Interactive storytelling enhances children's engagement, creativity, and enjoyment while fostering strong interpersonal relationships. It involves joyful activities that encourage active thinking, experimentation, and social interaction, which are critical for children's learning and development (Parker & Thomsen, 2019). While modern interactive technologies, such as mobile storytelling and mixed reality, expand the possibilities for storytelling, they also introduce complexities in narrative structure that may challenge younger audiences (Mazalek, 2001).

However, technology alone is not sufficient. Parental involvement plays a crucial role in making stories more engaging and meaningful for children. Studies have shown that when parents actively participate in storytelling, children's enthusiasm and engagement significantly increase

(Kim et al., 2018, 2020). Parents can adapt the storytelling experience in real-time, responding to their children's reactions and deepening their understanding of their children's thoughts and emotions.

Furthermore, active parental involvement in storytelling not only enhances the quality of the interaction but also promotes behavioral change, as children often emulate the behaviors modeled by their parents during these sessions. For instance, studies have shown that in parallel interaction through co-located and object-oriented storytelling, parents and children can construct stories interactively, leading to popular adaptation and positive engagement with the system (Chen et al., 2020). Similarly, research on wearable stories for children has highlighted the benefits of using wearable technology to support parents in facilitating and tracking their children's interest in and engagement with stories (Kim & Bacos, 2023). Additionally, studies on traditional and computer-based storybook reading demonstrate that the way parents interact with their children during joint book reading can significantly impact the development of vocabulary, literacy skills, and social and emotional growth (Lauricella et al., 2014).

In summary, the integration of interactive storytelling with active parental involvement represents a promising approach to enhancing children's development. This collaborative approach turns storytelling into a vital educational tool, fostering learning, empathy, and behavioral improvement.

1.4. Solutions to improve children's eating behaviors

Poor eating behaviors among children, such as picky eating and food refusal, are common issues that significantly impact their healthy development and impose considerable stress and burden on parents (Fisher et al., 2021; Hu et al., 2019; Taylor & Emmett, 2019).

There have been numerous design efforts aimed at improving children's eating behaviors. For example, Kadomura et al. (2014) combined sensor-equipped utensils with mobile story games to motivate children to eat properly while educating them on the importance of a balanced diet. MAMAS is a mealtime assistant that uses magnetometers and speech recognition to analyze interactions between children and parents during meals, promoting healthy eating behaviors in children (Leem et al., 2018).

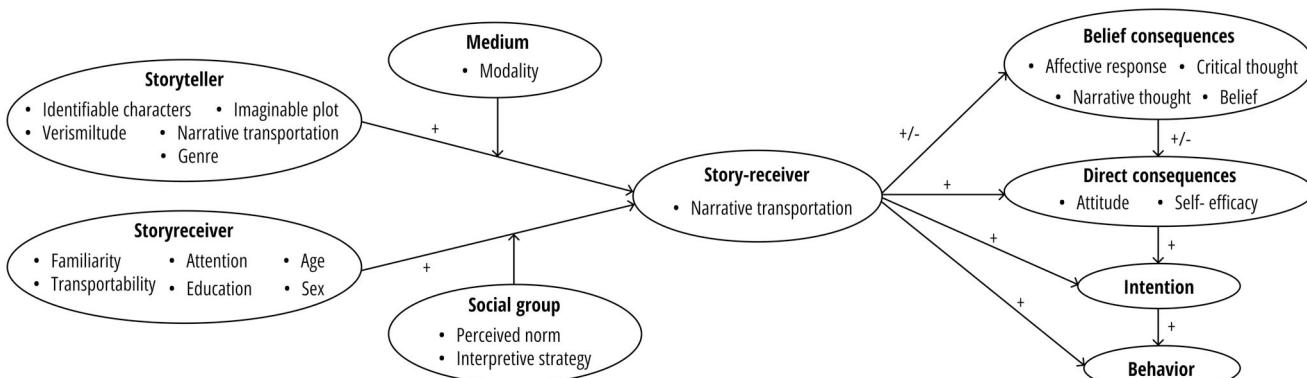


Figure 1. An overview of extended transportation-imagery model, which illustrates the process of narrative transportation and the factors that (may) influence its effectiveness. Figure adapted from Van Laer et al. (2014, pp. 797–817).

EdibleToy combines food with deformable wafer paper, allowing children to create transformable foods, thereby increasing their interest and engagement in eating (Shao et al., 2023).

However, existing solutions often require complex hardware or special materials, while the tangible narrative emphasizes integrating tangible elements with storytelling. This approach naturally captures children's attention and stimulates their intrinsic motivation through engaging storylines, making it more suitable for long-term use in home environments. In the field of Human–Computer Interaction (HCI), exploring the use of tangible narrative for interventions in children's eating behaviors is a promising and innovative method that has the potential to significantly improve their dietary habits (Table 1).

2. Supportive theories

Stories have been intertwined with human society since the beginning, influencing individuals from birth (Boyd, 2009; David et al., 2002). The use of functions, actions, and discourses as three different levels of structure makes the creation and interpretation of stories reasonable and even pleasurable (Barthes & Duisit, 1975). Stories lead to the activation of affective, cognitive, and belief changes in the audience, eventually impacting their attitudes, intentions, and behaviors (Adaval et al., 2007; Adaval & Wyer, 1998; Pennington & Hastie, 1988). In this chapter, we introduce narrative transportation theory (NTT), which proposes that when consumers lose themselves in a story, their attitudes and intentions may change to reflect that story (Green, 2008), to explain the potential for behavior change through storytelling (Table 2).

Table 1. Basic information of 12 pairs of participants in formative study 1.

ID	Age	Gender	ID	Age	Gender	ID	Age	Gender
P1	35	Female	P5	38	Female	P9	39	Female
C1	5	Female	C5	3	Male	C9	4	Female
P2	34	Male	P6	37	Male	P10	37	Female
C2	3	Female	C6	6	Male	C10	3	Female
P3	40	Female	P7	38	Male	P11	35	Female
C3	6	Male	C7	6	Female	C11	6	Male
P4	29	Female	P8	32	Female	P12	30	Male
C4	4	Female	C8	5	Male	C12	4	Male

"P" denotes parent, and "C" denotes child.

2.1. The definitions of story and narrative

To better comprehend the narrative transportation theory, it is essential to first understand the definitions of story and narrative in terms of narrative transportation.

Often, the terms 'story' and 'narrative' are used interchangeably (Van Laer et al., 2014). However, according to Thompson (1997)'s analysis, a narrative is derived from the process of endowing a story with meaning and interpretation. In classical narratology, a narrative text is defined as a text in which an agent or subject conveys a story to an addressee through a medium. A story is the content of a narrative text that provides specific manifestation, inflection, and "coloring" to a fabula. A fabula is a sequence of logically and chronologically related events caused or experienced by actors (Bal, 2009). From these definitions, it is evident that the concepts of 'story' and 'narrative' are interrelated and not entirely distinct. This paper refers to Van Laer et al. (2014)'s research to reinterpret the meanings of 'story' and 'narrative' within its context (Table 3).

Firstly, a story is defined as a depiction by the storyteller of one or multiple events that transition from an initial state to a subsequent state or outcome (Bennett & Royle, 2023; Van Laer et al., 2014). In contrast to a series of sequential sentences, a story encompasses four essential components: 1) a plot delineating the chronological order of events; 2) characters assuming roles within the plot; 3) a climax resulting from the modulation of dramatic intensity throughout the plot; 4) an outcome representing the conclusive state of the plot (Banerjee & Greene, 2012; Green & Brock, 2000; Phillips & McQuarrie, 2010; Stern, 1994).

Narrative, on the other hand, is defined as the consumption of the story by the story receiver (Van Laer et al., 2014). The story receiver themselves are not merely readers of the story but active interpreters of the narrative, which means that through the process of reading and interpretation, they engage with the story (Weick, 2004). This interpretation process has the potential to transform consumption into a memorable experience (Deighton, 1992).

2.2. Narrative transportation theory

Narrative transportation is a phenomenon that occurs when the story receiver psychologically enters the world of the story. Within the field, scholars have repeatedly mentioned

Table 2. Basic information of the designers in formative study 2.

ID	Gender	Background
D1, D11	Male	Industrial designers focusing on behavioral change, with 5 years of design experience
D2	Male	Industrial designer with 4 years of experience
D3	Female	Illustrator with 7 years of experience
D4	Male	Industrial designer with 4 years of experience
D5	Male	Industrial designer with 4 years of experience
D6	Female	Industrial designer with 4 years of experience
D7–8	Female	Graphic designer with 8 years of experience
D9	Male	Industrial designer with experience in toy design
D10	Male	Industrial designer with experience in toy design
D12	Male	Illustrator with 5 years of experience
D13	Female	Industrial designer with experience in toy design
D14	Male	Industrial designer with 3 years of experience
D15	Male	Senior designer with experience in toy design

"D" denotes designer.

**Table 3.** Basic information of the children and parents participating in the case study.

Experiment Group					
ID	Age & Gender	ID	Age & Gender	ID	Age & Gender
Group 1	Parent:35; Female Child:5; Female	Group 5	Parent:36; Female Child:4; Male	Group 9	Parent:33; Male Child:3; Male
Group 2	Parent:34; Female Child:5; Male	Group 6	Parent:32; Female Child:3; Female	Group 10	Parent:36; Female Child1:4; F; Child2:5; M
Group 3	Parent:30; Female Child:5; Female	Group 7	Parent:32; Male Child:4; Female	Group 11	Parent:35; Male Child1:6,M; Child2:5,M
Group 4	Parent:33; Male Child:5; Male	Group 8	Parent:32; Female Child:3; Female	Group 12	Parent:42; Female. Child1:6,M; Child2:6,M
Control Group					
Group 13	Parent:32; Female Child:4; Male	Group 17	Parent:39; Female Child:6; Female	Group 21	Parent:40; Male Child:3; Male
Group 14	Parent:38; Female Child:3; Male	Group 18	Parent:35; Female Child:4; Male	Group 22	Parent:37; Female Child:6; Male
Group 15	Parent:32; Male Child:5; Male	Group 19	Parent:33; Female Child:4; Male	Group 23	Parent:35; Male Child:6; Female
Group 16	Parent:34; Male Child:5; Female	Group 20	Parent:35; Female Child:4; Female	Group 24	Parent:31; Female. Child:3; Female

"P" denotes parent, and "C" denotes child.

three related features of narrative transportation (Van Laer et al., 2014): firstly, the story receiver needs to receive and interpret the story; secondly, the story receiver is transported through empathy (Slater & Rouner, 2002) and mental imagery (Green & Brock, 2003), where empathy refers to knowing and feeling this world in the same way as the characters in the story, and mental imagery refers to the story receiver generating vivid images based on the story plot, as if they were experiencing events with the characters in the story; thirdly, during transportation, the story receiver may lose track of reality in a physiological sense. Based on these features, narrative transportation can be defined as the extent to which the story receiver empathizes with the story characters and the story plot activates their imagination.

Narrative transportation ultimately leads to persuasion in the story receiver (Van Laer et al., 2014). Compared to traditional analytical persuasion, narrative persuasion is more effective than cognitive, with potentially enduring effects (Appel & Richter, 2007).

Previous research has explored the influencing factors of narrative transportation effects, forming the transportation-imagery model (Green & Brock, 2003). Subsequent studies have further investigated the potential consequences of narrative transportation based on this model, resulting in the extended transportation-imagery model (Van Laer et al., 2014).

The effects influencing narrative transportation consist of two antecedents (Van Laer et al., 2014). Firstly, from the storyteller antecedents perspective, it is noted that "The more stories have characters with whom story receivers can identify, a plot that story receivers can imagine, and verisimilitude, the more narrative transportation increases". From the story receiver antecedents' perspective, research indicates that "the more story receivers are familiar with a story topic, pay attention to a story, possess transportability, are young, are educated, and are female, the more narrative transportation increases".

When it comes to the consequences of narrative transportation, Van Laer et al. conclude "The more narrative

transportation increases, the more story-consistent affective responses increase, critical thoughts decrease, narrative thoughts increase, story-consistent beliefs increase, story-consistent attitudes increase, and story-consistent intentions increase (Van Laer et al., 2014)."

Due to limitations in research methods and data availability, there may still be other factors influencing the effects of narrative transportation and potential consequences. Among these, behavioral change is one potential consequence. Van Laer et al. speculate, "The more narrative transportation increases, the more story-consistent behavior increases" (Van Laer et al., 2014). In fact, narrative has been shown to have a positive impact on health behavior in some studies (Moyer-GusA & Nabi, 2010; Murphy et al., 2015; Zhou et al., 2020). Braddock and Dillard (2016), on the other hand, assess the durability of the narrative-persuasion relationship and hypothesize and validate that "Exposure to a narrative produces story-consistent change in beliefs, attitudes, intentions, and behaviors."

3. Study procedure

Our objective is to improve children's eating behaviors through the creation of tangible narrative during interactions with their parents. To accomplish this, we have synthesized theoretical materials and conducted a series of empirical studies to formulate the guidelines, as shown in Figure 2.

3.1. Supportive theories

To enhance our design methodology for promoting children's eating behaviors through tangible narrative, we build on the previously discussed narrative transportation theory. Recognizing its widespread application and proven effectiveness in various fields, we leverage this theory to inform our approach.

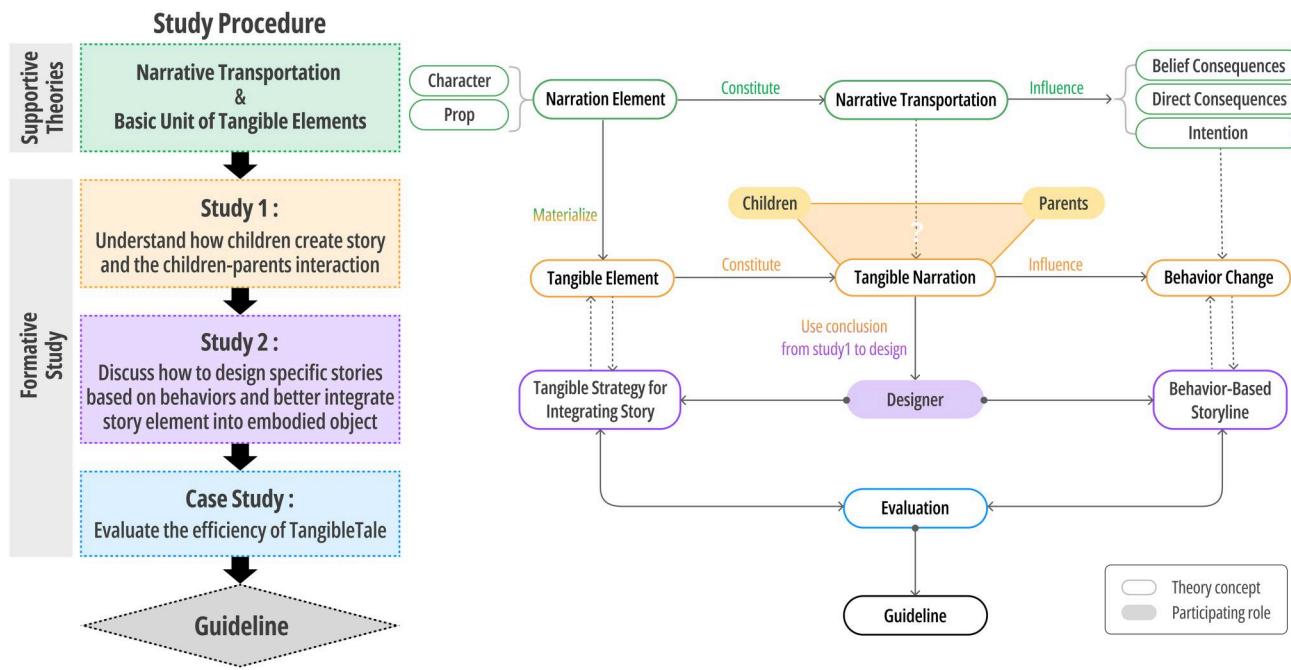


Figure 2. This figure illustrates the comprehensive research process, highlighting the conclusions drawn at each stage and the interconnections between different phases of the study. It depicts how we integrated theoretical exploration with practical experimental results to ultimately develop design guidelines for TangibleTale, aimed at fostering behavior change in children.

3.1.1. Study 1 – understanding child-parent storytelling interaction

Before the study, we first provided a comprehensive library of tangible elements to facilitate children in crafting their stories. Then, we conducted an observational study with 12 child-parent pairs. Our results reveal how (1) children tell stories based on different types of tangible elements, and (2) parents link the stages of story development to behavior change guidance.

3.1.2. Study 2 – design workshop with designers

A design workshop with designers ($N=12$) translated the insights from our study 1 into specific strategies for tangible-based story construction and enhancing child-parent interactions: (1) Introduce tangible story references based on the purpose of behavior change. (2) From the designers' perspective, suggest strategies for integrating tangible components into the narrative setting. (3) Propose a set of auxiliary tools, encompassing both software and tangible products, designed to assist users in developing narrative plots.

3.1.3. Study 3 – case study

We conducted an evaluation of the TangibleTale system within the context of enhancing children's eating behaviors. To assess the effectiveness of our approach, we implemented a one-week case study with 24 child-parent pairs, divided into two groups: 12 pairs used the TangibleTale system, forming the experimental group, and 12 pairs engaged with OralTale (traditional oral storytelling), forming the control group. This comparative experiment not only validated the

effectiveness of narrative but also highlighted the advantages of tangible narrative, with the analysis incorporating both quantitative and qualitative research methods.

3.1.4. Guideline

Building on insights from the earlier sections, we synthesized the findings from three formative studies to develop comprehensive tangible narrative design guidelines. These guidelines are intended to support designers in leveraging narrative techniques to drive behavior change in children, specifically through the integration of tangible elements in storytelling.

4. Formative studies

4.1. Formative study 1: Understanding children–parent storytelling interaction

To ensure that the tangible narrative was both user-friendly and easily accepted by children, we conducted an observational study to identify key characteristics and commonalities in children's storytelling. This study provided valuable insights into the logic children use when engaging with stories that incorporate tangible elements, as well as the methods parents employ to intervene and guide the storytelling process. Our formative study was approved by the IRB of our institute (Approval NO. [2024]109).

4.1.1. Preparation: Tangible element

Creating a story always involves choosing and developing five basic elements: setting, character, plot, conflict, and theme. For tangible narrative, the characters and props

(a) Character Library				(b) Prop Library					
	Artificial			Natural			Small	Medium	Large
	Small	Medium	Large	Small	Medium	Large			
Theatre Props									
Display Props									
Atmospheric Props									
Even Theater Props									

Figure 3. This figure showcases two libraries: (a) character library featuring a variety of rabbit characters, each with distinct appearances to encourage diverse storytelling. (b) Prop library categorized into artificial and natural props, further divided by size and function (theatre Props, Display Props, Atmospheric Props, and even theater Props) to support various narrative scenarios.

could be physically provided and the other elements of the story could be supplemented from the creation of children and parents. Thus, we decomposed tangible elements into two sub-categories: (1) characters and (2) props. Based on this, we provided two types of tangible element sets: a character library and a prop library. Children could select from these collections to create stories during the experiment.

We pre-categorized characters to ensure a diverse selection for children. As illustrated in Figure 3(a), we provided 20 character options, each with distinct visual characteristics. Our objective was to explore the relationship between different character types and storylines rather than explore all possible variations. To do this, we selected a specific character type and presented a series of stylistically varied characters. We chose the rabbit as our focus because it frequently appears in children's stories, picture books, and cartoons, making it widely recognizable and relatable to children. Moreover, rabbits can represent a range of personality traits. It is important to note that, given the diverse visual perceptions among children regarding tangible elements, we did not impose strict classifications on the characters. Instead, we presented them as part of a library and explained to the children that these characters could be categorized based on abilities, moral qualities, and backgrounds, as determined by the children themselves (Frye, 2006).

The categorization of props is more straightforward and intuitive. As illustrated in Figure 3(b), props are divided into three main categories based on their function: *Theatrical Props* (items directly related to character performance), *Display Props* (objects that enhance the visual setting of the performance), and *Atmospheric Props* (items that create or enhance the ambiance and help convey the story's context).

Additionally, we considered whether the props are artificial or natural objects. Props are further categorized by size into three dimensions: small, medium, and large.

4.1.2. Participants

We recruited 12 children and their parents through offline visits. This age group was selected based on Erikson (1993)'s theory of psychosocial development, which states that children between the ages of 3 and 6 are in the initiative versus guilt stage. During this stage, children begin to assert their power and control over the world through play and social interactions.

During the formative study, parents sat beside their children, guiding them in creating stories to bridge the connection between real-life behavior and the virtual narrative. All participants signed a consent form approved by our institution (Approval NO. [2024]109]).

4.1.3. Procedure

Each session of the formative study was videotaped and lasted approximately 30 minutes.

We listed the procedure as follows.

- **Introduction to Definitions and Motivation.** After obtaining informed consent from the parents, we first introduced the study's motivation and experimental method to them. The children were then briefed on their tasks and encouraged to express themselves freely during play.
- **Brainstorming with a Single Character.** Initially, we provided each child with a character element to stimulate associations and facilitate story creation. If the child

encountered obstacles, we allowed three minutes for reflection. When necessary, we asked three guiding questions related to the scenes, events, and characters, and introduced additional characters or props to help fill in any gaps.

- **Brainstorming with Multiple Characters.** As the number of story elements increased, we shifted our focus from basic story elements to exploring the broader context. We encouraged the children to think creatively about the logical cause-and-effect relationships within the plot, the sequence of events, and other narrative aspects.
- **Behavior-Related Prompts.** When the story's development involved behavior-related scenarios (e.g., sleeping, walking, eating), we provided prompts about potential character actions to gain insight into the children's daily routines and the parents' usual responses. For example, if the story mentioned that the rabbit was going to bed, we might ask, "*What time is it?*" to encourage further story development.
- **Parental Engagement.** When children proposed ideas about character behaviors, we encouraged parents to co-create the story with them. Additionally, parents were advised to guide the main character toward positive behaviors.
- **Semi-Structured Post-Interview.** At the end of the study, we conducted individual interviews with each group of participants to discuss the characteristics of the children's stories and the nature of parent-child interactions. Furthermore, each group of participants (including both children and parents) was asked to vote for their favorite story. The selected stories were determined based on these voting results.

4.1.4. Findings: Tangible narrative

- **Characteristics of Children's Storytelling.** Overall, the storylines generally followed the four traditional stages of narrative structure—'beginning, development, climax, and ending'—which align with the typical developmental pattern of novels (Morrow, 1985). **Beginning:** In the experiment, more than half of the children first selected a specific rabbit from among the various toys as the foundation for their story's development. Simultaneously, they often set up various backgrounds for the story, establishing conditions and goals for the characters' subsequent actions. We referred to this stage as the beginning. **Development and Climax:** As the narrative progressed, the children engaged different characters and props, creating interactions that led to the build-up of narrative tension. Through cooperative or conflict-driven plots, the story's atmosphere and emotions gradually intensified, reaching a climax. For example, C3 and C7 used props like shovels and wings to help the rabbit protagonist obtain food or defeat enemies. The protagonist's journey toward the final goal typically unfolded during these stages, which we identified as the development and climax of the story. **Ending:** Finally, the children depicted the completion of the protagonist's goal. However, the conclusion of these short stories often left room for further narrative development, as children

frequently described endings as dynamic states, leaving ample space for future expansion and added interest. We referred to this stage as the ending.

- **Children's Narrative States.** Throughout the study, we observed fluctuations in the children's narrative engagement, including emotional highs and lows, as well as varying levels of enthusiasm for story creation. For instance, when C10 interacted with a twig prop, they associated it with a magic wand from their real life, which allowed them to independently create subsequent storylines, leading to a more effective storytelling experience. When children were immersed in the narrative, they not only advanced the story spontaneously but did so at a faster pace, investing more emotion and experiencing a stronger effect of narrative transportation. Conversely, when they encountered storytelling obstacles, they required external assistance to continue the story, struggled with empathy for the narrative, and experienced weaker effects of narrative transportation. Based on these observations, we categorized children's narrative states into three types: negative, average, and positive.
- **Influence of Characters on Plot Development.** Our experimental observations revealed that different character archetypes influenced the development of children's storylines in unique ways. A distinctive protagonist, for example, often drove the narrative forward through their actions and decisions. Supporting characters with more modest abilities added diversity, enriching the story's complexity. Meanwhile, antagonists representing injustice typically created conflicts with the protagonist, propelling the story toward its climax. **Strategies for Child-Parent Interaction.** Children encountered various situations while creating stories, affecting both the quality of their storytelling and the effectiveness of behavior change. Parents, while assisting in story creation, provided targeted guidance based on their child's level of engagement and the specific behavior change goals. For instance, parents like P1 and P8 introduced new rabbit characters or visually appealing props, such as carrots or clocks, to recapture their children's attention when engagement waned. This approach not only enhanced interaction opportunities but also sustained the children's interest in the story. Parental support needed to be tailored according to the child's state during storytelling. Children's engagement and creativity peaked when they were in a positive state, with the story progressing smoothly. In such cases, parents could reduce their intervention or add creative stimuli. Conversely, when a child's progress slowed, parents needed to introduce more direct story elements and creative ideas. If a child entered a negative state, parents had to provide content creation assistance and emotional support to re-engage the child. Specific parental strategies are illustrated in Figure 4.

4.2. Formative Study 2: Design workshop

To integrate user-centered findings from study 1 with design methodologies, we organized a design workshop. This

Factor Strategy \ Stage	Belief Consequences (Narrative Transportation can instill a belief in the authenticity of fictional stories.)		Direct Consequences (Narrative Transportation directly impacts the receivers' attitudes and self-efficacy.)		Intention (Narrative Transportation enhances the likelihood of receivers taking action according to narration.)	
Beginning	😊 Positive	Extend from the real world into the realm of stories	😊 Positive		😊 Positive	
	😐 average	Extend from the real world into the realm of stories	😐 average	1.Add supporting role 2. Infer relationship between characters	😐 average	
	☹️ Negative	Extend from the real world into the realm of stories	☹️ Negative	1.Add supporting role 2.Build characters' relationship	☹️ Negative	Stimulate by praising
Development	😊 Positive	Actively diverge plotlines	😊 Positive		😊 Positive	
	😐 average	Discuss the plot with parents	😐 average	Guide children to develop narrative-behavioral logic	😐 average	
	☹️ Negative	Discuss the plot with parents	☹️ Negative	1.Guide children to develop narrative-behavioral logic 2.Provide positive guidance	☹️ Negative	Reward
Climax	😊 Positive	Create conflicts, pushing towards a climax	😊 Positive		😊 Positive	
	😐 average	Create conflicts, pushing towards a climax with parents	😐 average	Evaluate the plot and characters of the story	😐 average	
	☹️ Negative	Create and solving conflicts, pushing towards a climax	☹️ Negative	1.Administer justice 2.Caution against unreasonable behavior	☹️ Negative	Give verbal warnings
Ending	😊 Positive	Advance the story to conclusion and envision the sequel to the narrative	😊 Positive		😊 Positive	
	😐 average	Advance the story to conclusion and review the story	😐 average	Encourage children to learn from stories	😐 average	
	☹️ Negative	Continue to finish the story	☹️ Negative	Reveal the truths behind the story and align them with real-life behaviors	☹️ Negative	Assist children in advancing the story

Figure 4. The behavior-change-oriented narrative methods used in different behavior change stages. There are three levels—positive, average and negative, to represent the status of children's behavior change stage. At different behavior stage, diverse methods are proposed according to the narrative plot and the status of children.

initiative aimed to deepen parents' understanding of their children's narrative and to facilitate behavior change through these stories. Formative study 2 detailed the initial low-fidelity framework developed collaboratively with 15 designers and present a general case design distilled from this collaboration.

4.2.1. Participants

We recruited 15 designers (Female 6, Male 9; Ages: 20-39 years) from a local university and three local design studios. All participants had proficient design experience ranging from 3 to 8 years. Among them, 3 designers had experience in children's toy design, 2 designers were experienced illustrators, and 2 designers specialized in design related to behavior change. Each participant was compensated with \$25 after completing the design workshop. All participants signed a consent form approved by our institution (Approval NO. [2024]109]).

4.2.2. Procedure

The procedure of the workshop was summarized as follows.

- **Introduction.** We initially explained that the goal of our design workshop was to utilize design language to compress user-centered findings into generalized guidelines (e.g., some common tendencies in children's stories, how parents could better guide tale development to assist children in altering behavior). Then, to help them understand our targeted users, we introduced the findings of previous studies, covering (1) the concept and characteristics of tangible narrative, (2) the deconstruction and specific classification of the story elements, and (3) the narrative thinking of children.
- **During Task.** Participants were invited to create a story for their own use, employing hand-drawn illustrations, board drawings, or modeling. Each participant was asked to create a story, outline the key elements based on their

own narrative, depict the narrative elements, and craft a visually appealing story with specific scenarios. Additionally, participants were asked to create a specific ancillary item that accompanies their tangible story within the context of their use scenario. We instructed the designers to develop alternative tale developments for each level based on the performance of the children (negative, no-change, positive) (Park et al., 2018).

- **Focus Interview and Work Refinement.** We conducted a focus group discussion to delve deeper with this group of participants. Each participant was encouraged to share their creative ideas and logic. Then, we encouraged them to comment on each other's work, discuss, and have a collision of ideas. Finally, we urged participants to refine their work further by incorporating useful suggestions and ideas from others.

4.2.3. Workshop result

- **Tangible Strategy for Integrating Story.** From the designers' perspective, we proposed a universal tangible design strategy that integrates tangible elements into the usage environment. We believed that by using a baseboard to connect all props and utensils and designing matching connectors for the characters with the baseboard, characters with props, and props with the baseboard, more space for plot creation could be provided, such as interactions between characters, enhancement of characters' attribute functions, etc.
- **Behavior-Change Oriented Tangible Story.** Considering the convergence of some works, we presented three representative low-fidelity prototypes, as shown in Figure 5. We found that some designers made the story development highly related to detailed applications. For example, in P7's prototype, the rabbit was drinking Chinese medication, but the application scene encouraged children to drink medicine. Some designers believed that children's stories are free and spontaneous and that there was no need for parents to make the story relevant to precise application scenes. For example, in P14's prototype, despite his desire to assist children in brushing their teeth, the story was about a rabbit who crossed the mountain and eventually sold the turnips after careful irrigation and battling with robbers. Furthermore, all designers believed that giving parents more particular story development suggestions step by step, rather than overall findings all at once, would really be beneficial.

4.2.4. Case design

According to the suggestions from designers D2 and D15, the assistant tools were divided into two parts: a mobile application that allowed parents to acquire ideas on what actions they should take at each step, and tangible elements.

As shown in Figure 6(a and b), our tangible products included: (1) the tangible elements; and (2) the connecting component, which included the baseboard capable of holding the bowl and securing the tangible elements. The proposer of this connection scheme is D10. For the tangible

elements, we demonstrated a set of cases using rabbits as characters. The tangible connecting component was designed to facilitate the easy integration of our tangible elements into commonly used devices in practical settings. The baseboard had various bumps, allowing users to easily attach the elements to create stories. Additionally, the large board could support the swapping of different scenes, enabling users to place tableware, cups, and other items on it. We incorporated a notch structure on the bottom of the elements, allowing them to be securely attached to the baseboard.

However, it is important to note that the tangible connecting component may not be suitable for all dining scenarios, particularly in households where the table might not have sufficient space to accommodate it. While the tangible connecting component offers a stronger sense of narrative immersion, its use should be decided based on the practicalities of the setting.

Based on our workshop, we developed a mobile application to assist parents, eliminating the need to frequently consult the table. The software application interface was primarily designed by two illustrators, D7 and D8, to guide the selection of tangible elements. Other designers participated in the creation of the storylines.

As shown in Figure 6(c), the specific introduction of the functionalities was as follows:

- **Start.** After the children had completed the related activities and the parents had prepared their tangible elements, the parents could click Start to launch the application.
- **TangibleTale guidance.** This was a comprehensive interface that contained the recommended tangible product and suggestions on how parents could guide their children. In the Figure 6(c2), apart from the character and prop, we offered the event and the status of the main character to enrich the story. For parents, we provided leading suggestions including Promotion Method, Inspirational Method, Participating Method, and Education Method to inform them how to develop the story while inspiring children to learn from it. Additionally, Figure 6(c4), which contained different plots, was presented when children performed better or worse.
- **Progress.** As shown in Figure 6(c3), after finishing eating, this page had a line showing the progress of the story and an assessment of children's performance to prepare different story plots to map children's different statuses.
- **Congratulation.** This page was the ending page that encouraged parents and children to co-complete a trail of the tangible narrative behavior change experiment.

4.3. Case study: Evaluate the efficiency of guideline

The case study validated the effectiveness of applying tangible narrative to improve children's eating behaviors.

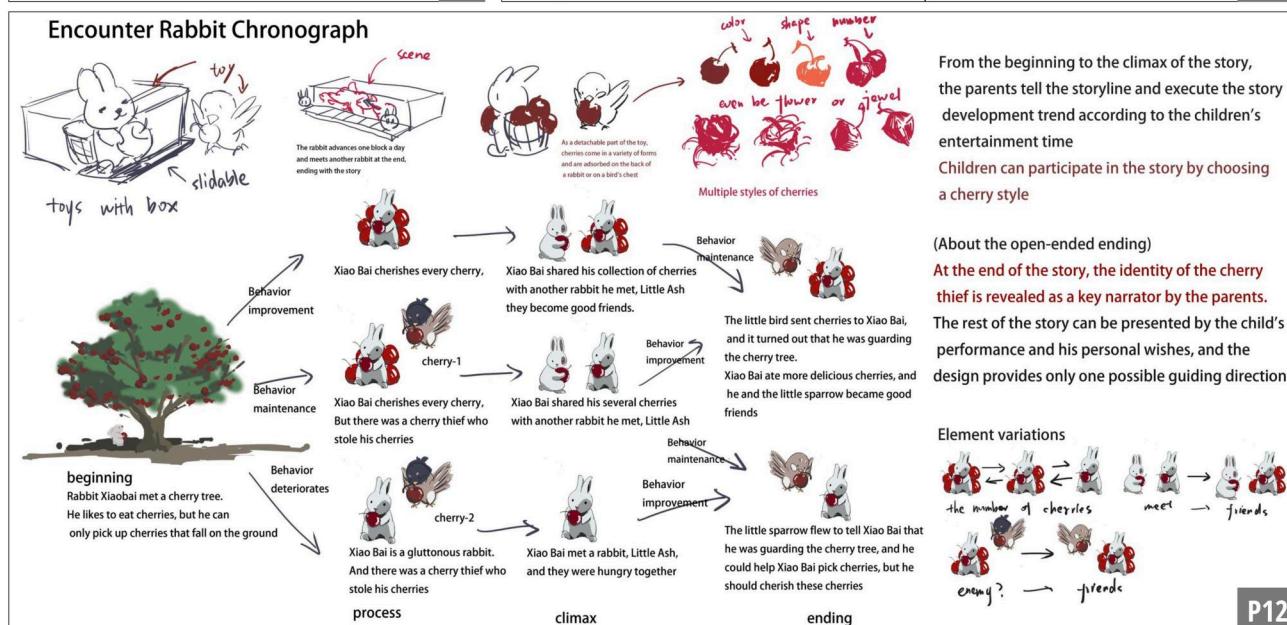
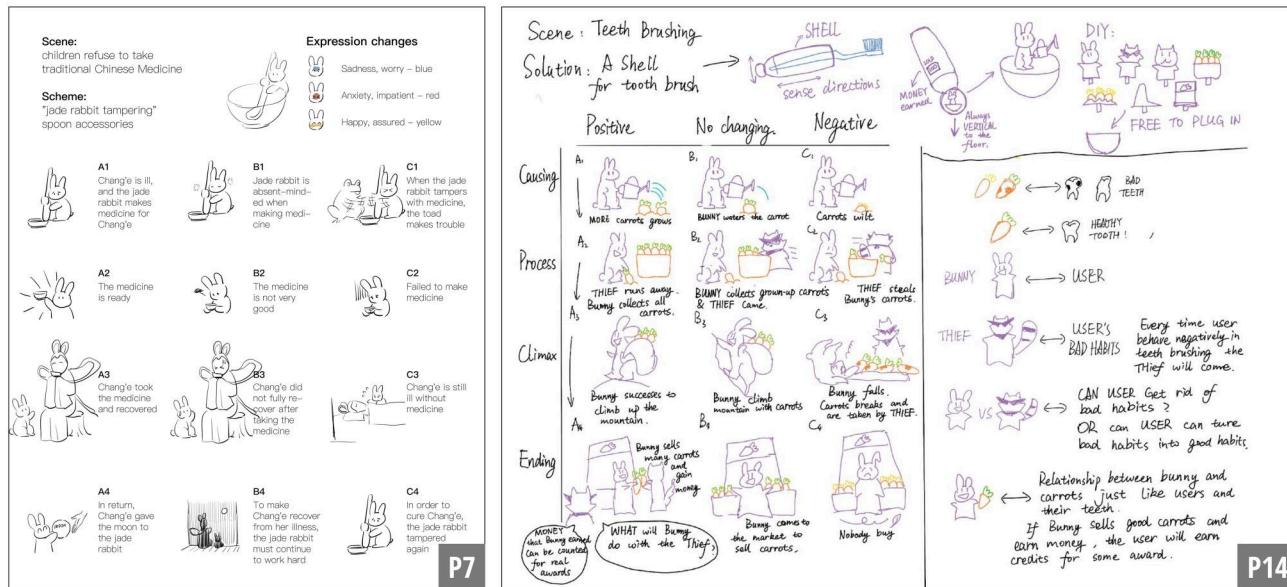


Figure 5. Low-fidelity prototypes developed during the workshop: the story on P7 was adapted from familiar children's stories for easier comprehension. The modular design approach on P12 and P14 allowed for volume accumulation, enhancing narrative depth and interaction.

4.3.1. Participants

A total of 24 groups of parents and children participated in the case study, half of them were the experimental group using TangibleTale (G1-12), half of them are the control group using the OralTale (G13-24), which means parents tell the story only in an oral way with the assistance of the application interface. The age of all sets of children was 3 to 6 years. Of note, there were four groups consisting of one parent and two children together. None of them had participated in Study 1 or Study 2. All participants received a \$25 gift card as compensation. Our case study was approved by the Institutional Review Board (IRB) of our institute (Approval NO. [2024]109).

4.3.2. Procedure

- Pre-task.** We gathered all participants' parents and conducted a preliminary interview about their children's

eating habits, which we compared with the examination results after utilizing TangibleTale or OralTale. Then, we walked the parents through the technique and flow of employing assistance tools. Both children and parents pre-tested to interact before the official task so that children would become more familiar with and comprehend the plot and characters, and parents would understand how to link story and behavior change counseling.

- During task.** The task was planned to last seven days, considering it a short cycle of behavior change (Baranowski et al., 2003). The goal was for children to participate in three meals a day with TangibleTale or OralTale, with parents assessing each meal and advancing the story as directed by the mobile app. However, it was emphasized that participation should be encouraged but not forced. Parents were advised not to push their children to use the system if they were unwilling or declined

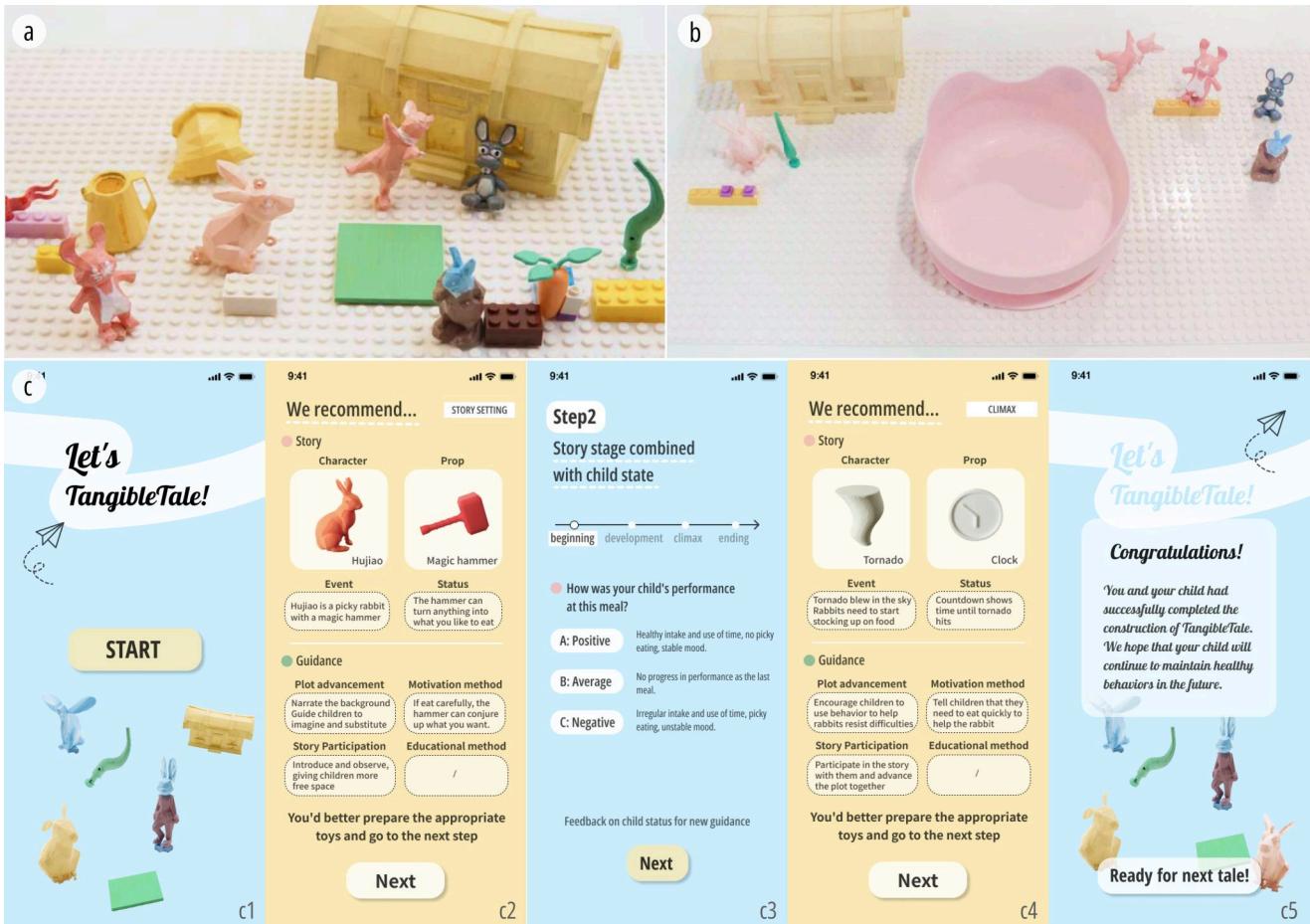


Figure 6. (a) A set of tangible elements used in the case study; (b) tangible connector designed for eating scenarios, ensuring the bowl and elements stay in place; (c) child interacting with TangibleTale during a meal; (d1–d5) TangibleTale app interface: the mobile application provides real-time guidance and feedback based on the child's performance, helping parents adjust the story and maintain healthy behavior practices.

to do so. We documented the participants' performance during the task through various methods, including video recordings, audio recordings, and photographs.

- **Post-survey.** Upon the conclusion of the experiment, we used a five-point Likert scale along with semi-structured interviews to thoroughly investigate the usability and effectiveness of the TangibleTale or OralTale system. The five-point scale included questions as shown in Figure 7, exploring dimensions such as user experience and behavioral change effects of the system in a quantitative manner. Simultaneously, we engaged parents in interviews to more intricately discuss their overall impressions of the system, specific difficulties they encountered during use, and children's acceptance of the product.

4.3.3. Quantitative results

Considering the potential challenge of young children accurately identifying their emotions, we opted not to administer the transportation scale during the study. Instead, we incorporated the impact of narrative transportation into our comprehensive evaluation of the TangibleTale and OralTale. We solicited questionnaire responses from the parents (Figure 8) to assess various aspects including users' experience, the systems' influence on children's eating behavior, and its role in fostering interaction between children and parents. Based on

the questionnaire data, TangibleTale demonstrated good usability and was found to be engaging, while OraTale was relatively less convenient to use (Q2, Q3, Q4). Both TangibleTale and OraTale provided story cues that were well understood by children (Q1, Q6). However, TangibleTale better matched the children's interests and cognitive levels (Q5, Q9). Both groups of children were able to empathize with the characters in the story to varying degrees (Q7), but the children in the experimental group were noticeably more active in understanding and creating the story (Q10). In terms of the impact on eating behavior, children in both groups understood the lessons from the story and ate seriously as a result (Q8). Finally, both TangibleTale and OraTale gave parents new insights into their children's thinking patterns (Q11), but TangibleTale provided a better platform and more effectively facilitated interaction and communication between them (Q12). For specific experimental data, please refer to the files in the appendix.

4.3.4. Qualitative results

Through interviews with participants and observations during the eating experiment, it became evident that both the TangibleTale and OralTale systems were effective in enhancing children's eating behaviors. However, the TangibleTale system proved to be more user-friendly and engaging,



Figure 7. The group of photos shows the experimental process of using the OralTale/TangibleTale system to assist parents in improving children's eating behavior: (a-d) control group experiment using OralTale; (e-h) experimental group using TangibleTale.

Questionnaire

1. Children can easily understand the storyline through **tangible** elements / **oral narrative** and explanations provided by parents.
2. **TangibleTale** / **OralTale** is easy to use.
3. I can easily access and comprehend the content and assistance provided by the **TangibleTale** / **OralTale**.
4. Using the **TangibleTale** / **OralTale** can give us enjoyment.
5. Children are enthusiastic while eating.
6. Children can clearly perceive the progression of the story.
7. Children can sufficiently comprehend the plot and empathize well with the characters in the story.
8. Children can understand the morals from the story well and improve their eating behavior accordingly.
9. **TangibleTale** can effectively capture children's attention during mealtime.
10. Children can actively engage in the tangible story during the interaction.
11. I gained updated and deeper insights into children's thinking patterns.
12. **TangibleTale** / **OralTale** facilitates better expression from children, making our communication and interaction easier.

Questionnaire Data Feedback

(1: strongly disagree - 5: strongly agree)

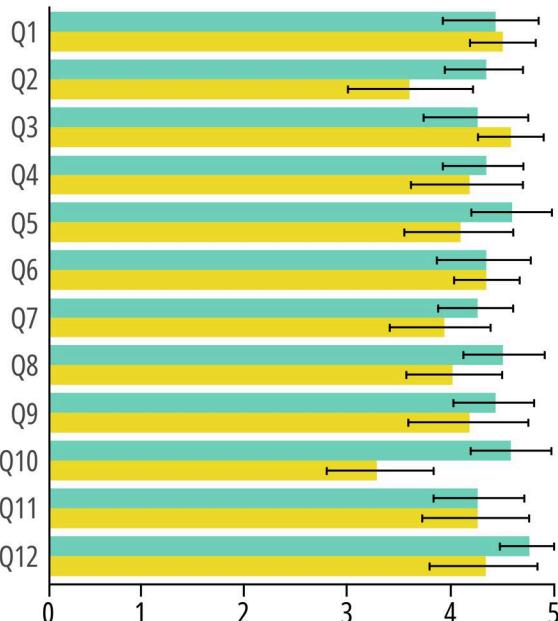


Figure 8. On the left side of the figure, a five-point likert scale questionnaire consisting of 12 items is presented. On the right side, visualizations depict the average scores and variance for each item. The experimental group data is represented in green, while the control group data is shown in yellow.

delivering a more sustained impact on both eating habits and parent-child interactions.

To ensure the rigor and clarity of our qualitative analysis, we employed thematic analysis following the approach outlined by Braun and Clarke (2006). This process involved thoroughly familiarizing ourselves with the data through repeated readings of the transcripts, generating initial codes, and organizing these codes into potential themes. We then reviewed and refined the themes to ensure they accurately reflected the data and provided meaningful insights into the participants' experiences with both the TangibleTale and

OralTale systems. This method allowed us to systematically identify and interpret patterns within the data.

- **Theme 1: Impact of Tangible Elements on Story and Children.**

We discovered that tangible elements during meals challenge the conventional belief that they distract children. In reality, tangible elements significantly enhance children's focus and engagement in stories. Tangible media, compared to oral storytelling, allows children to become deeply immersed in the narrative.

For example, P4 noted, “*My child usually likes to walk around during meals. However, during the experiment, he stayed seated because he was captivated by the tangible elements. Combining the story with mealtime was significantly different for me. I noticed he was more focused than usual, not constantly wanting to watch TV, which was delightful.*” Parents in the experimental group unanimously agreed that TangibleTale was highly effective. The stories captured the children’s interest, and the tangible elements enhanced immersion, fostering a sense of identification with the story, which aligns with narrative transportation theory. As P5 pointed out, “*I believe this product is particularly engaging during mealtime. Children can project themselves into the story’s characters. Unlike passive spectators, they become active participants in shaping the story, which benefits their eating.*”

In contrast, oral storytelling struggles to maintain focus and often becomes a distraction. Participants in the control group, such as P15 and P18, consistently noted, “*Although children understood the story, they lacked the motivation to create their own stories and tended to accept the storylines I provided.*” P21 mentioned, “*Children are easily distracted by the app interface in my hand and want to use my phone, which affects their eating behavior. While they enjoy the story, they only take a bite when I prompt them.*”

Additionally, we found that the storylines in the control group were more one-dimensional, with parents acting more like conveyors of concepts. This resulted in weaker immersion for children and less parent-child interaction.

Compared to OralTale, tangible elements provide more intuitive visual representations, increasing the user’s active creative possibilities and thereby enhancing the richness of the story. The uncertainty of the plot can also engage children more deeply in their self-created worlds.

For example, children will often add new content spontaneously, as P1 said, “*My child created a scene that was almost unrelated to the original story, saying that the rabbit built a skyscraper with an elevator to store food.*” At the same time, P1 can also flexibly adjust the props according to the children’s descriptions to collaboratively create new story developments.

• Theme 2: Impact of Plots on Children.

We found that when children participated in storytelling, parents often linked the story’s progression with eating behavior, encouraging children to eat actively to advance the story. Children ate purposefully due to their eager anticipation of the story’s development. Over time, children developed a subconscious belief that eating would positively drive changes in the story, leading them to eat actively or request food during the experiment.

For example, P2 shared, “*This experiment was a surprise. The whole setup was impressive. I provided my child with two meal options, including foods like big bones, broccoli, garlic sprouts, and cucumbers, all of which were*

eaten.” As the experiment progressed, my child showed a positive attitude. Even though she couldn’t use chopsticks, she asked me to feed her, eagerly opened her mouth, and even asked me to continue the story.” In the control group, P13 noted, “*As the story deepened, the children anticipated the story’s development.*”

Overall, many children in the study began to believe that eating well could lead the story in a positive direction. Parents viewed this improvement as a form of mental encouragement, and seeing the enthusiasm displayed by their children, they hoped to continue encouraging children to eat in this way in the future.

It is worth noting that children who participated in oral storytelling typically developed a negative attitude toward the story by the third day, with some even losing interest sooner. P15 mentioned, “*After the second meal in the oral storytelling environment, my child said the story was fake and was no longer very interested. I asked her if she thought the stories in her favorite cartoons were real, and she said the stories I tell now aren’t as interesting as those in cartoons.*”

In contrast, parents in the tangible storytelling group did not report similar issues, indicating that the effects lasted longer, likely due to the greater flexibility and extended engagement that tangible stories provide. However, even in the tangible storytelling group, children generally did not sustain interest beyond the fifth day, and parents’ enthusiasm waned as the creative storylines became harder to generate. P16 suggested, “*Towards the end of the experiment, I often felt anxious and helpless about not being able to come up with new storylines. Whenever I ran out of new ideas, my child’s eating performance would worsen, sometimes even more than before the experiment.*”

• Theme 3: Impact of Interaction on Engagement and Eating Behavior in Collaborative Storytelling.

We observed that active parental involvement encouraged children to engage more comfortably in character dialogues. During the experiment, some children even invited their parents to join them for meals, which increased the children’s level of participation.

For example, P3 commented, “*I believe that when parents are involved in the story, children are more engaged, and their receptiveness to the story increases.*” Surprisingly, parents and children eating together during the experiment demonstrated an expansion of cooperative interaction. Both children and parents expressed different views and opinions, which facilitated discussion and communication, thereby building emotional bonds. Parents also provided conceptual explanations while storytelling. When children encountered challenging concepts in the story, such as “wealth” and “kindness,” parents skillfully expanded the story to clarify these concepts, offering explanations and insights. This enriched the story’s content and was a result of collaborative creation with the children. As P1 described, “*Children have rich imaginations, so I often direct the story towards eating. For example,*

I might say, ‘The rabbit needs to eat to gain strength for the adventure,’ or ‘What does the rabbit want to eat?’ Sometimes, if the child mentions Elsa’s magic wand, I would say, ‘This meal was conjured by Elsa’s magic wand; eating it will give the rabbit the strength needed for work.’ Then, I would gently bring the conversation back to the story.” Through the joint efforts of parents and children in completing tasks and discussing different viewpoints, it became evident that TangibleTale facilitated communication and cooperation between parents and children. However, parental involvement in the control group generally did not have the same positive effect. P16 mentioned, “When the child was not behaving well, I tried to interact with him to stimulate his interest in storytelling, but the child paid little attention to me and was only interested in knowing what happens next in the story.”

Additionally, based on the experiment with Groups 10–12, we found that when multiple children participated in the same experiment, they not only showed higher enthusiasm in storytelling but also performed better in their eating behaviors.

The interaction among children sparked creativity and a sense of competition, significantly enhancing their engagement with the story and their positive attitude toward eating. The lower barrier to communication among children also made the process more enjoyable. P10 shared, “I noticed that when children participated in the experiment together, their interaction was very interesting. My child saw other kids actively participating and didn’t want to fall behind. He listened to the story more attentively, contributed to the storytelling, and even asked to eat more because he knew it would help the story progress.” Similarly, P12 noted, “When other kids were involved, my child became more engaged. They would discuss the story’s development together and even encourage each other to eat during meals, resulting in a noticeable increase in my child’s appetite.”

5. Guideline

In the previous sections, we first explored the theoretical relationship between tangible elements and narrative transportation, investigating the potential application of tangible elements in the field of narrative. The subsequent formative study examined the interactive relationship between children and parents within tangible narrative, gaining insights into how stories can be linked with improving children’s eating behavior. We then incorporated designers’ ideas to propose the presentation format of TangibleTale. Finally, we validated the effectiveness of TangibleTale through comparative experimental results. We believe this system is not the only design solution. Therefore, to enable designers to leverage tangible narrative and create more design solutions for children and parents, we present the following design guidelines.

5.1. Designing tangible elements for engagement and story depth

5.1.1. Expanding design dimensions

Expanding design dimensions for tangible elements is crucial for maximizing children’s imaginative potential. This involves providing characters with diverse body types, skin colors, and occupational symbols. A comprehensive library of these elements allows children to explore various narrative and create unique stories. Designers should develop customizable elements that reflect a range of characters and scenarios, equipping children with the tools to fully engage with and expand their narrative. It is worth noting that the appearance of tangible elements can play different roles in storytelling. Designers can tailor these appearances with varying degrees of clarity for specific contexts to meet design goals. For instance, clear designs are used for guidance, while more abstract designs encourage idea generation and exploration. By strategically employing these different types of appearances, designers can support diverse narrative experiences and enhance children’s creative engagement.

5.1.2. Incorporating dynamic features

Incorporate dynamic, interactive features into tangible elements to enhance engagement and immersion. For instance, the rabbit character could rotate its body, with some limbs designed to be movable. This dynamic capability allows children to physically interact with the elements, making the narrative more engaging and immersive. Incorporating these interactive features encourages children to manipulate the tangible elements, thereby deepening their connection with the story.

5.1.3. Creating modular tangible elements:

Adopt a modular design approach for tangible characters and props to allow for greater flexibility and adaptability in storytelling. For example, the initial design of the rabbit character featured empty hands, allowing for the attachment of various props, such as a hammer or frying pan, as the story progressed. This modular approach also includes the addition of accessories like hats and clothing, enabling characters to adapt to different narrative contexts. By utilizing modular designs, tangible elements become more flexible and varied, which in turn enhances the storytelling experience.

5.2. Structuring plots to drive engagement and behavior change

5.2.1. Designing logical and coherent storylines

Design storylines with clear logical progression to effectively engage children and reinforce desired behaviors. To create stories that resonate with children, ensure the storyline includes key components: a well-defined beginning that introduces the setting, the development of character relationships, the climax that presents conflicts and heightened

tension, and a satisfying ending that resolves the narrative. These stages should form a cohesive and believable chain of events within the story world.

5.2.2. Embedding moral consistency in story logic

Embed moral consistency in the narrative's internal logic to guide children's behavior effectively. While the story may unfold in imaginative or fantastical worlds, the actions and decisions within the narrative should adhere to the ethical standards and rules of conduct found in real life. This alignment helps children internalize the lessons of the story, enabling them to relate to the narrative and apply its moral and behavioral guidance to their own lives. Designers should develop narrative prompts that assist parents in crafting these ethically consistent storylines, thereby reducing the complexity of storytelling while ensuring that the story remains engaging and fosters positive behavior changes, such as improved eating habits.

5.2.3. Creating open-ended narrative clues

Design narrative clues that avoid forming closed loops to keep the story evolving and support long-term behavioral improvement in children. When developing the story framework, it's crucial that designers ensure the narrative remains open-ended, allowing for the continuous expansion of the storyline. This open-ended approach encourages children to stay engaged with the story over extended periods, offering ongoing opportunities for behavior reinforcement. To achieve this, narrative clues—such as characters, props, and their interactions—should be designed in a way that they naturally lead to new scenarios or challenges, rather than bringing the story to a final conclusion. For instance, a character's journey might end one chapter but simultaneously open up possibilities for a new adventure, keeping the narrative momentum going.

5.2.4. Designing plots to enhance multi-child interaction

Structure plots that encourage multi-child interaction by integrating collaborative tasks and competitive challenges within the storyline. By crafting narrative where children must work together or compete to advance the plot, designers can enhance the children's engagement and foster a healthy sense of competition. Our observations from case study revealed that when children collaborated on the same story, their shared cognition and emotions facilitated divergent thinking and enriched the narrative. Children in pairs were more enthusiastic, taking on different roles and connecting more deeply with each other than with adults. This peer collaboration fostered empathy and a sense of recognition, forming a small social group that heightened the narrative atmosphere. According to narrative transportation theory, such dynamic interaction leads to a more immersive and effective storytelling experience. By strategically designing these plots, designers can not only make the storytelling experience more enjoyable but also reinforce positive behaviors through the natural dynamics of peer interaction.

5.3. Facilitating interaction to enhance story engagement and behavior

5.3.1. Integrating digital tools with tangible elements to guide parental involvement

Integrating portable digital tools, such as apps, with tangible storytelling elements can help parents effectively manage the progression of the narrative and choose suitable interaction methods for their children. This combination not only enhances parents' understanding and control over the storytelling process, but also allows them to seamlessly adapt the narrative to various environments and situations. This ensures a continuous and engaging experience for the children, as parents can readily adjust the pace, interactivity, and delivery of the story to best suit their child's needs and preferences. By leveraging both digital and tangible elements, parents can create a more dynamic and responsive storytelling experience that captivates children's attention and fosters deeper engagement and communication.

5.3.2. Adapting parental guidance to children's engagement levels

Tailor parental guidance across different interaction dimensions to match children's varying engagement levels and behaviors throughout the story. Our formative studies highlight four key areas for adaptation: Plot Advancement, Story Participation, Motivation, and Education.

- **Plot Advancement:** When children are less engaged, parents should guide the story more directly, linking behavior to narrative progression. As engagement grows, parents can adopt a more relaxed approach, allowing children greater freedom to explore the story.
- **Story Participation:** Active communication is crucial when children are less involved. Parents should initiate discussions to strengthen the child's connection to the narrative, reinforcing the story's impact on behavior.
- **Motivation:** Early in the story, parents can motivate children by linking their actions to narrative outcomes. As the plot develops, introducing challenges can maintain interest and reinforce behavioral lessons.
- **Education:** In later stages, parents should tie the story's outcomes to real-life morals, reflecting on the child's performance to encourage lasting behavior change.

By adapting these methods with the child's engagement and the story's progression, parents can enhance the storytelling experience and foster positive behavior changes.

6. Discussion, limitation and future work

TangibleTale not only encourages children to actively make changes but also provides parents with a more engaging and effective educational approach. However, there are still many aspects of TangibleTale that warrant further exploration.

6.1. Involving tangibles: Extending “minds-on” to “hands-on”

TangibleTale strengthens the connection between physical activity and learning, facilitating the development of healthy behaviors in children. A growing consensus suggests that people learn best through active participation, yet traditional education often relies on passive knowledge absorption. TangibleTale offers a child-centric platform that uses storytelling to create an educational environment where children can actively engage. Through plot changes and parental guidance, children participate in the story, learn valuable lessons, and eventually manage their behavior independently. TangibleTale successfully extends the concept from “Minds-on” to “Hands-on”.

6.2. Child–Parent interaction: I lead, you help but with guidance by osmosis

At this crucial stage of cognitive development, children need the space to form their own values and ideas. Therefore, it is essential to empower children to take the initiative to seek change. Simultaneously, parental guidance is necessary to ensure ideas develop in a reasonable direction, providing adequate support. However, in everyday situations, clear communication between children and parents can be challenging. TangibleTale offers a platform for children and parents to communicate and collaborate, ensuring children retain initiative. It is important to note that parental guidance and collaboration are not rigid interventions but objective prompts and encouragements for children’s independent exploration, helping them move toward their preferred path.

6.3. Exploring contrasting outcomes: Adapting tangible narrative to diverse child behaviors

In the case study, we found that for a few children, the storyline may have had a negative impact: some children attempted to halt the story’s progression by refusing to eat. Although this was not the intended outcome of our experiment, this result suggested that the TangibleTale system could produce unexpected effects on the same type of behavior. This indicates that we need to conduct more in-depth research into children’s responses to interactive stories. For instance, if a child has issues with overeating, the TangibleTale system could potentially be adapted to curb this undesirable behavior. Future work could explore this aspect more thoroughly, developing suitable interactive stories for different types of behavioral issues. Additionally, further research is necessary to understand children’s responses in various contexts to ensure that TangibleTale effectively promotes healthy behaviors in children.

6.4. Adapting narrative interaction to personality differences

During our experimental process, we discovered that the personalities of different parents and children can affect the effectiveness of tangible stories and interactions, as well as

the children’s receptiveness. Therefore, fine-tuning narrative guidance to accommodate personality differences may lead to more effective interactions between children and their parents, thereby enhancing the impact of tangible storytelling.

6.5. AI-involved TangibleTale creation model

We also found that some families experienced a decline in children’s interest due to the repetitive stories. This is because parents and children often face cognitive and experiential limitations, leading to a lack of inspiration for story creation. To address this, we propose integrating AI into the TangibleTale creation process. In the future, AI-generated content (AIGC) could serve as a content generation assistant, helping children and parents create more diverse and engaging stories.

6.6. The value of categorizing tangible elements in storytelling and education

Before conducting our formative study, we aimed to define a classification framework for tangible elements—such as categorizing characters based on their abilities and moral qualities—to observe how different types might influence the experimental outcomes. However, during the experiment, we found that both children and designers naturally formed their own classification systems. Despite this, they often subjectively assigned different labels to the same tangible element, making it challenging to establish universally accepted characteristics for any specific element. From a storytelling perspective, categorizing tangible elements is both necessary and effective, as it helps to create a structured and engaging narrative. However, our previous discussion primarily focused on the appeal of the story and did not sufficiently explore whether these elements effectively contributed to the development of positive moral values in children. This highlights a limitation of our study, as we did not fully investigate the educational significance of different tangible elements—a crucial aspect that warrants further exploration in future research.

6.7. Interactive and programmable tangible narrative

Using TangibleTale with interactive and programmable technology will be a wonderful choice. All present TangibleTale pieces are monotonous and static, and programmable technology can provide new tale parts, such as different sensations, and richer development methods, such as dictation, painting, and physical activities to fit different children for a set of children. TangibleTale improves overall due to the varied levels of acceptance of the new system. Using music, light, electrical, pneumatic, and other technologies to provide users with immediate and fascinating feedback, such as capture, editing, exploration, and sharing, interactive technology can add dynamic to the story and inspire children’s imagination and creativity. TangibleTale’s interaction mode may allow it to form social interactions.

7. Conclusion

Based on the work presented in this article, we conclude that TangibleTale effectively integrates tangible elements with narrative transportation theory to promote healthier eating habits in children. Specifically, we proposed a behavior-change hypothesis that links tangible narrative elements with narrative transportation, and we provided empirical evidence showing that this approach significantly enhances engagement and eating behavior more effectively than traditional methods. Additionally, we distilled our findings into actionable design guidelines for broader application in various behavioral domains. While our research has demonstrated the effectiveness of tangible narrative in promoting healthy eating behaviors, there remain opportunities for further exploration. Future studies could investigate the educational significance of different tangible elements and how their design might further influence behavioral outcomes. TangibleTale represents a significant step forward in the design and application of behavior-change-oriented narrative. Our findings contribute to the expanding research on tangible interaction and narrative-driven behavior change, providing practical insights and tools for future innovations in this field.

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Appendices.

Appendix A. Semi-structured interview outline

Figure A1 shows the semi-structured interview outline for Formative Study 2. Figure A2 shows the pre-experimental semi-structured interview outline and Figure A3 shows the post-experimental semi-structured interview outline for Case Study.

Appendix B. Selected workshop outputs

Figure B1 shows the selected outputs for workshop: The story from P1 reflected the performance of children by changing the image of the protagonist. The story from P3 combined application scenarios to develop vivid tangible elements of the story. The stories from P5 and P11 combined the plot in the story with reality, and P5 intervened in the replacement of parts to achieve sustainable design. The stories from P7 and P8 were adapted from stories familiar to children for easier understanding. The stories from P12 and P14 achieved volume accumulation with the help of modular design.

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Part1: Problem Definition

Q1: Initial Thought Process	How did you approach the design task when you first received it? From whose perspective (children's or parents') did you consider the problem?
Q2: Design Objectives and Decomposition	What are your design goals for this product? How did you break down a large design problem into specific design expressions for each part? What outcomes did you anticipate?
Q3: Innovation Points	At the beginning of the design, where did you see potential innovation? (Consider dimensions such as story, product, and interaction methods.)

Part 2: Story-Related Elements

Q1: Story Inspiration	Can you provide an overview of the story content? What inspired the story? Does the story leave room for children to create their own narratives?
Q2: Story Element Deconstruction	What connections do you see between the elements within the story? (For example, relationships between characters, between characters and props, or between props and settings.) How did you categorize and use the characters and props we provided in the story? What did you think makes your story appealing to children, and how do you convey this?
Q3: Story Plot Development	What inspiration did you get from the story plot we provided? How did you choose and integrate the provided story into your own? Where do you think the highlights of your story's plot changes are? Do these children's stories have commonalities? Can other stories be extended from these commonalities? What do you think are the characteristics of children's stories, and how do they differ from adult stories?

Part 3: Design Elements

Q1: Product Type and Goals	Based on the previous questions about your story's inspiration, how does your story relate to the type of product and the goals you set for children's engagement?
Q2: Design Elements and Form	How do you incorporate elements from the story into the design's form? If there is a prototype testing phase, how do you envision it will be presented? What role do you think parents play in your product design?
Q3: Flexibility and Openness	How do you continue your design if children's behavior changes in ways that don't align with the story's logic? Have you left open story spaces in your plot design for children to exercise creativity? • If so, explain. If not, are there areas where improvements could be made?

Part 4: Behavior-Related Aspects

Q1: Behavior Change Goals	What logic does your story follow in its development? Did you consider the perspective of cultivating children's habits when developing the story and plot? Does your product design use interaction to attract children? How significant is the parents' role in your product? How should children and parents participate in the interaction?
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Additional Question

Story Deconstruction	If you were to deconstruct your story into several parts, can you identify: <ul style="list-style-type: none"> • Separate element changes? • Changes in relationships between elements, such as character-to-character and character-to-prop relationships? • Changes in interaction methods with the medium?
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Figure A1. Semi-structured interview outline for Formative study 2.

Pre-Experiment

Child-Focused Questions

Q1: Child's Age and Eating Habits	<p>What is the child's age?</p> <p>Does the child usually have eating habits such as being picky, eating slowly, or eating very little?</p> <ul style="list-style-type: none"> For example, the child eats very little or eats slowly.
Q2: Snack Consumption Before Meals	<p>Does the child have a consistent habit of eating snacks before meals?</p> <ul style="list-style-type: none"> Always eats snacks before meals. Often eats snacks before meals but can occasionally be persuaded otherwise. Occasionally eats snacks before meals, which affects their appetite. Never eats snacks before meals.

Parent-Focused Questions

Q3: Parental Guidance in Eating	<p>Have you previously guided your child in their eating habits? What methods have you used to encourage better eating (e.g., telling stories, using cartoons)?</p> <ul style="list-style-type: none"> Yes, I usually insist the child eats a little, but if they really don't want to, I won't force them. Let the child do something they enjoy (watching TV, playing with toys) while eating. Verbally encourage the child to eat (e.g., verbal rewards, promising something, telling stories). No, I haven't.
Q4: Child's Reaction to Parental Guidance	<p>How does the child react when you intervene in while eating (emotional and behavioral responses)?</p> <ul style="list-style-type: none"> Resists (emotional outbursts, defiant behavior). Cooperates (calm emotions, compliant behavior). Negotiates (calm emotions, partially compliant behavior, requires conditions). Begrudgingly complies with conditions set by the parent.
Q5: Acceptance of Parental Guidance	<p>How does the child accept different methods of guidance?</p> <ul style="list-style-type: none"> Always accepts well. Gradually becomes less accepting over time. Never really accepts. Slowly becomes more accepting over time.
Q6: Challenges in Current Interventions	<p>What challenges do you face with current intervention methods?</p> <ul style="list-style-type: none"> The novelty wears off over time. It requires too much time and effort from the parents. It can lead to other bad habits (e.g., drink water while eating, which causes stomach pain).

Figure A2. Case study pre-experimental semi-structured interview outline.

Post-Experiment

Child – Understanding and Empathy

Q1: Comprehension of Story	Do you think your child understood and showed interest in the story conveyed by the TangibleTale/OralTale during the eating process?
Q2: Emotional Connection	When the story changed, did your child empathize with the main character (e.g., feeling anxious for the rabbit when it faced difficulties, or relating the rabbit's situation to their own)?
Q3: Understanding Moral Lessons	Do you think your child understood the moral lessons behind the story? How did they demonstrate this understanding?
Q4: Engagement with Tangible/Oral Story	Did the tangible/oral story significantly enhance your child's engagement? Did it provide new motivation or understanding regarding eating well?

Child – Participation

Q5: Active Participation with Tangible/Oral Elements	Did your child actively participate in the TangibleTale/OralTale? What specific actions showed their involvement?
Q6: Story Creation with Tangible/Oral Elements	Was your child able to construct stories easily with your guidance (characters, props, some plot)? What surprising or interesting elements did they contribute?
Q7: Behavioral Changes with Tangible/Oral Elements	Did your child exhibit different behaviors when using tangible/oral elements compared to their usual eating habits (e.g., increased focus, better emotional control, more trust)?
Q8: Role Transformation with Tangible/Oral Elements	Compared to their usual role during storytelling, do you think your child's role has shifted from being a passive listener to an active participant in the story?

Child – Behavioral Changes

Q9: Motivation to Eat	Did the story and tangible/oral elements encourage your child to eat more willingly than during their usual eating habits?
Q10: Story Progression and Behavioral Change	Did the degree of your child's behavioral change vary with the story's progression?
Q11: Impact of Tangible/Oral Elements	Do you think tangible/oral elements had a more profound impact on your child's behavior compared to their regular eating habits?
Q12: Pathway from Behavior to Thought	Can tangible/oral stories bridge the gap between behavioral and cognitive changes in children?

Parent – Understanding

Q13: Comprehension of TangibleTale/OralTale	Was there any difficulty in understanding the information provided by TangibleTale/OralTale? Did it help you construct the story effectively?
Q14: Communication and Storytelling	Did the guidance offered by TangibleTale/OralTale make it easier for you to narrate or assist your child in constructing stories? Did it help you communicate appropriately with your child?
Q15: Moral Lessons for Parents	Did TangibleTale/OralTale elements help you understand some life lessons (e.g., honesty)?

Parent – Participation

Q16: Active Involvement	Were you able to actively participate in the storytelling process? Did the elements provided engage you enough to be involved?
Q17: Impact of Parental Participation	How did your participation affect your child's enthusiasm for the story and changes in eating behavior?

Collaborative Story Creation

Q18: New Communication Method	Did TangibleTale/OralTale offer a new way to communicate with your child? How did this new communication method develop and function, and what was your experience?
Q19: Role and Influence	What role did you play in your child's eating process using TangibleTale/OralTale, and was it positive? How did it help your child?
Q20: From Hands-On to Minds-On	Did you and your child experience a shift from hands-on to minds-on in using TangibleTale/OralTale (i.e., better eating behavior and maintaining good eating habits)?
Q21: Reducing Concerns with TangibleTale/OralTale	Has this approach reduced your concerns about your child's eating habits? Do you have a positive outlook on guiding behavior through parental involvement and tangible/oral stories?

Figure A3. Case study post-experimental semi-structured interview outline.

Scene: Eating

Carrier: chopsticks or knife and fork

Scene: drink water

Plan : straw

Child behavior	Story stage	Positive	Unchanged	Negative
Start	start	Rabbit comes to drink water for little goldfish sleep in the water.	Rabbit feels lonely	Rabbit refuse to drink water because goldfish sleep in the water.
	development	Rabbit finds a fish, starts to fish.	Look forward	Rabbit is unwilling to help goldfish so it is sad and disappointed.
	climax	Rabbit tries hard to pull the fishing rod.	urge	Rabbit catches a fish. Goldfish is dead and disappointed.
end	end	Find a partner, come home happily.	Still try	No friends found, disappointed.

Scene: having meals

Solution: a 3D storyboard theme: Survive on Mars

P1

Scene: children refuse to take traditional Chinese Medicine

Scheme: "jade rabbit tampering" spoon accessories

P3

Expression changes

SOLUTION : Pen cap corrector

P5

Scenario: Brushing Teeth

Plan: A cup base with a 3D storyboard

P7

Encounter Rabbit Chronograph

P8

From the beginning to the climax of the story, the parents tell the storyline and execute the story development trend according to the children's entertainment time
Children can participate in the story by choosing a cherry style

(About the open-ended ending)
At the end of the story, the identity of the cherry thief is revealed as a key narrator by the parents.
The rest of the story can be presented by the child's performance and his personal wishes, and the design provides only one possible guiding direction

P11

Scene: Teeth Brushing

Solution: A Shell for teeth brush

Figure B1. Eight low-fidelity prototypes of behavior-change-oriented tangible story development were selected in the workshop.