UNIVERSITY OF CALIFORNIA

Los Angeles

# Transfer and Podcasts:

# Applying the Science of Learning to Podcasts

A dissertation submitted in partial satisfaction of the

requirements for the degree Doctor of Philosophy

in Psychology

by

Emily Mikayla Neer

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ABSTRACT OF THE DISSERTATION

Transfer and Podcasts:

Applying the Science of Learning to Podcasts

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Emily Mikayla Neer

Doctor of Philosophy in Psychology

University of California, Los Angeles, 2024

Professor Catherine M. Sandhofer, Chair

Children's ability to use higher-order thinking and learn complex, higher-order concepts is crucial for academic and later employment success. One form of higher-order thinking is transfer, which occurs when learning in one context affects learning in another. Many science concepts require higher-order thinking and relational reasoning so understanding transfer in this domain is particularly valuable in understanding how children learn these concepts. The present studies consider how children's science, technology, engineering, and mathematics (STEM) podcasts, digital audio programs that aim to engage children with STEM topics, and parent-child conversation while listening to podcasts support children's learning and transfer. Children's podcasts are a unique unimodal modality because they include features like conversation, description, and sound effects to encourage audio engagement. However, not much is known about how children learn from podcasts and the factors that could facilitate children's transfer of science concepts presented in podcasts.

Study 1 examined whether children learn from podcasts, and if supporting visual information affected their learning. Participants were 69 children between 7- and 8-years-old who listened (or listened and viewed related images) to an 11-minute science podcast about the water cycle and answered recall and transfer questions. Results from this study revealed no effect of modality on children's learning, and children in both audio and audiovisual conditions performed above chance on transfer questions. Using a semantic textual similarity analysis, we showed that children in the audiovisual condition did not incorporate visual information in their description of concepts. These results highlight the value of podcasts as a unimodal context that could benefit higher-order concept learning.

Study 2 investigated the effect of parent-child conversation while listening to a podcast on children's learning and transfer. Participants were 61 parent-child dyads who listened to an 11-minute science podcast about the water cycle together. Dyads were randomly assigned into one of three conditions in which parents received conversation cards that either prompted general conversation (control), open-ended questions about the water cycle (water cycle questions), or open-ended questions to evoke children's prior knowledge and experience (prior knowledge questions). Results revealed interesting parent-child conversation patterns while listening to the podcast. An effect of conversation cards on parents' use of prior knowledge connections and an effect of conversation cards on children's recall of content presented in the podcast, but not children's generalization of content presented in the podcast, were found. The results provide a first look at parent-child conversation when listening to a podcast and highlight the need for additional research examining the effects of various characteristics of parent-child conversation on children's recall and transfer of science concepts presented in podcasts.

Taken together, these two studies aimed to answer if STEM podcasts and parent-child listening contexts supported children's higher-order concept learning. Overall, these results show that children learn higher-order concepts from podcasts and highlight effects of parent-child interactions while listening to podcasts together. These results are informative for existing theories on learning from media and media engagement and have implications for families and podcast creators dedicated to supporting children's engagement with and learning from podcasts.

The dissertation of Emily Mikayla Neer is approved.

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Study 1 of the present dissertation is a version of (Neer, Shao, & Sandhofer, in press). Raymond Shao, second author, assisted in writing code for the semantic textual similarity analysis and generating related images. Dr. Catherine Sandhofer was the PI.

VITA

**EDUCATION**

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Shaw, S. T., McReynolds, A., **Neer, E.,** Fang, T., & Givvin, K., (under review). A mixed-methods investigation of undergraduate students' values and experiences with rest, leisure, and breaks. *Journal of College Student Development.*

**Neer, E. M.,** *Brahmbhatt, A., Walsh, C. R., & Warlaumont, A. S. (in prep). *Effects of Pragmatic Context, Adult Gender, and Infant Gender on the Pitch Characteristics of Real-World Infant-Directed Speech.*

**Neer, E. M.** (2014). Meaningful international service-learning experiences: Looking at the reciprocal nature of reflection and group connection. *VA Engage Journal, 3(3*), 1-16. http://scholarship.richmond.edu/vaej/vol3/iss1/3

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## SELECTED PRESENTATIONS

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***Neer, E. M.,** & Sandhofer, C. M. (2023, March). *To watch or to listen? Learning about science in different modalities.* Talk given at the 2023 Society for Research in Child Development Conference, Salt Lake City, UT, United States.

***Neer, E. M.,** *Zhang, E., & Sandhofer, C. M. (2023, March). *Parents' use of nouns, pronouns, and nonverbal social cues in everyday play settings.* Poster presented at the 2023 Society for Research in Child Development Conference, Salt Lake City, UT, United States.

***Neer, E. M.,** & Warlaumont, A. S. (2022, July). *Pragmatic contexts and acoustic characteristics of infant-directed and adult-directed adult speech in daylong audio recordings.* Poster presented at the 2022 International Congress of Infant Studies, Ottawa, ON, Canada.

***Neer, E. M.,** & Siobhan, G., & Sandhofer, C. M. (2022, July). *Toddler perspective taking during video chat interactions.* Pre-registration poster presented at the 2022 International Congress of Infant Studies, Ottawa, ON, Canada.

***Neer, E. M.,** *Shah, U., & Sandhofer, C. M. (2022, April). *Are you listening? A pilot study on parent-child conversation while listening to podcasts.* Poster presented at the 2022 Cognitive Development Society, Madison, WI, United States.

***Neer, E. M.,** & Sandhofer, C. M. (2019, June). *Memory retention in word learning through overhearing.* Talk given at the 14th Annual Symposium on Cognitive and Language Development, Los Angeles, CA, United States.

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## RESEARCH MENTORSHIP

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| 2021 | Kalysa To – "Category Hierarchy and Labeling Strategies in Parent Speech" |
| 2020 | Cristina Sarmiento – "Is There a Bilingual Advantage in Generalizing and Retaining Overheard Novel Words?" |

# General Introduction

Children's ability to use higher-order thinking and learn complex, higher-order concepts is crucial for academic and later employment success (National Research Council, 2012). Higher-order thinking involves making inferences, drawing connections, and building representations beyond the provided material (Resnick, 1987). One form of higher-order thinking is transfer, which occurs when learning in one context affects learning in another (Thorndike & Woodworth, 1901; Gick & Holyoak, 1980; Bransford & Schwartz, 1999).

Mapping information learned in one context to another makes transfer difficult for learners. Researchers disagree about the prevalence of transfer – challenging that transfer has not been shown in empirical studies (Detterman, 1993; Barnett & Ceci, 2002; Blume et al., 2010). Even though transfer may be difficult (or debated to be difficult) to show empirically, transfer does occur in everyday settings. For example, students may learn to add specific numbers in class and later apply this knowledge to different numbers. They can also add in other contexts (e.g., in the classroom, at the grocery store, etc.). Children are constantly learning in their everyday environments, and it is essential to understand how children's transfer of learned information is supported in these environments.

In this dissertation, I focus on positive transfer, when information learned in one context benefits learning in the new context, as well as transfer based on structural similarities, that is, the underlying functional similarities between two situations (Gick & Holyoak, 1980; Gentner, 1983; for definitions of transfer types see Appendix A). In addition, I examine children's ability to transfer information in the science, technology, engineering, and mathematics (STEM) domain, specifically the ability to transfer information about the water cycle. Many science concepts require higher-order thinking and relational reasoning so understanding transfer in this domain is particularly valuable in understanding how children learn these concepts.

Furthermore, I consider how children's STEM podcasts, digital audio programs that aim to engage children with STEM topics, and family engagement while listening to podcasts support children's learning and transfer. Podcasts are a rich medium in which novel information can be explained and explored; however, it is a unique modality (i.e., audio-only) that children today may not have much experience with due to the popularity of multimedia like YouTube videos and television programs. Recently, families with children have sought out podcasts created for child audiences as an alternative to screen time and as an activity to entertain and expose children to educational content (Kids Listen, 2021).

Children's podcasts are a unique medium designed to engage children with information auditorily. Podcasts often include two or more hosts and experts discussing a topic using rich verbal imagery and comparisons or analogies. To engage child listeners, podcast hosts often directly address the listener (e.g., "What are some birds you see in your neighborhood?") and include suggestions for related learning activities that children can complete at home. Podcasts also include descriptive sound effects, background music, and humor to engage children. STEM podcasts are particularly interesting because they engage children with complex concepts (i.e., the structure of an atom, the water cycle) auditorily. Intuitively, learning these complex concepts may be facilitated by visual representations (Mayer et al., 1996; Seger et al., 2019) and parent scaffolding (e.g., Valle & Callanan, 2006; Fender & Crowley, 2007; Haden, 2010) as prior research shows, but visuals and parent scaffolding are two elements that podcasts lack.

While listening habits surveys have been collected on how parents and children engage with podcasts (Kids Listen, 2016, 2021; Grack Nelson et al., 2021), little to no research has been conducted on how children learn from podcasts and the characteristics of parent-child conversation during a podcast listening activity. This dissertation examined if 1) STEM podcasts and 2) children's listening contexts supported children's science concept learning.

**Recall and Transfer Supports**

To understand transfer, it is necessary to distinguish between and consider the relationship between recall and transfer – two critical aspects of the learning process. Learning requires encoding, consolidating, and retrieving information (Tulving & Thomson, 1973; Anderson & Bower, 1973). Recall of information depends on how the information was encoded, organized, relevant, and useful in the *current context*. Transfer functions similarly, except that information must be encoded, organized, relevant, and useful in the *new context* in which the information is to be transferred (Sternberg & Frensch, 1993).

Recall can be supported through repetition and spacing out rehearsal of information (Toppino et al., 1991; Bjork, 1994), implementing prior knowledge or familiarity at the time of encoding (Alba & Hasher, 1983; Shing & Brod, 2016), and generating explanations for concepts (Bobrow & Bower, 1969; Jacoby, 1978; Chi, 2000). Rehearsing and repeating information aids in retaining information in the long-term, especially when rehearsal is spaced out in time (Toppino et al., 1991; Bjork, 1994). Spacing the rehearsal of information allows for the forgetting of irrelevant details and the abstraction of the core details, strengthening the memory trace of the encoded information at the time of recall (Bjork, 1994; Vlach & Kalish, 2014). Work in museums and during at-home play have found that parent-child conversation and reminiscing support children's ability to recall information from the museum or the play event weeks later (Fivush, et al., 2006; Hedrick et al., 2009; Jant et al., 2014). Reminiscing is a form of rehearsal and spacing. Therefore, reminiscing about a visit to the museum will help a child remember what they saw and learned – abstracting the essential details of the visit and strengthening the memory trace for that visit.

Prior knowledge affects learners' ability to recall information as prior knowledge provides a framework in which to-be-learned information can be integrated, ultimately aiding in the recall of this information due to the integration of the information into already existing knowledge structures (Craik & Lockhart, 1972; Shing & Brod, 2016). In addition, parents will provide prior knowledge associations for their children while interacting with a museum exhibit to help their children process the exhibit information (Callanan & Jipson, 2001; Callanan et al., 1995).

Prior work has also found that generating explanations for concepts also aids in retaining information (Bobrow & Bower, 1969; Jacoby, 1978). Generating explanations promotes exploration and the invention of new problem-solving techniques (Siegler, 2002), which could positively influence how information is encoded and subsequently recalled. Young children's spontaneous generation of explanations may be rare (Siegler, 1995; Göncü & Rogoff, 1998), but parent explanation of concepts while interacting at a science exhibit has been found to support children's recall of concepts and conceptual understanding (Crowley & Galco, 2001; Fender & Crowley, 2007).

However, recalling information is just a portion of the learning process. Recalling information does not require that learned information be applied in a new context. Prior research has shown that when children were taught strategies to play tic-tac-toe, those who just memorized the moves of the strategy rather than trying to understand the strategy itself abandoned the use of the strategy in later games (Crowley & Siegler, 1999). When children were encouraged to explain the strategy rather than memorize the moves, children were more likely to implement the strategy in future games. Therefore, understanding the underlying concepts and explaining those concepts aids children's ability to transfer the strategy of the game to endless iterations of game play.

Transfer relies on understanding the underlying structural or relational elements of a concept. For example, a child could remember that an example of evaporation is when the stove warms up liquid water in a pot and turns it into water vapor. However, if the child wanted to be able to transfer evaporation to a new context (i.e., the water cycle), they would need to understand the structural similarity between the stove (a heat source) and the sun (a heat source) and their effects on liquid water. In this example, the stove is the familiar source analog, while the sun is the target analog, which is more unfamiliar. In order to transfer the concept of evaporation to the novel context of the sun, the child would need to identify the similar relations between the source and the target analog and map the relations based on their role patterns (e.g., stove to sun; Gentner, 1983; Gray & Holyoak, 2021).

Transfer may be difficult for young children because they must overcome the fixation on surface similarities between the two concepts to focus on structural similarities. In the evaporation example, children need to look beyond the surface similarities of a stove and a sun to understand the structural similarity of both being heat sources. Young children focus more on these surface-level features than on the underlying commonalities of two entities (Landau et al., 1988; Baldwin, 1989). In fact, children younger than nine years of age still struggle with identifying structural similarities (Gentner & Toupin, 1986).

In addition to children's higher-order reasoning, the learning context can play a large role in guiding children to understand the underlying commonalities, or structural similarities, between two contexts. From a situated cognition perspective, transfer often develops through meaningful participation in social contexts (Lave, 1988; Greeno et al., 1993; Engle, 2006). In Engle (2006), teachers who encouraged students to think about relevant past learning contexts and imagine future, relevant learning opportunities in which this knowledge could be useful, signaled to students that the current learning event is helping them prepare for future learning while drawing on their past knowledge (Bransford & Schwartz, 1999). Furthermore, framing students as active "authors" engaging in learning with their community prompts children to express ideas and take ownership of this acquired knowledge in future situations (Engle, 2006). The learning environment and framing of a learning context can promote transfer of learned information.

Additionally, Bransford and Schwartz (1999) defined transfer as a preparation for future learning. When learners can learn in rich learning contexts, they are better prepared for new learning, building expertise with each context they encounter. Therefore, this definition of transfer focuses on people's ability to "know with," or interpret and judge a new situation based on previous experiences (Broudy, 1977). The preparation for future learning perspective also supports learners' exploration of their learning experiences and capitalizes on their lived experiences. For example, Schwartz and Moore (1998) found that when learners had an opportunity to experiment with variance between various datasets and generate their own formulas for comparing variance (even wrong formulas), they were more likely to notice the details of a provided formula for standard deviation. In other words, their prior experiences with variance influenced their learning of the standard deviation formula and potentially their future application of this formula. Furthermore, varied, lived experiences, like living in another country, and the ability to reflect on this experience, influences how people interact with others from different backgrounds and cultures they encounter throughout their life (Bransford &

Schwartz, 1999). The preparation of future learning perspective is significant as it focuses on extended learning and considers a learner's prior knowledge and experience in the learning process.

**Recall and Transfer Supports in Podcasted Media**

Podcasts are a rich learning environment within themselves – providing explanations, examples, and applications of concepts – that could support children's retention and transfer of information. Podcast hosts often suggest activities (e.g., science experiments) for parents and children to complete after listening to the podcast episode introducing an opportunity to reminisce on the podcast's topic and introduce an element of spaced learning. Podcast hosts also provide explanations of concepts, often re-framing an expert's explanation to make it accessible to children. To do so, they will make connections, or analogies, to familiar concepts to help children process the new concept. Furthermore, podcast hosts will direct questions and prompts directly to the child listener, encouraging them to think about how the concept applies to their everyday lives. In sum, podcast episodes often implement strategies that have been shown to support children's retention and transfer of information. However, it is not known if children retain, and transfer information learned in this modality.

In addition, parents report that children listen to podcasts with others, which invites an opportunity for meaningful social interactions and conversation around a podcast topic to further support children's learning (Engle, 2006; Bransford & Schwartz, 1999; Kids Listen, 2021; Grack Nelson et al., 2021). Children and parents have opportunities to discuss concepts with each other while listening to the podcast or after listening, implementing elements of spacing and explanations in the learning context. Parents are also positioned to help children make personal, prior knowledge connections to the podcast. These personally and even culturally relevant connections have been shown to benefit children's STEM learning (Morris et al., 2021).

From the Joint Media Engagement (JME) framework, parent-child conversation while engaging with media together mediates children's learning experiences in media contexts (e.g., apps, e-books, video games; Takeuchi & Stevens, 2011; Strouse et al., 2013; Dore & Zimmerman, 2020; Ewin et al., 2021). For example, pausing the media, asking questions, and encouraging children to elaborate on the content have been shown to improve children's memory of media content. However, podcasts have not been studied within the JME framework. Whether parent-child conversations while listening to children's podcasts benefit children's learning and transfer of podcast content remains an open question.

Examining elements of podcast episodes and children's podcast-listening environments can highlight the constructs (e.g., modality, co-listening, etc.) inherent in this medium and learning environments that support children's ability to recall and transfer information learned from a podcast. In two studies, I examined 7- and 8-year-old children's learning and transfer to understand if and how children learn information from podcasts. In both studies, children listened to a podcast about the water cycle, a challenging scientific model that students are not usually taught until late elementary or junior high school (National Research Council, 2013). Learning the water cycle and its processes (e.g., evaporation) requires an understanding of the cyclic nature of the cycle and how each process fits into the cycle (Bar, 1989; Assarf & Orion, 2005). Typically, the water cycle is taught multimodally, with a teacher providing explanations and gestures with images, diagrams, and text (Márquez et al., 2006). However, these studies examined if children could learn a complex science concept in an unimodal context.

**Study 1: Modality Effects on Learning.** Podcasts are unique unimodal modalities because they include features like conversation, description, explanations, and sound effects to encourage audio engagement. Research shows learners benefit from learning in two modalities (audio and visual) when information is complementary, not redundant (Mayer, 1997; Mayer & Johnson, 2008; Yue et al., 2013). However, these studies use audio narration of *text* as auditory stimuli which differs from a podcast format that is scripted for audio engagement. Furthermore, prior research has focused mainly on adults' learning outcomes from multimodal media. Thus, Study 1 examined whether children learn from podcasts and whether providing supporting visual information affected their learning. Children listened (or listened and viewed related images) to an 11-minute science podcast about the water cycle and answered recall and transfer questions.

**Study 2: Family Conversation Effects on Learning.** In Study 2, parent-child conversations were examined to investigate how parent-child conversation supports children's learning and transfer of information heard in a podcast. The JME framework proposes that parent-child engagement in media contexts benefits children's learning outcomes (Takeuchi & Stevens, 2011; Ewin et al., 2021). However, children's podcasts have not been examined within the JME framework; thus, it is unclear if parent-child conversation during podcast listening sessions supports children's learning and transfer abilities. Furthermore, it is unknown if prompting parent-child conversation in a podcast listening experience through conversation cards affects what parents talk about with their children and, consequently, children's learning outcomes.

In Study 2, parents and children listened to an 11-minute podcast about the water cycle. Parents were provided a conversation card that differed in the types of prompts (open-ended questions about the water cycle, prior knowledge connections, or facts about the effects of conversation on learning outcomes) parents could use to engage in conversation with their child during the study session. Parents were instructed to listen to the podcast as they normally would with their child and were given five minutes after the podcast had ended to engage in or continue discussion. Parent-child conversations were transcribed and coded for conversational turns and content of their conversations (e.g., open-ended questions, prior knowledge connections, etc.).

Taken together, these two studies aimed to extend our knowledge of whether and how podcasted media and their listening environments support children's higher-order concept learning. Study 1 examined the effects of modality on children's learning and transfer in a podcast context. Study 2 aimed to understand the nature of prompted parent-child conversation while listening to podcasts and the effect of parent-child conversation on children's learning and transfer abilities.

## Study 1

Audio podcasts are digital media delivered in a single modality (i.e., the auditory modality). Audio podcasts have gained popularity in families with young children as an alternative to screen media (Kids Listen, 2021). Children's science podcasts are of particular interest because they attempt to engage children with higher-order, complex concepts (e.g., components of an atom, the evolutionary history of dinosaurs). Higher-order concepts involve making inferences, drawing connections, and building representations beyond the provided material (Resnick, 1987).

Children's podcasts include multiple features to encourage audio engagement. One feature of children's podcasts is that they are conversational. In an interview-style format, a host or a couple of hosts interview an expert and discuss a science topic, typically by the host asking questions and clarifying the expert's explanations. In another format, narrative-style science podcasts, characters act out a storyline that encompasses the science topic (e.g., traveling to Mars to learn about NASA's Martian research). Often, hosts will add elements of humor to these conversations and storylines. In addition, podcast hosts often speak directly to the child listener by asking questions to help children make connections to the topic being discussed, or they suggest related learning activities (i.e., experiments) that children can complete at home. Furthermore, children's podcasts use sound effects and music effects throughout the podcast episode to further engage listeners. Combined, these features attempt to attract and maintain children's attention to information presented in the podcast.

Little research exists on the degree to which children learn information presented in podcasts. Studies have found podcasts positively affect children's engagement with material (Grack Nelson et al., 2021), but have not examined whether children learn and remember information presented in podcasts created for children. Studies on adult learning from podcasts show mixed results. Some studies report positive learning outcomes when college students have access to podcasts as a resource with course material (e.g., Lonn & Teasley, 2009; Kennedy et al., 2016). On the other hand, other studies show that podcasts do not support learners' retention of information (e.g., Daniel & Woody, 2009). However, a key feature of the podcasts in these adult studies is that they are adaptations of text-based information (e.g., reading the textbook aloud). This differs substantively from the structures of podcasts produced for child audiences (e.g., conversational, interview style).

This misalignment of perceptual information (i.e., text-based information delivered in the auditory modality) used in adult podcast learning studies may contribute to the mixed findings of learning from podcasts. Would learning outcomes differ if learners were provided with podcasts in which content and format aligned with the modality? In the current study, we compared children's higher-order concept learning from a unimodal context formatted like a child's podcast and a multimodal context (child's podcast + related static images) to examine the effect of modality on children's learning in this unique unimodal format.

**Learning in Unimodal Contexts**

There are multiple reasons to expect unimodal contexts to be effective learning contexts. One approach is to compare the cues, or information, available to learners when engaging with different forms of media and how these cues affect learners' attention and processing of information.

The cognitive theory of multimedia learning (Mayer, 1997) proposes that learners simultaneously use verbally- and visually- based models to select, organize, and integrate to-be-learned information. However, learning can be impaired in dual modal contexts when information like on-screen text and narration conveys redundant information (Mayer, 2005; Kalyuga & Sweller, 2014). This is known as the redundancy principle. Receiving redundant information in a dual modality context could have negative effects because redundancy splits a learner's attention between the two streams of information (Sweller et al., 1998). Split-attention introduces cognitive load as the learner is overwhelmed with information, leading to decreased learning performance (Sweller & Chandler, 1994). Redundant information like audio narration and on-screen text overwhelms the learner's auditory channel. So, if the narration of a concept can be understood on its own, then adding additional information, like on-screen text, would not provide additional relevant information, placing a burden on the learner. Information presented in a unimodal context would mitigate the issue of redundancy in learning materials.
However, redundancy is not a detriment to learning when the visual stimulus presented with an audio narration is an image (i.e., a picture). According to the Integrated Model of Text and

Picture Comprehension (ITPC) and the redundancy principle, presenting auditory text narration with visual images is optimal for learning because the visual information and auditory information are processed in the visual and auditory channels, respectively, and do not overwhelm one channel (Mayer et al., 1996; Schnotz, 2005).

**Learning in Dual Modal Contexts**

Prior research shows that humans are more likely to learn information presented in more than one modality compared to a single modality (e.g., Bahrick et al., 2002; Mayer, 1997; Seger et al., 2019). According to the cognitive theory of multimedia learning, it is important to have both verbal and visual representations in order to make connections across modalities. However, how the verbal and visual representations are presented is important. Cues from the verbally- and visually-based models aid learning in situations where the cues are complementary and not redundant. Prior research with adults shows that learners demonstrate greater retention of information when short captions are presented with images and narration versus on-screen text that is identical to narration (Adesope & Nesbit, 2012; Yue et al., 2013; de Koning et al., 2017). Similarly, learners presented with short on-screen captions and narrations outperform learners who receive just narration on retention tests (Mayer et al., 1996; Mayer & Johnson, 2008). Furthermore, receiving information from audio narration and picture visuals would benefit learning because these cues are processed in two different channels. Therefore, learning in dual modalities can benefit learning when information is not redundant.

Children also demonstrate greater memory and transfer of information when text-based information is presented in an audiovisual format (with static or dynamic visual representations) compared to an auditory-only format (Knoop-van Campen et al., 2018; Seger et al., 2019). One reason we may expect a positive effect of audiovisual contexts on children's learning is that audiovisual cues provide enriched information (audio + visual) that could be helpful for children learning a concept for the first time. In other words, visuals could provide children with concrete representations of new, unfamiliar concepts. For example, elementary school-aged children learning a second language performed better on a retention test when provided with narration, visuals, and on-screen text, indicating that the redundancy principle may not extend to all learning contexts and ages (Jeu & Mohamad, 2014).

Relatedly, research with children has shown that correlated, redundant cues support children's learning of information in word learning and categorization domains (e.g., co-occurrence of features that matter for specific categories like using shape to learn the categories of solid objects; Sloutsky & Fisher, 2004; Yoshida & Smith, 2005; Sloutsky & Robinson, 2013; Luna & Sandhofer, 2021). Young children are sensitive to co-occurrence in their environments, and redundant cues can strengthen connections between concepts (Thiessen & Saffran, 2003; Yoshida & Smith, 2005; Luna & Sandhofer, 2021). Therefore, correlated cues provide children with the necessary support to learn a concept.

**Current Study**

Children's podcasts are a unique medium that include features for audio engagement with complex topics. In the current study, we asked if children learn from podcasts and if providing supporting visual information affects their learning. Based on the cognitive theory of multimedia learning, co-occurring information from the audio and visual modalities may be useful for children in learning a challenging science concept. However, due to the auditorily engaging nature of podcasts, it is possible that visual information in this context may not benefit children's learning because the visuals do not contribute additional, relevant information to the information conveyed through audio.

To examine how a unimodal context formatted like a podcast affects learning, we compared the learning outcomes of children who listened to a podcast (unimodal) or listened to a podcast and viewed relevant images (dual modality). Children answered ten questions that assessed a) recall of information presented in the podcast and b) transfer to new contexts. Our design diverges from previous studies examining the effects of podcasted media on learning. Instead of taking a predominately visual modality context (i.e., text) and adapting it into an auditory only format, we took information designed for an auditory context (e.g., sound effects, conversation between individuals, vivid description) and added visual cues.

## Method

### Participants

Participants were 69 elementary school aged children ($M_{age}$ = 8.1 years, range = 7.0 – 8.9 years, 34 females) recruited through social media platforms, email listservs, and a birth records database. Parents reported children's racial and ethnic identity with majority of children identified as White ($N$ = 39). The majority of parents ($N$ = 65) held a college degree. Parents also reported children's podcast listening habits. Twenty-five of the participants reported that their child frequently (1.5 hours/week) listened to podcasts. Four participants were excluded due to parental interference during testing, technical difficulties, and missing data. This study was approved by the authors' institutional review board and families received a $5 gift card via email after the study concluded.

### Design and Materials

This study was a 2x2 mixed-subjects design in which condition (i.e., audio-only and audiovisual) was between-subjects, and test question type was within-subjects (i.e., memory and transfer). The water cycle topic was selected as the science topic for this podcast to mitigate prior knowledge concerns as it is typically incorporated into science curriculums in $5^{th}$ or $6^{th}$ grade (National Research Council, 2013).

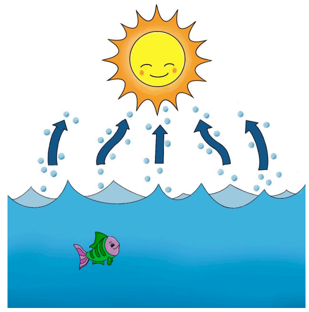
In both conditions, children listened to an 11-minute podcast created specifically for the study. The podcast included two female speakers discussing the water cycle and its various processes (i.e., precipitation, evaporation, condensation, and transpiration). The number of times the term of a process (i.e., precipitation, evaporation, condensation, and transpiration) was mentioned within the podcast was standardized, with each term mentioned eight times. Sound effects were also added to the podcast to maintain attention and model the typical podcast format produced for child audiences. Sound effects included intro and outro music and highlighted main processes (e.g., boiling water sound effect when discussing evaporation examples) and tangential information (e.g., cricket and frog sound effects when ponds are mentioned).

**Audio-only and Audiovisual Media**

In the audio-only condition, children viewed a blank white screen while listening to the podcast. In the audiovisual condition, children viewed a PowerPoint of relevant images synced with the audio (Figure 1). Each image appeared on the screen for 8 seconds. Two images were associated with each concept (e.g., evaporation). Each image depicted an example of a process mentioned within the podcast. However, details like arrows, dots representing water molecules, and animals were included in the images to provide children with rich visual representations of the processes. The images were loosely modeled after how the water cycle is depicted in textbooks (e.g., arrows showing the direction of water movement). See Appendix B for all eight images used in the study. These types of details were not explicitly mentioned in the podcast. When an image was not present on the screen, children viewed a blank white screen while listening to the audio.

**Figure 1**

*Example Evaporation Image*



*Note.* One of the eight images presented to children in the audiovisual condition. This image depicts the process of evaporation.

**Engagement Questionnaire**

Children's engagement with the media was measured using an adapted version of the Engagement in Science Learning Activities instrument (Chung et al., 2016). Children were asked eight questions that assessed their affective, behavioral, and cognitive engagement with the media (e.g., "During the podcast: I felt bored."; see Appendix C). Children were shown a green bidirectional arrow with incremental magnitudes of yes and no along the arrow. The experimenter read a statement, and children were asked to verbally indicate how much they agreed or disagreed with the statement. Each item was based on a 4-point Likert scale with four items reverse coded. Children's responses were scored and averaged across eight items, resulting in an overall engagement score.

**Test Questions**

A 10-item test assessed children's recall and transfer of information presented in the study. Five recall questions assessed children's memory of information by asking children to recall information directly stated in the media (e.g., What is it called when water vapor gets cold, turns into a liquid, and then turns into a cloud?). Five transfer questions required children to transfer the information learned from the podcast to a novel scenario (e.g., "When it is hot outside, and we are drinking a cold drink from a glass, sometimes water droplets form on the outside of the glass. Is this an example of evaporation, condensation, or precipitation?). The order of test questions was randomized within the recall and transfer blocks. However, each child received all five recall questions first and then the five transfer questions. Responses to questions were scored using the rubric described below.

**Procedure**

Study sessions took place over Zoom and were recorded. Participants were randomly assigned to the audio-only or audiovisual condition. In the audio-only condition, parents were walked through how to minimize the Zoom participant and self-view windows to reduce distraction. The experimenter shared a blank, white PowerPoint slide through Zoom screen sharing for children to look at while listening to the podcast. Parents and children were sent a Box link to the podcast using the Zoom chat function and asked to play the audio when ready. Once the podcast started playing, they were asked to switch back to the Zoom screen so that they viewed the blank white screen. Participants were asked to keep their video and audio on while the experimenter muted themselves and turned off their video camera.

In the audiovisual condition, children were sent a Box link to a video that included the audio synced with visual images using the Zoom chat function. Each image was on the screen for 10 seconds. Parents and children were asked to keep their attention on the web browser and not switch to Zoom when they pressed play on the video. In both conditions, the experimenter asked parents not to comment on the media material or help their children throughout the study.

After children finished listening to or listening to and watching the media, the experimenter assessed their engagement with the podcast using the Engagement in Science

Learning Activities instrument (Chung et al., 2016). Children were told that the podcast creators were looking for feedback to make the podcast the best it could be for other children to enjoy; therefore, they should share their honest opinions.

To assess children's recall and transfer of information from the media, the experimenter read the ten questions and noted the child's answers on the test answer sheet. Children were not provided any feedback, but experimenters responded with neutral statements of encouragement (e.g., "You are doing great!"). After answering the ten test questions, we asked children, "In your own words, can you define [evaporation/precipitation]?"

**Scoring and Reliability Coding of Test Questions**

Responses to test questions were scored using a rubric designed by the first author. Each question was worth one point except for the first recall question, which had three correct responses, liquid, solid, and gas. Partial points were possible for the majority of questions.

The experimenter scored each child's responses after the study session. To assess scoring reliability, a second research assistant viewed each study session recording and scored children's responses to test questions. We obtained intra-class correlation coefficients (ICC) using the *irr* package (0.84.1; Gamer et al., 2022) in R version 4.3.1 (R Core Team, 2023). ICC was calculated based on a single measure ($k$ =2), absolute agreement, 2-way mixed-effects model, ICC = .934, 95% CI [.923 – .947]. Any disagreements were resolved by a third coder and included in the final dataset.

**Semantic Textual Similarity Analysis**

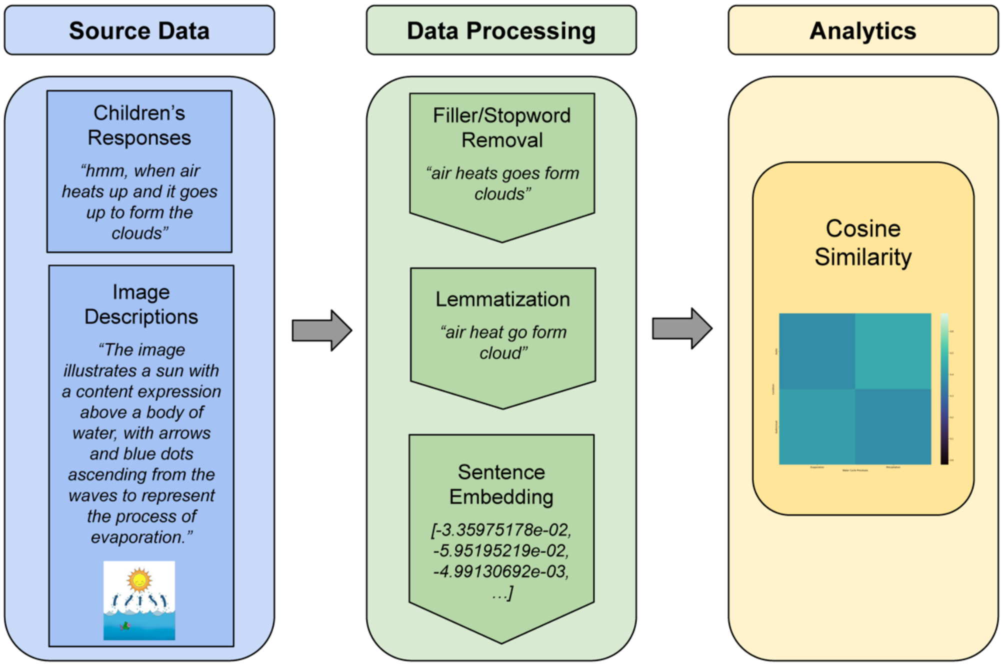
We conducted a semantic textual similarity analysis comparing children's responses to the two open-ended evaporation and precipitation questions at the end of the study and descriptions of the evaporation and precipitation images presented to children (Figure 2). We were specifically interested in whether children in the audiovisual condition attended to and incorporated the information in the images into their understanding of evaporation and precipitation. If so, we would expect children's similarity scores in the audiovisual condition to be significantly higher than in the audio-only condition because children in the audio-only condition did not see the visuals. Therefore, the audio-only similarity scores served as a baseline measure. We chose to ask children open-ended questions about evaporation and precipitation processes because children in the piloting stage, regardless of condition, demonstrated a greater understanding of these processes compared to transpiration and condensation. This was confirmed after data collection was completed based on a test item analysis (Appendix E).

A trained research assistant transcribed children's open-ended responses. GPT-4 generated image descriptions based on the images and the prompt, "This is an illustration of [precipitation/evaporation] in a children's educational book. Can you write a description of this image using two sentences? Do not comment on whether the quality of the picture serves its purpose, focusing on describing the content."

To compare the similarity between children's open-ended responses and image descriptions, we used cosine similarity, a term-based similarity measure that calculates the cosine of the angle between two vectors (i.e., sentence embedding pairs; Gomaa & Fahmy, 2013). In our study, a high cosine similarity value means that a child's response to the question shared a high semantic similarity to the image description. For the analysis, we removed filler words (e.g., "uhm" and "hmm") along with stop words (e.g., "I" and "this") from children's responses. Words were then lemmatized (e.g., "goes" would become "go") and converted into embeddings with the Sentence Transformers library (version 2.2.2; Reimers & Gurevych, 2019) in Python (version 3.10.13). These embeddings were then compared using cosine similarity.

**Figure 2**

*Data Processing Schematic for Semantic Textual Similarity Analysis*




# Results

## Preliminary Results

To ensure that both conditions included children of similar ages, we examined if participants' ages differed between the audiovisual and audio-only conditions. We found no difference between the age of participants in the audio-only condition ($M_{age}$ = 8.0 years, *SD* = 0.63 years) and the audiovisual condition ($M_{age}$ = 8.2 years, *SD* = 0.56; $t(67) = -1.48$, $p = .144$). Therefore, further analyses do not include the age of participants.

Furthermore, we conducted a linear regression analysis to assess if modality affected children's self-reported engagement. Out of the 67 children who reported engagement, we found no differences between the audio-only (*M* = 3.20, *SD* = 0.55) and audiovisual condition (*M* = 3.19, *SD* = 0.50) in children's overall engagement ratings, $R^2 = -0.02$, $F(1, 65) = .003$, $\beta$ = -

0.007, *p* = .957, 95% CI[-0.26, 0.25]. In other words, modality did not influence children's engagement in the study, and thus engagement would not account for any modality differences in recall and transfer performance at test.

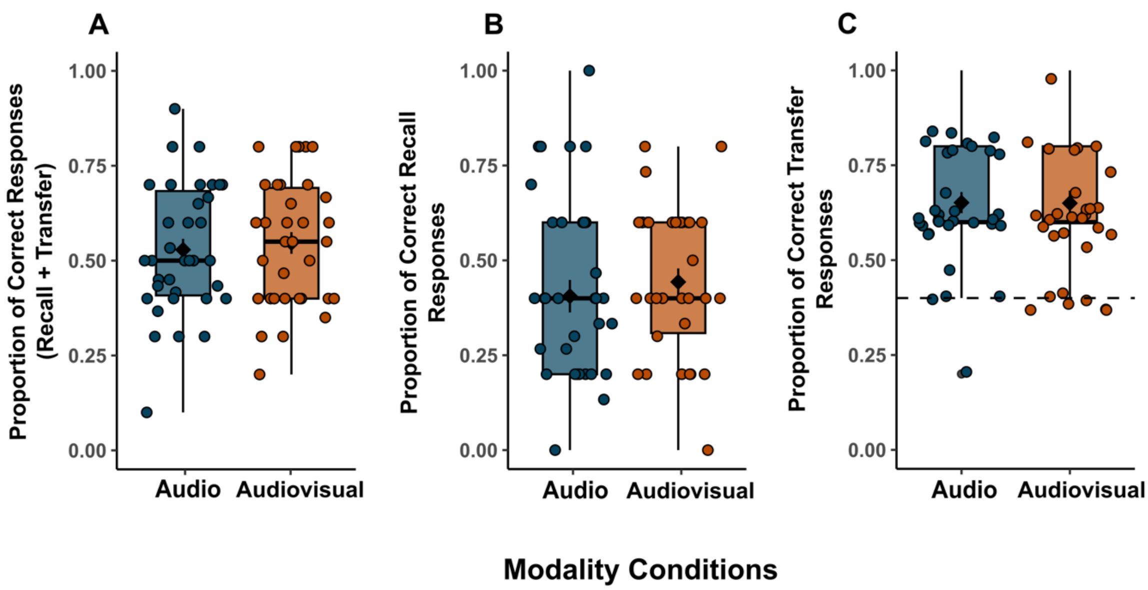
**Modality and Learning**

Our primary questions involved whether children's learning performance differed between the audio-only (*n* = 35) and audiovisual (*n* = 34) conditions. Because chance levels differed for the recall and transfer questions, we examined children's overall test performance, as well as their performance on recall and transfer questions separately. As seen in Figure 3A, children's overall performance at test did not significantly differ between the audio-only and audiovisual conditions, $t(67) = 0.44$, $p = .66$. We could not compare children's recall performance to chance on recall questions because chance on these questions was theoretically infinite. Recall questions provided children with a definition, and they had to generate the term in their responses. As shown in Figure 3B, we compared children's performance on recall test questions only, and also found no significant difference in children's performance in the auditory-only condition ($M = 0.44$, $SD = 0.25$) compared to the audiovisual condition ($M = 0.41$, $SD = 0.21$) on recall test questions, $t(67) = 0.66$, $p = .506$.

However, because transfer questions provided children with answer choices, we could compare children's transfer performance to chance. Chance performance on transfer questions was 0.40. We conducted two, one-sample t-tests comparing children's transfer performance in the audio condition and children's transfer performance to chance. We found that children in the audio-only condition ($M = 0.65$, $SD = 0.17$) performed significantly above chance on transfer questions ($p < .05$). Children in the audiovisual condition ($M = 0.65$, $SD = 0.19$) also performed significantly above chance on transfer questions ($p < .05$). As shown in Figure 3C, we found no difference in children's performance in the auditory-only condition compared to the audiovisual condition on the transfer test questions, $t(67) = -0.03$, $p = .97$. In our task, children did not show any significant differences in their learning performance when presented science information in an auditory-only format like a podcast or an audiovisual format (a podcast with associated static images). However, children in both the audio-only and audiovisual conditions demonstrated evidence of learning, specifically the ability to transfer concepts presented in the podcast.

**Figure 3**

*Children's Proportion of Correct Responses by Modality Condition*




*Note.* Each point represents an individual participant. The solid black diamond and vertical bars represent mean and standard error.

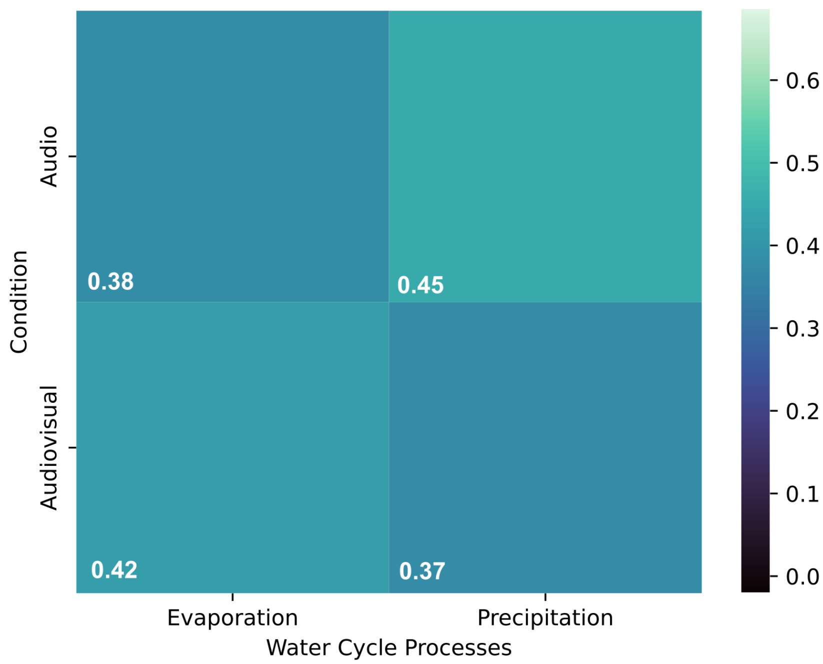
**Analysis of Children's Open-Ended Responses**

We calculated cosine similarity values for children's responses to the open-ended evaporation and precipitation questions and the evaporation and precipitation image descriptions generated by GPT-4. Each participant in the audio and audiovisual condition had four cosine similarity values – two values for the two evaporation image descriptions and two for the precipitation image descriptions.

First, we averaged the participants' two cosine values for evaporation to create an average cosine similarity value for that process. We followed the same procedure for precipitation cosine similarity values. Then, we calculated an average cosine similarity value for the audio-only and the audiovisual conditions for evaporation responses. We also calculated an average for the two conditions for precipitation. We conducted two t-tests (with Bonferroni corrections to account for multiple comparisons) to compare children's cosine values in the audio-only and audiovisual conditions for each process. As Figure 4 shows, we found no significant difference between the cosine similarity values of children in the audio-only condition ($M = 0.38$, $SD = 0.10$) and the audiovisual condition ($M = 0.42$, $SD = 0.08$) for evaporation, $t(51) = -1.63$, $p = .11$. Similarly, we found no significant difference between the cosine similarity values of children in the audio-only condition ($M = 0.45$, $SD = 0.13$) and the audiovisual condition ($M = 0.37$, $SD = 0.17$) for precipitation, $t(38) = 1.53$, $p = .14$. In other words, we did not find evidence that children in the audiovisual condition used the visual information in their explanation of evaporation and precipitation processes.

**Figure 4**

*Semantic Text Similarity Across Modality Conditions*




*Note.* Heat map showing the average cosine similarity values (denoted in each cell) between children's responses to the open-ended evaporation and precipitation questions and image descriptions. No significant differences were found when comparing the average cosine similarities of children in the audio and audiovisual conditions for both the evaporation and precipitation processes.

## Discussion

The aim of this study was to examine the effect of modality, audio-only versus audiovisual, on children's higher-order learning. Our study took a novel approach by using an audio-only stimulus designed for the auditory modality (e.g., a conversational interview format with sound effects) instead of narrating written text. We found no significant differences in learning between the audio-only and audiovisual conditions. However, we found evidence that children learned about the water cycle in both conditions as children in both conditions performed above chance on transfer questions.

Prior research on the effect of modality on learners' comprehension and retention of material is mixed. However, those studies used text narration as their audio stimulus. Studies with adults sometimes find that dual modal contexts are not beneficial for learning, especially when students read a passage and listen to its audio narration (e.g., Ari & Calandra, 2022). According to the redundancy principle in the cognitive theory of multimedia learning, this introduces cognitive load and impairs learning.

Conversely, some studies show an effect of modality on learners' performance (Mayer et al., 1996; Harskamp et al., 2007). Particularly with science information, secondary school students and college students retained and transferred information when they received narration of science lessons with illustrations (Harskamp et al., 2007) or when summaries of science lessons included narration with images (Mayer et al., 1996) providing evidence that dual modal contexts are beneficial for learning when visual (i.e., images) and audio information are complementary.

It is possible that visual information in our study was neither redundant nor complementary to the information presented auditorily. A semantic textual similarity analysis found no evidence that children were using the visual information in their explanations of evaporation and precipitation in the audiovisual condition. This could indicate that information presented in a podcast format with features that engage listeners auditorily is sufficient for children's learning. In other words, maybe they do not need the support from the visual modality to learn the information. However, we only queried open ended responses for the evaporation and precipitation concepts. Children demonstrated greater mastery of evaporation and precipitation compared to condensation and transpiration concepts. Perhaps visual information would have a greater effect on learning more challenging concepts.

Additionally, the visuals in our study were static images and were only on the screen for a brief period of time (8 seconds each). Our images may not have been salient enough to attract children's attention and affect learning. It is also possible that the information provided in the visuals significantly overlapped with the information provided auditorily in the podcast. Redundancy between visual and auditory information could have potentially improved performance on the post test, or alternatively have had no effect on learning. That there were no significant differences between the audio-only and audiovisual conditions suggesting that redundancy may not have improved performance. However, the study was not designed to examine how redundancy affected learning at a granular level and we could not analyze learning based on the degree of similarity between the visuals and podcast transcript. Therefore, future research is needed to assess the effect of visual information on children's learning while listening to a podcast. Research could examine if changing the nature of visual information presented with podcasts, for example, using dynamic visualizations or introducing irrelevant information in the visuals, affects children's attention and learning. It is possible that different types of visual cues would show different learning outcomes. According to the ITPC framework, visual information creates a mental model for learners, resulting in deeper processing (Schnotz, 2005). However, the podcast audio could create a mental model for learners through vivid, verbal description and sound effects. Future work should examine the effect of podcast audio on learning within the ITPC framework.

One cognitive process that we do not account for in the current study is selective attention. Selective attention, the ability to attend to relevant information and ignore irrelevant details, develops with age (Chong & Treisman, 2005). Prior research has found that young children attend holistically to multiple details rather than attending narrowly to the relevant information needed for learning (Deng & Sloutsky, 2016; Plebanek & Sloutsky, 2017). In contexts where multiple cues (i.e., narration and visuals) are vying for the learners' attention, it may be difficult for children to identify and attend to relevant information needed for successful learning. Our results may not capture individual differences in children's selective attention. Future research could include selective attention measures to examine how children's selective attention abilities affect learning in unimodal and dual-modal contexts.

Overall, the current study highlights the potential of podcasts to scaffold higher-order concept learning. Future research can build on this study to examine unimodal learning from an audio-only stimulus formatted like a podcast. Examining the effect of a podcast compared to a text-based audio recording on learning could extend our current understanding of learning from media and the cognitive processes involved in processing information in unimodal media contexts.

### Conclusion

The current study found no effect of modality on children's learning of a science concept. However, changes in specifics of the study design may find effects. Children demonstrated learning of science information from both a single (i.e., podcast) and dual (i.e., podcast and images) modality context. Interestingly, in the dual modality context, children did not appear to use the visual information to learn the science concepts. This study calls for additional research using podcasts as an audio-only stimulus to understand modality effects on higher-order learning.

## Study 2

Parent-child conversation during informal learning experiences supports children's understanding of complex science concepts. One particular conversation technique known as prior knowledge connections, or connections that link a child's previous experiences to the concept being learned, has been shown to facilitate children's learning and transfer of information (Crowley & Jacobs, 2002; Valle & Callanan, 2006; Jant et al., 2014). However, it has been found that parents do not often organically produce these connections during learning experiences (Boland et al., 2003; Zimmerman et al., 2010).

Science information is encountered in various contexts including trips to the science museum and through educational media like television and apps. Parent-child conversation in both contexts have been shown to support children's science learning outcomes (e.g., Crowley et al., 2001a; Sheehan et al., 2019). However, the effect of prompting parent-child conversation in children's science podcasts, has not been examined. Podcasts created for child audiences are an attractive alternative to screen media for many parents (Grack Nelson et al., 2021). Further, children's science podcasts are a unique form of media in that they aim to teach children complex concepts and engage children auditorily. The goal of the current study was to examine how prompting parent-child conversation while listening to a science podcast affected parent-child conversation and, subsequently, children's learning and transfer.

**Conversation and Higher-Order Concept Learning**

Parent-child conversation, also known as joint talk, while engaged in an activity is beneficial for children's engagement and learning of higher-order concepts (Crowley et al., 2001a; Hedrick et al., 2009; Jant et a1., 2014). In contexts such as museums and everyday conversation, numerous studies report positive effects of parent-child conversation on children's science, technology, engineering and mathematics (STEM) engagement and learning (e.g., Benjamin et al., 2010; Callanan & Jipson, 2001; Ocular et al., 2022; Polinksy et al., 2017). Parents play an important role in parent-child conversation by asking questions or providing explanations. When parents ask children open-ended questions, they are helping children build representations of the event that include core details that will be remembered in the future (Benjamin et al., 2010). Even "explanatoids," incomplete or very simple explanations in the moment of the learning event, help children process information in real time (Crowley & Galco, 2001; Fender & Crowley, 2007). Parents often spontaneously generate "explanatoids," and the cumulative effect of these explanations helps children construct and develop scientific thinking (Crowley & Jacobs, 2002).

Much of the research on parent-child engagement in learning environments is informed by Sociocultural Theory, in which learners construct knowledge in conversation and everyday interactions with more knowledgeable others (Vygotsky, 1978). According to Sociocultural Theory, conversation is the mechanism by which learning occurs (Fivush et al., 2006). When parents ask questions and provide explanations, children's learning is scaffolded. In other words, children are provided with information that makes the concept they are learning more accessible than if they were learning the concept on their own. In rich learning contexts like science museums, parent-child conversation, or joint verbal engagement, that elaborates and builds on the experience helps children form a salient memory and build a framework that aids in learning (Ornstein et al., 2004; Benjamin et al., 2010).

In addition, Sociocultural Theory embraces individualized learning (Haden, 2010). Children's learning outcomes are guided by their experiences and interests (Crowley & Jacobs, 2002; Palmquist & Crowley, 2007). Children's learning is also affected by their parents' willingness to engage and beliefs about engaging with their children in the learning experience (Crowley et al., 2001a; Crowley et al., 2001b). Parents are uniquely positioned to scaffold their children's learning capitalizing on their child's interests and experiences. Parents can cultivate a richer learning experience for their children by connecting concepts to their family's lived experiences. This connection introduces a culturally and personally relevant element to the learning context – a critical factor for informal STEM learning experiences (Morris et al., 2021).

***Prior Knowledge Connections***

Prior knowledge connections are one particular conversation technique that has been shown to scaffold children's higher order concept learning (Crowley & Jacobs, 2002; Valle & Callanan, 2006; Jant et al., 2014). Prior knowledge connections are when a parent links a child's prior knowledge or past experiences with the to-be-learned concept (Tessler & Nelson, 1994; Boland et al., 2003). Prior knowledge connections scaffold children's learning by facilitating categorization processes and providing children with relevant and meaningful information to process the new concept. For example, if a parent and child are learning about different types of pollinators (e.g., bees, hummingbirds, moths, etc.) from a museum exhibit, the parent could first help the child aggregate (i.e., combine disparate examples) by synthesizing the key features of a pollinator (i.e., pollen sticks to their body while drinking nectar). To decontextualize or abstract the examples and pollinator concept from the immediate context, the parent could make a prior knowledge connection by comparing the bee in the exhibit with those they see at the park (e.g., "This bee looks like the bee we saw while eating ice cream at the park."). This example provides the child with a salient and meaningful example from their lived experience that helps them think about pollinators in different contexts outside of the museum exhibit.

Through prior knowledge connections, parents are prompting children to aggregate examples across varied contexts by drawing connections for children between encountered examples (Jant et al., 2014; Marcus et al., 2018). When parents scaffold the aggregation and decontextualization processes, children's transfer of information is supported. When children are encouraged to draw a connection to a prior experience to help explain a new concept, they identify similarities and differences between the two contexts to make sense of the concept in question (Valle & Callanan, 2006). This active comparison aids children in abstracting the core details of the concept to apply it across different contexts. Over time, the core details of the concept are strengthened in memory, and peripheral details are not strengthened. For example, once children understand that pollinators are organisms that carry pollen from plant to plant, they will be able to identify pollinators in various contexts.

Prior work has shown that generalization is best supported when the relation between the two contexts is emphasized and when learners can learn in rich learning contexts (Bransford & Schwartz, 1999; Engle, 2006). Successful generalization takes into account prior experiences and the effect of these prior experiences in new learning contexts. Parents who engage with their children at museum exhibits help them aggregate examples of the concept through explanation and drawing connections between examples. Decontextualization is supported when parents connect the newly encountered information to something already familiar to the child. This explanation helps children process the new information using a concept they already understand. Children learning a complex concept for the first time may need opportunities to aggregate and decontextualize examples to acquire and generalize the new concept.

**Conversation and Media Contexts**

Some research has found that media and technology (e.g., television, apps, e-books) can negatively impact children's learning outcomes and positive parent-child engagement as parents allow the media to support the child's learning or focus on how to control the device instead of a focus on media content (Parish-Morris et al., 2013; Hiniker et al., 2018; Aladé et al., 2016). However, a wealth of research exists on the benefits of parent-child conversation and interaction while engaging with media to mitigate any adverse effects (e.g., Riser et al., 1984; Yelland & Masters, 2007; Takeuchi & Stevens, 2011). Parents report frequently co-viewing media with children (Dore & Zimmermann, 2020), which promotes children's engagement with content and learning (Reiser et al., 1984; Charkoff & Nathanson, 2008; Strouse et al., 2013). Additionally, digital technologies frameworks (e.g., Joint Media Engagement, Takeuchi & Stevens, 2011; Ewin et al., 2021; Emergent Digital Literacy, Neumann et al., 2016; and Bers' Positive Technological Development framework, Bers, 2007, 2010) collectively suggest the importance of social interaction on children's engagement with digital media.

The current study aimed to situate podcasts in the Joint Media Engagement framework (JME). The JME framework outlines the practice of engaging in media together and extends the concept of co-viewing to various types of media (e.g., apps, e-books, video games; Takeuchi & Stevens, 2011; Ewin et al., 2021). JME emphasizes the importance of shared attention to the media and attention to each other through conversation. Interactions that scaffold and mediate children's learning experiences are especially helpful in supporting children's learning outcomes (Strouse et al., 2013; Dore & Zimmerman, 2020). For example, pausing the media, asking questions, and encouraging children to elaborate on the content have been shown to improve children's memory of media content.

Podcasts, programs formatted as online accessible digital audio files, are a type of media that are understudied and have not been examined in the JME framework. Podcasts created for child audiences are an emerging source of STEM engagement opportunities for children (Grack Nelson et al., 2021). These podcasts are designed to be engaging for child audiences. Children's science podcast hosts talk to each other or to guest experts as they discuss a topic. They use vivid imagery, sound effects, and examples to explain concepts. The hosts will often directly address the child listener to encourage them to apply the concept to the child's own experiences (i.e., make prior knowledge connections). Due to the nature of podcasts, children may develop a parasocial relationship, a one-sided relationship in which children perceive that they are interacting meaningfully with podcast hosts, over time. Prior research has shown that children who have developed parasocial relationships with television characters demonstrate educational gains (Linebarger & Walker, 2005; Lauricella et al., 2011).

The engaging nature of children's podcasts and the possibility of children developing parasocial relationships with podcast hosts could make parent-child conversation while listening to a podcast redundant. Parents' questions or interpretations during a podcast may not provide additional benefits because children's podcasts are already structured conversationally. Moreover, parents may step back from scaffolding their children's learning if they perceive that the device or media program is prompting and supporting learning (Hiniker et al., 2018). However, given the importance of parent-child engagement in informal learning and media contexts, examining how parents and children listen to podcasts together and how this affects children's learning is an open and important question.

**Prompting Parent-Child Conversation**

Research in informal learning settings, specifically museums, has shown how prompting parent-child conversation increases parents' open-ended question use and explanations and supports children's higher order concept learning (Haden et al., 2014; Polinksy et al., 2017; Marcus et al., 2018; Willard et al., 2019; Chandler-Campbell et al., 2020). The degree of prompting in these studies varies from providing parents and children with just verbal prompts (Polinsky et al., 2017; Willard et al., 2019) to verbal prompts and hands-on demonstrations to support parent-child interaction (Haden et al., 2014; Marcus et al., 2018; Chandler-Campbell et al., 2020). Additionally, research in the learning media field has found positive effects on children's language development when parents were sent links to videos about ways to interact with children while playing an app-based game (Rowe et al., 2021).

One technique that capitalizes on verbal prompts to promote parent-child conversation is conversation cards (Jant et al., 2014). Conversation cards include written questions that parents can ask their child while interacting with a museum exhibit to further engage their children with the content in the exhibit. Jant et al. (2014) found that when parents were prompted to ask open-ended questions prior to engaging in an exhibit with their child, they were more likely to do so while visiting the exhibit. Furthermore, parents and children engaged in more conversation and made more connections between two exhibits when parents were provided with conversation cards. Another study found that parents who were provided with conversation prompts that highlighted spatial language increased their spatial language use during an activity and children's spatial language use in that activity improved children's performance in a follow up spatial activity (Polinsky et al., 2017).

In the current study, we used conversation cards to prompt parents to ask open-ended questions and make prior knowledge connections with their children during their podcast listening experience. Research shows that prior knowledge connections in parent-child conversation during a learning experience are rare (Boland et al., 2003; Zimmerman et al., 2009), despite evidence that these connections support children's learning and transfer (Crowley & Jacobs, 2002; Valle & Callanan, 2006; Jant et al., 2014). By prompting parents to use prior knowledge connections, we could test the effect of conversation cards on children's use of these connections and children's successful transfer of information presented in the podcast.

## Current Study

According to the JME framework, parent-child conversation should benefit children's learning of a science concept from a podcast. However, podcasts are designed to be engaging; thus, perhaps parent-child conversation would be redundant in this context. For example, children's podcasts include rich imagery, concrete examples, and prompts for children to make prior knowledge connections. This design parallels informal learning research in museums and public spaces that uses conversation cards and signs to highlight learning opportunities for parents (Gutwill & Allen, 2010; Hanner et al., 2019; Jant et al., 2014; Song et al., 2017).

However, compared to in-person conversation, podcasts do not provide social contingency, which has demonstrated benefits for children's learning (e.g., Strouse et al., 2018). Additionally, parents are uniquely positioned to provide children with personally-relevant connections to the concept – helping children to aggregate and decontextualize complex information as they learn. In the current study, parents and children listened to an 11-minute science podcast together. Parents were provided with conversation cards that included conversation prompts. Parent-child, podcast-related conversations were recorded, transcribed, and coded for contingency (e.g., bouts of conversation) and content (e.g., open-ended questions, prior knowledge associations). We were interested in examining if parents and children have conversations while listening to a podcast and if so, what the characteristics of these conversations are. Additionally, we examined if conversation cards, specifically the cards that prompted parents to make prior knowledge connections, affected parent prompts and consequently, children's retention and generalization of information presented in the podcast.

# Method

## Participants

Participants were 61 seven- to eight-year-olds and their parents ($M_{age}$ = 8.01 years, range = 7.02 – 8.98 years, 33 females) recruited through social media platforms and Children Helping Science, a platform for remote data created by the 2023 merger of Lookit (Scott & Schulz, 2017) and Children Helping Science (Sheskin et al., 2020). Parents reported children's racial and ethnic identity. Children identified as White ($N$ = 40), Asian ($N$ = 12), African American ($N$ = 2), American Indian/Alaskan Native ($N$ = 1), and Chose Not to Respond ($N$ = 1). Five participants identified as multiracial, specifically Asian and White ($N$ = 4) and American Indian/Alaskan Native and White ($N$ = 1). Six participants identified as Hispanic or Latino. The majority of parents ($N$ = 55) held a college degree. Nineteen participants were excluded due to noncompliance ($N$ = 5), outside of age range ($N$ = 3), experimenter error ($N$ = 1) and inadequate recording quality of parent-child conversation ($N$ = 10). This study was approved by the UCLA's Institutional Review Board (#22-001520) and families received a $5 gift card via email after the study concluded.

## Design and Materials

This study was a 3x2 mixed-subjects design in which conversation prompt condition (i.e., prior knowledge questions, water cycle questions, control) is between-subjects, and test question type (i.e., recall and transfer) is within-subjects.

### *Conversation Cards*

Parents were provided with conversation prompts prior to listening to the podcast with their children. In the prior knowledge questions and water cycle questions conditions, parents received an image with five typed conversation prompts and this instruction, "Take a look at the following questions and consider using these kinds of questions in your conversation with your child!" (see Appendix F). In the prior knowledge questions condition, the questions prompted parents to ask questions that connected the content of the podcast with their child's personal prior experience (e.g., "How do the plants and trees that we see in our backyard or on walks or hikes play a role in the water cycle?"). In the water cycle questions condition, parents were prompted to ask general questions about the podcast content (e.g., "How do trees play a role in the water cycle?"). In the control condition, parents read statements about how conversation can support children's learning (e.g., "Asking open-ended questions (e.g., "What do you think?") encourages children to elaborate on their thoughts and ideas.").

***Audio Media***

Parents and children listened to an 11-minute podcast created and produced by the first author and a team of research assistants. The podcast includes two female speakers discussing the water cycle and its various processes (i.e., precipitation, evaporation, condensation, and transpiration). The water cycle topic was selected as the science topic for this podcast to mitigate prior knowledge concerns. The water cycle is not typically incorporated into science curriculums until the 5$^{th}$ or 6$^{th}$ grade (National Research Council, 2013). The number of times a process (i.e., precipitation, evaporation, condensation, and transpiration) is mentioned within the podcast was standardized, with each process mentioned eight times. Sound effects were also added to the podcast to model the typical podcast format produced for child audiences. Sound effects throughout the podcast include intro and outro music, highlighting the main processes and tangential information.

***Test Questions***

Children were asked four questions before the start of the podcast to assess their understanding of the processes in the water cycle (e.g., "In your own words, can you tell me what evaporation means?"). After listening to the podcast with their parent, children were asked

10 questions to assess their retention of the information heard in the podcast. Five questions assessed children's retention of information presented in the podcast and five questions assessed children's ability to transfer information heard in the podcast to novel scenarios. Appendix D includes the pre- and post- test questions.

**Procedure**

Study sessions took place over Zoom and were recorded. Prior to the study, parents were informed that they would need a separate device with them at the appointment (e.g., phone, iPad). Parents provided a phone number or email address so the experimenter could send them the conversation card and a demographics questionnaire. Participants were randomly assigned to one of the conversation prompt conditions. At the beginning of the study, parents were emailed or texted the conversation card based on their conversation card condition. They were instructed to read the card to themselves. During this time, the experimenter asked the child four pretest questions to assess their understanding of the water cycle. Then the experimenter explained the podcast-listening procedure to the parent and the child. The experimenter sent the parent a link via the Zoom chat, and they were instructed to listen to the podcast with their child as they normally would (i.e., listening straight through, pausing to discuss, etc.). The experimenter muted themselves and turned off their camera while the child and parent listened to the podcast.

When the podcast ended, the experimenter explained that while they were getting set up for the next part of the study, parents and children would have an additional five minutes to discuss the podcast or hang out. Parents and children were provided a link via Zoom chat to an online sketchpad that they could use during that time and asked to stick by their device during the five minutes. The experimenter, again, muted themselves, turned off their video, and used a timer set to five minutes to time the session. When the five minutes concluded, the experimenter sent a link to the demographics questionnaire for the parent to complete on their separate device. During this time, the experimenter asked the child the 10 test questions, noting the child's responses on a test answer sheet. After the parent completed the questionnaire and the child finished answering the test questions, the experimenter debriefed the parent and concluded the experiment. Parents were sent a gift card via email after the session.

**Transcription and Coding**

Recordings of the study session were transcribed using Zoom's transcription software. The Zoom transcripts were then formatted into Excel sheets using AI software for further transcription and coding. A transcriber further formatted the Excel sheet using a coding template developed by the author. The transcriber deleted the experimenter's speech and podcast audio so that the transcript only included parent and child speech while listening to the podcast and during the five minutes after the podcast ended. While listening to the recorded audio, the transcriber then went line-by-line to identify the speaker and separate speech into utterances defined by uninterrupted speech of a speaker. A long pause by a speaker and a change in speakers indicated a new utterance. The transcriber also corrected any speech that was inaccurately transcribed by software and corrected the timestamps of the utterances. Additionally, transcribers noted in the transcript when conversation took place – while the podcast was playing in the background, during pauses, or after the podcast had ended.

Transcripts were passed on to a coding team of research assistants who coded conversational turns and exchanges using the timestamps. A conversational turn is counted in pairs, for example, one utterance by an adult/child followed by a child/adult response (Romeo et al., 2018). For each family, we calculated conversational turns per minute by dividing the sum of conversational turns by total duration of conversation to provide a standardized measure of conversation (Alper et al., 2021). In addition, coders annotated conversational exchanges, defined as a block of continuous conversation that could consist of one or more conversational turns. Coders indicated if the parent or child initiated the exchange.

Finally, a separate coding team received the transcript to code for parent-child conversation content. This team used the Standard Taxonomy of Dyadic Conversation (Mulwa & Kucker, 2022) with some modifications to code parent and child speech (Appendix G). In the first round, coders annotated each utterance using the coding scheme. Coding was non-mutually exclusive. In other words, one utterance could have more than one code. In the second round, coders identified the source of parent questions. We were interested in whether parents were asking questions based on information presented in the podcast and if parents were asking questions directly from the conversation cards presented at the beginning of the study.

***Reliability Procedures***

Coders were trained on coding procedures until reliability was established (Krippendorff, 2011). We obtained Krippendorff's alpha coefficient using the irr package (0.84.1; Gamer et al., 2022) in R version 4.3.1 (R Core Team, 2023). Reliability for conversational coding was high ($M_{alpha}$ = 0.90). Reliability for parent and child speech was moderate ($M_{alpha}$ = 0.59). Disagreements were resolved through discussion and included in the final dataset.

***Statistical Analyses***

Analyses were run in R version 4.3.1 (R Core Team, 2023). Our pretest variable was dummy coded and included as a covariate in a few analyses described in detail below: (score of zero = 0, score of greater than zero = 1). Confidence intervals reported below in brackets next to the coefficients are 95% confidence intervals. The mediation analysis was conducted using the

PROCESS-macro in R (Hayes, 2018). Visualizations (except for the mediation model) were created using the R package *ggplot2* (version 3.4.2; Wickham, 2016).

## Results

### Podcast Listening Habits

Of the 61 study participants, 35 parents reported that their child had previously listened to podcasts. On average, these 35 parents indicated that their child listened to podcasts for 1.8 hours (range = 1 hour to 7 hours) each week. Additionally, parents rated their own familiarity with the water cycle prior to the study using a 5-point Likert scale (1=Poor, 5 = Excellent). On average, parents rated their understanding of the water cycle as good.

### Preliminary Analyses

One participant was excluded from further analyses because the parent and child did not talk to each other during the podcast listening session. First, we examined if age correlated with children's test performance. We conducted a regression with test scores as the dependent variable, age as an independent variable, and pretest scores as a covariate. Controlling for pretest performance, we found a marginal effect of age on children's test scores, $\beta = 0.09$ CI [-0.008, 0.18], $SE = 0.05$, $p = .07$.

Additionally, we examined if families' prior experiences with podcasts affected children's test scores and the quantity of parent-child conversation. Families' prior experiences with podcasts were collected from the demographics survey. Parents responded to the question, "Has your child listened to podcasts before?" by selecting either yes, frequently ($n = 19$), yes, once or twice ($n = 16$), and no ($n = 25$). To examine the effect of prior podcast experiences on children's test performance, we conducted an ANCOVA with children's test scores as the dependent variable, children's experience with podcasts as the independent variable, and pretest scores as the co-variate. We found a marginal effect of children's experiences with podcasts on their performance at test, controlling for pretest scores, $F(2, 55) = 2.84$, $p = .07$.

Finally, to examine if families' prior experiences with podcasts affected parent-child conversation, we conducted an ANOVA with prior podcast experiences as the independent variable and parent-child conversational turns per minute as the dependent variable. We found no effect of prior podcast experiences on parent-child conversational turns per minute, $F(2, 56) = 1.60$, $p = .21$. In other words, families' prior experiences with podcasts did not significantly affect the amount of parent-child conversation.

**Description of Parent-Child Conversation**

In this study, we aimed to characterize parent-child conversation during the podcast-listening session. We examined variables related to the quantities and durations of parent-child conversation. Then, we examined the *content* of parent-child conversation for specific variables of interest like prior knowledge connections and open-ended questions.

***Interaction***

Table 1 summarizes interaction variables such as duration of talk, number of utterances, and number of pauses by conversation card condition. We approximated the duration of conversation by summing the duration of parent and child utterances from the transcripts. While listening to the podcast, parents and children talked for an average of two and a half minutes. For many families ($n = 30$), this talk occurred while the podcast played in the background and when parents paused the podcast. During the five-minute interval after the podcast ended, parents and children talked about the podcast for between two and a half to three minutes.

Across conditions, we found that parents were generally talking more ($M = 67.15$, $SD = 36.60$) compared to children ($M = 48.38$, $SD = 28.74$), as evidenced by the number of utterances.

In addition, parents initiated more conversation as defined by the number of initiated conversational exchanges or continuous bouts of conversation ($M$ = 8.10, $SD$ = 5.50) compared to children ($M$ = 3.33, $SD$ = 2.64) across the three conditions.

To examine the conversation patterns of parent-child dyads, we grouped dyads into categories based on when they chose to talk during the podcast-listening session. As shown in Figure 5, most parents and children ($n$ = 30) talked to each other while the podcast was playing in the background, when they paused the podcast, and during the 5-minute interval after the podcast had ended. Fourteen dyads did not pause the podcast but rather talked over the podcast and talked after the podcast had ended. An additional six dyads only talked when they paused the podcast and after the it ended, and five dyads only talked after the podcast ended. For the 37 dyads that intentionally paused the podcast, we found that parents paused about five times, on average.

**Table 1**

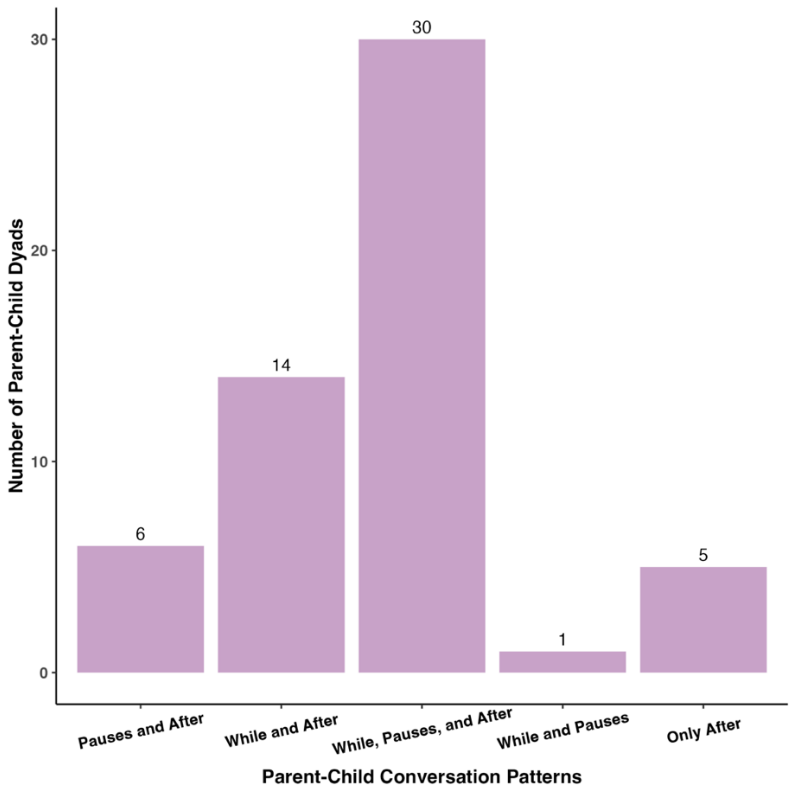
*Means and Standard Deviations of Parent-Child Conversation Variables*

| | Total ($N$ = 60) | Control ($n$ = 21) | Prior Knowledge Questions ($n$ = 21) | Water Cycle Questions ($n$ = 18) |
|---|---|---|---|---|
| Conversational Turns per Minute | 7.67 (2.45) | 7.69 (2.14) | 7.79 (2.34) | 7.48 (3.00) |
| Conversational Exchanges | | | | |
| *Parent-Initiated* | 8.10 (5.50) | 9.10 (5.90) | 6.62 (4.75) | 8.67 (5.78) |
| *Child-Initiated* | 3.33 (2.64) | 3.24 (2.36) | 3.14 (2.56) | 3.67 (3.12) |
| Utterances | | | | |
| *Parent* | 67.15 (36.60) | 66.71 (38.85) | 66.95 (35.53) | 67.83 (37.28) |
| *Child* | 48.38 (28.74) | 48.90 (28.90) | 45.76 (29.93) | 50.83 (28.54) |
| Number of Pauses | 4.55 (4.91) | 3.90 (5.44) | 3.35 (3.17) | 6.88 (5.48) |
| Duration of Talk (minutes) | | | | |
| *During* | 2.49 (2.63) | 2.78 (3.29) | 2.02 (2.19) | 2.72 (2.25) |
| *After* | 2.84 (1.55) | 2.56 (1.74) | 3.00 (1.40) | 2.96 (1.50) |

*Note.* Standard deviations are presented in parentheses. Due to poor recording quality, we were unable to determine if four families paused the podcast during their discussions. These four families are excluded from the number of pauses row.

**Figure 5**

*Conversation Patterns of Parent-Child Dyads*




*Note.* The counts above the bars denote the number of parent-child dyads that fall into the conversation pattern. Pauses, while, and after are defined as follows: pauses are when conversation occurred when parents paused the podcast, while is when parents and children talked while the podcast played in the background, and after is when conversation occurred during the 5-minute block of time that was allocated for each family after the podcast had ended. Due to poor recording quality, we could not decipher if four families paused the podcast to talk, talked while it played in the background, or both. These four families are included in the While and After category.

***Engagement***

Using an adapted version of Mulwa and Kucker's (2022) Standard Taxonomy of Dyadic Conversation, we annotated the content of parent-child conversation. We first excluded any irrelevant utterances, utterances that do not pertain to the podcast content ($N = 113$), and utterances that were exclusively coded as unknown due to the transcribers' inability to decipher what was said in the recording ($N = 648$).

We first examined the number of questions parents posed during their conversation by condition. On average, parents asked about 27 questions during the podcast listening session. An average of three questions were prompted by the podcast, meaning that the parents asked a question in which they referred to something introduced by one of the podcast hosts (e.g., "Have you thought about that?"). Most of parents' questions were annotated as "other" questions ($M = 22.55$, $SD = 12.99$). "Other" questions are questions that are not a direct follow-up to a concept introduced in the podcast or read from the conversation card. Often, these questions were asked by parents to encourage their child to continue the conversation or initiate conversation after the podcast had ended (e.g., "What's one thing that you learned?").

While annotating the transcripts, we also noted some additional behaviors that some families exhibited during the study session. One of the behaviors, *responding to the podcast*, was added to our adapted coding scheme. This behavior involved parents or children responding to something that the podcast host said, but these responses did not prompt additional conversation between the parent and child (e.g., "I knew that."). We found that, on average, parents responded to the podcast two times and children about one time.

Some additional behaviors we noticed while annotating the transcripts that were not captured by our coding scheme were parents' strategic use of pauses and how they chose to review content with their children during the study session. We found that some parents would pause the podcast after the podcast host posed a question to the other podcast host to give their child an opportunity to answer before the podcast hosts revealed and discussed the answer. One parent even took the time to prep their child before starting the podcast by introducing the processes and their definitions. During the 5-minute interval after the podcast had ended and before children were tested, many parents ($n$ = 18) used the online sketchpad we provided to draw the processes of the water cycle with their child and further review the concepts. One of the 18 parents even drew out the at-home water cycle experiment mentioned by the hosts at the end of the podcast and discussed with their child how the experiment is a small-scale representation of evaporation, precipitation, and condensation in Earth's atmosphere.

Additionally, parents and children often remarked how difficult the words *evaporation, precipitation, condensation*, and *transpiration* were to pronounce. Many parents corrected their child's pronunciation of the word or facilitated sounding out the word for their child. Finally, we noticed that a few parents in the prior knowledge questions condition and the water cycle questions condition read the questions directly from the card to their child. Table 2 shows the average number of questions from the conversation card asked by parents in the prior knowledge questions and water cycle questions conditions and is described in more detail below.

**Table 2**

*Means and Standard Deviations of Parent-Child Content Variables*

| | Total ($N$ = 60) | Control ($n$ = 21) | Prior Knowledge Questions ($n$ = 21) | Water Cycle Questions ($n$ = 18) |
|---|---|---|---|---|
| Parent-Posed Questions | 27.62 (15.25) | 25.00 (13.98) | 30.90 (16.35) | 26.95 (15.50) |

| | | | | |
|---|---|---|---|---|
| *Podcast-Prompted* | 3.55 (3.63) | 3.33 (3.04) | 3.00 (3.02) | 4.44 (4.79) |
| *Conversation Card* | NA | NA | 2.52 (2.42) | 2.67 (2.40) |
| *Other* | 22.55 (12.99) | 21.85 (12.02) | 25.45 (14.65) | 20.35 (12.27) |
| Prior Knowledge Connections | | | | |
| *Parent* | 1.82 (3.20) | 1.38 (2.96) | 2.09 (2.70) | 2.00 (4.04) |
| *Child* | 0.83 (1.29) | 0.43 (0.87) | 1.19 (1.54) | 0.89 (1.32) |
| Responding to Podcast | | | | |
| *Parent* | 2.33 (3.66) | 2.86 (3.84) | 2.67 (4.35) | 1.33 (2.33) |
| *Child* | 0.88 (1.85) | 0.86 (1.28) | 0.90 (2.49) | 0.89 (1.64) |
| Number of Times Parents Stated Water Cycle Processes in Conversation | 5.50 (5.92) | 4.33 (6.22) | 5.57 (5.30) | 6.78 (6.29) |

*Note.* Standard deviations are presented in parentheses. For the prior knowledge connections condition, the mean of parents' prior knowledge connections does not reflect the prior knowledge questions many parents read directly from the conversation card. The means of prior knowledge connections only reflect the prior knowledge connections *statements* made during conversation.

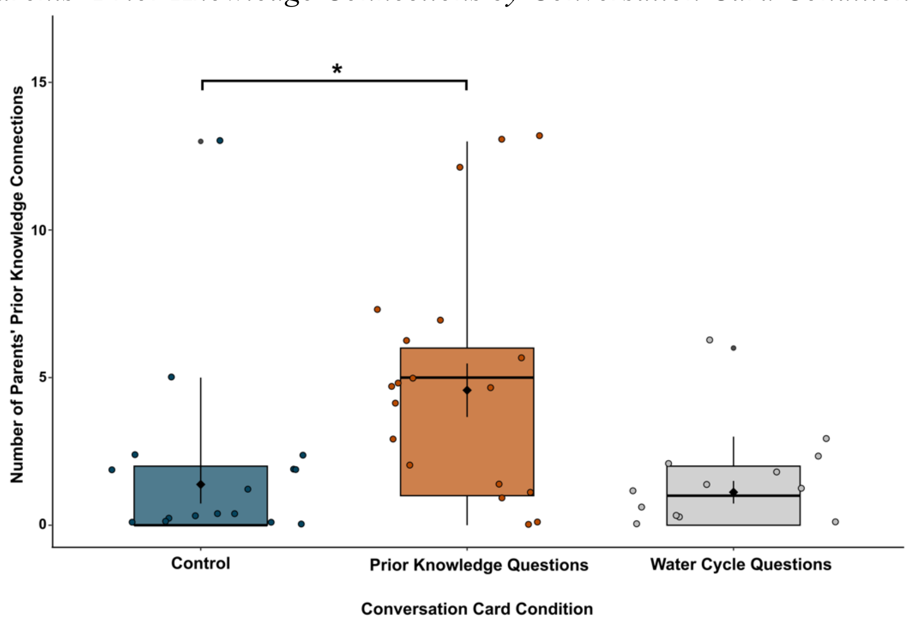
**Effect of Conversation Cards on Parents' Prior Knowledge Connections**

While annotating parent-child conversations, we noted when parents asked questions directly from the conversation cards. In the prior knowledge condition, 57% (12 out of 21) of parents asked the conversation card questions. In the water cycle condition, 87% (14 out of 18) of parents asked questions from the conversation card they were provided.

We examined parent-child conversation for prior knowledge connections, or parent utterances that referred to or elaborated on a child's experience with the topic (e.g., "Because the water vapors on your window in your room from the humidifier made it all foggy, and then, after a while, it was really wet."). To examine if parents used different amounts of prior knowledge connections based on their conversation card condition, we conducted a one-way ANOVA. The dependent variable consisted of parents' prior knowledge connections *and* conversation card prior knowledge questions parents may have asked in the prior knowledge condition. Results showed a significant difference between the number of prior knowledge connections made by parents in the control ($M$ = 1.38, $SD$ = 2.96), prior knowledge questions ($M$ = 4.57, $SD$ = 4.15), and water cycle questions ($M$ = 2.00, $SD$ = 4.04) conditions, $F(2, 57) = 4.25$, $p = .019$, $\eta^2 = 0.13$. Tukey HSD post-hoc comparisons showed that parents in the prior knowledge questions condition made significantly more prior knowledge connections than parents in the control condition ($q$ = 3.19 [0.41, 5 .97], $SE$ = 1.16, $p$ = .021; Figure 6). No significant differences were found between parents in the water cycle questions condition and the control condition ($q$ = 0.62, $p$ = .864) and the water cycle questions condition and the prior knowledge questions condition ($q$ = -2.57, $p$ = .091).

**Figure 6**

*Number of Parents' Prior Knowledge Connections by Conversation Card Condition*



*Note.* Each point represents an individual participant. The solid black diamond and vertical bars represent mean and standard error. The significance bars and asterisks denote significant post hoc comparisons.

**Children's Retention of Podcast Information**

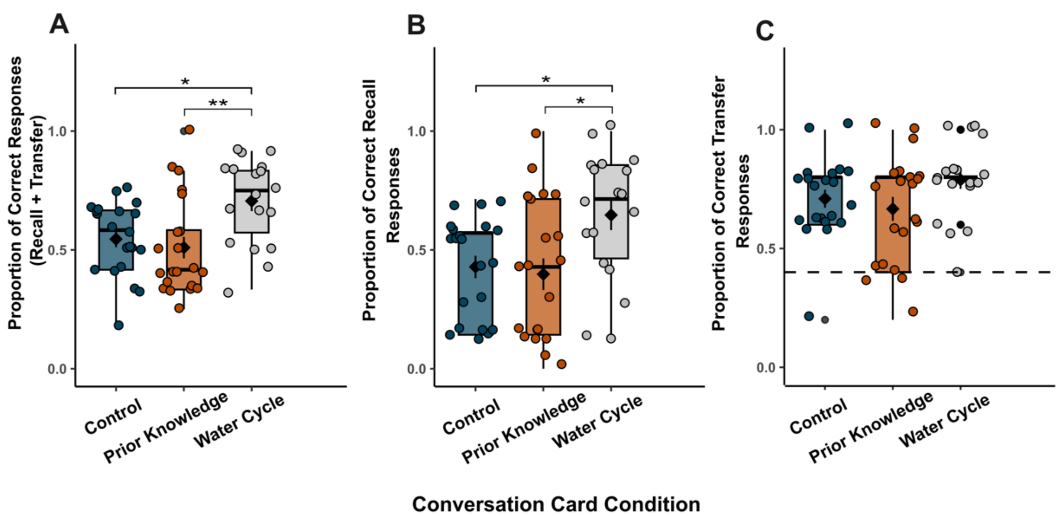
We next examined the effect of condition on children's recall and generalization test scores independent of parent-child conversation. We conducted an ANCOVA with children's test scores as the dependent variable and conversation card conditions as the independent variable. Controlling for children's pretest performance, we found a significant effect of condition on children's test scores, $F(2, 56) = 5.92$, $p = .005$, $\eta^2 = 0.15$, as Figure7A shows. Tukey HSD post-hoc comparisons revealed that children in the water cycle questions condition scored significantly higher on the post-test than children in the prior knowledge conversation card condition ($q = 0.17$ [0.04, 0.31], $SE = 0.06$, $p = .008$) and the control condition ($q = 0.16$ [0.03, 0.30], $SE = 0.06$, $p = .014$). There was no significant difference in post-test performance between the prior knowledge questions and control conditions ($q = -0.01$, $p = .973$).

To examine if there was an effect of condition on recall and transfer question performance, separately, we conducted two ANCOVAs, again controlling for pretest performance. As Figure 7B shows, we found a significant effect of condition on post-test performance for recall questions, $F(2, 56) = 4.62$, $p = .014$, $\eta^2 = 0.13$. Tukey HSD post-hoc comparisons showed that children in the water cycle questions condition scored significantly higher on recall questions than children in the prior knowledge questions conversation card condition ($q = 0.23$ [0.02, 0.43], $SE = 0.08$, $p = .026$) and the control condition ($q = 0.22$ [0.02, 0.42], $SE = 0.08$, $p = .028$). There was no significant difference on recall question performance between the prior knowledge questions and control conditions ($q = -0.01$, $p = .998$).

Additionally, we did not find a significant effect of condition on children's performance on transfer questions, $F(2, 56) = 1.60$, $p = .211$, as Figure 7C shows. Thus, there was no significant effect of parents' use of prior knowledge connections on children's transfer performance. However, because transfer questions provided children with answer choices, we could compare children's transfer performance to chance to assess evidence of transfer. Chance performance on transfer questions was 0.40. We conducted three one-sample t-tests comparing children's transfer performance in each of the conversation card conditions to chance. We found that children in the control condition ($M = 0.71$, $SD = 0.17$), prior knowledge questions condition ($M = 0.67$, $SD = 0.23$), and water cycle questions condition ($M = 0.79$, $SD = 0.16$) performed significantly above chance on transfer questions ($p < .05$).

**Figure 7**

*Children's Proportion of Correct Responses by Conversation Card Condition*

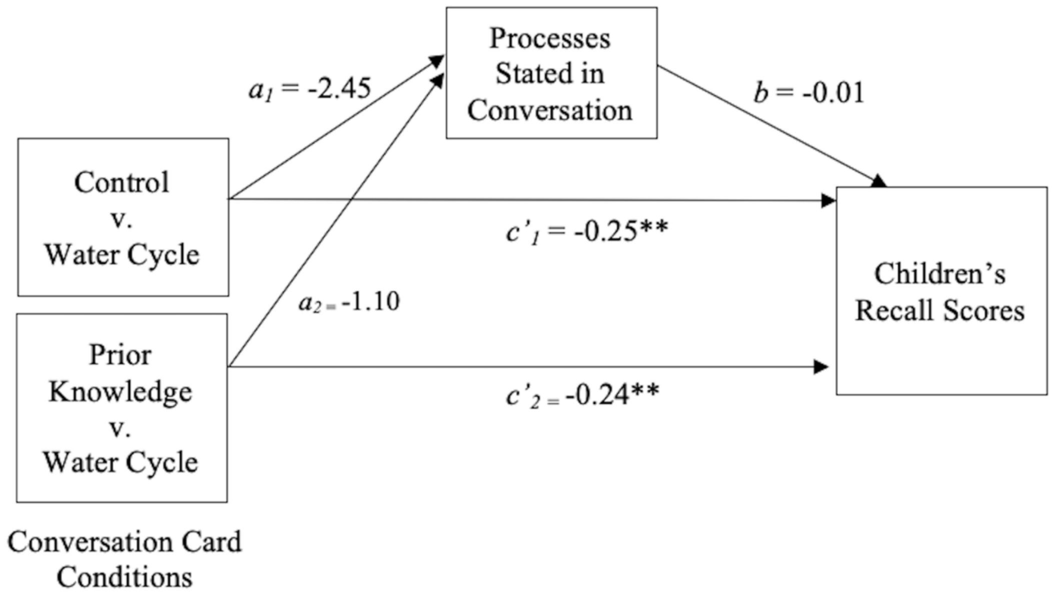



*Note.* Each point represents an individual participant. The solid black diamond and vertical bars represent mean and standard error. The significance bars and asterisks denote significant post hoc comparisons. The horizontal dotted line in Figure 6C denotes chance on transfer questions (0.40).

We were interested in further examining the effect of condition on children's recall test performance. We hypothesized that the number of times parents said the names of the water cycle processes (i.e., evaporation, condensation, precipitation, and transpiration) in conversation could affect children's recall test performance. Children had to generate the names of the processes to answer the recall test questions. Therefore, more exposure to the names of the processes could positively affect children's performance on recall test questions. We totaled the number of times parents said the words evaporation, condensation, precipitation, and transpiration during conversation, and averages by condition are reported in Table 2. We conducted one mediation analysis with the number of times the parents said the names of the water cycle processes as the mediator and pretest scores as a covariate in the mediation model. We dummy coded conversation card condition before entering it into the model (0 = control condition, 1 = prior knowledge questions condition, 2 = water cycle questions condition). Based on 95% bootstrapped confidence intervals, the number of times parents said the names of the water cycle processes in conversation did not mediate the effect of control versus water cycle question conversation cards on children's recall scores controlling for pretest scores, as indicated by the relative indirect effect ($a_1b$ path; $b = 0.03$ [-0.02, 0.09], $SE = 0.03$; Figure 8). Similarly, a nonsignificant relative indirect effect was observed when comparing prior knowledge questions to water cycle questions conversation cards on children's recall scores when controlling for pretest scores ($a_2b$ path; $b = -0.002$ [-0.04, 0.03], $SE = 0.02$).

**Figure 8**

*Mediation Analysis for Recall Test Performance*




*Note.* Unstandardized coefficients are reported. The conversation card condition did not have a significant effect on the number of times parents stated the water cycle processes in conversation when comparing the control condition to the water cycle questions condition ($a_1$ path; *b* = -2.45 [-6.30, 1.39], *SE* = 1.92, *p* = .207) and the prior knowledge questions condition to the water cycle questions condition ($a_2$ path; *b* = -2.45 [-6.30, 1.39], *SE* = 1.92, *p* = .207). The number of times parents stated the water cycle processes in conversation did not significantly affect children's recall scores (b path; *b* = -0.01 [-0.02, 0.001], *SE* = 0.01, *p* = 0.07). The relative indirect effect of control versus water cycle questions conditions on children's recall scores was not significant ($a_1b$ path; *b* = 0.03 [-0.02, 0.09], *SE* = 0.03). Similarly, the relative indirect effect of prior knowledge questions and water cycle questions condition on children's recall scores was not significant ($a_2b$ path; *b* = -0.002 [-0.04, 0.03], *SE* = 0.02). The relative direct effects of conversation card condition on children's recall scores remained significant after accounting for the number of times parents stated the water cycle processes in conversation ($c'_1$ path; *b* = -0.25 [-0.41, -0.08], *SE* = 0.08, *p* = .004 and $c'_2$ path; *b* = -0.24 [-0.40, -0.07], *SE* = 0.08, *p* = .006). $^{**}p < .01$.

# Discussion

## The Nature of Parent-Child Conversation

In analyzing the nature of parent-child conversation, we found that, generally, parents talked more and initiated more conversation than children. Additionally, many parent-child dyads talked over the podcast while it played, during intentional pauses in the podcast, and after the podcast had ended. Some parents deliberately paused the podcast after the host posed a question to another host to give their child the opportunity to answer the question themselves before the answer was stated in the podcast.

More parent-initiated conversations and strategic pausing behaviors could be affected by the fact that parents knew that their children would be tested after listening to the podcast. This knowledge could have prompted parents to engage in behaviors that they thought would help their child learn. Prior research has shown that parents will dominate a learning task, especially if they think the task is too difficult for their child (Gleason & Schauble, 1999). More than half of the children in the current study did not know any of the water cycle processes when asked to define them during the pretest. Parents could have watched their child struggle during the pretest and consequently worked to scaffold and engage their children while they listened to the podcast.

It has also been found that parents view more "structured" activities (e.g., flashcards) better for children's learning than "unstructured" activities (e.g., exploring a museum exhibit; Fisher et al., 2008). Parents could have been working to create structure within the podcast-listening experience to aid their children's understanding of the concepts.

Additionally, findings from parent-child interaction while engaging with media are mixed. Some studies have found an increase in parent-child engagement while interacting with digital toys and books (Lauricella et al., 2014; Sung, 2018) compared to non-digital media, while others have found decreased parental responsivity and parent-child engagement when engaged with digital media (Woolridge & Shapka., 2012). Sung (2018) speculated that the novelty of the media (i.e., a digital puppy doll) provided to parents and children in their study positively affected engagement. Podcasts are a relatively new medium for parents and children so the novelty of the format, along with the knowledge that children were tested after listening to the podcast, could have influenced parents' conversation behaviors.

One behavior that we observed is that parents used the online sketchpad provided to review concepts with their children during the 5-minute interval they were given before the experimenter tested their child. Using the sketchpad to review the water cycle is particularly interesting because a few parents remarked to experimenters after the session had ended that they believed their child did not do as well in the test because there was no visual component to the experiment. It is likely that parents' use of the sketchpad to draw the water cycle processes could be explained by their preconceived notions of "learning styles" and that visual learning is superior (Sun et al., 2023). In sum, the nature of parent-child conversation during the podcast-listening activity could have been influenced by the fact that children were tested at the end of the study session and parents' beliefs about learning and engagement with media.

**Parents' Use of Conversation Cards**

Parents in all three study conditions were provided with conversation cards. In the prior knowledge questions conversation card and the water cycle questions conversation card, we found that many parents in each condition read directly from the conversation card when asking their children questions. Prior studies that have used conversation cards in museum settings have not reported this type of behavior. Those studies used different designs in which parents were provided with a conversation card or prompt in a pre-exhibit activity, and parent-child conversation was assessed in a follow-up activity (Jant et al., 2014); parents were prompted with a specific learning goal before entering the exhibit (Pagano et al., 2020); or the card was provided during the parent-child interaction, but included general guidelines for how parents could interact with their child during the activity (Willard et al., 2019).

In contrast, parents in the current study had access to the conversation card throughout the podcast-listening activity, and many chose to use it more directly than others. A few parents even remarked to their children that they "had a few questions that they needed to ask them," indicating that the parents may have misinterpreted the purpose of the conversation card to prompt conversation rather than directly read from the card. In some previous studies, parents were provided a conversation card during the parent-child interaction task that included interaction prompts but did not report if parents read prompts directly from the cards (Polinksy et al., 2017).

We did find an effect of conversation card condition on parents' use of prior knowledge connections. Parents in the prior knowledge questions conversation card condition prompted more prior knowledge connections compared to other conditions when prior knowledge questions that parents read from the conversation cards and their own prior knowledge connections were examined together. Our finding is supported by the conversation card literature in museums that have found that conversation cards can affect parents' talk and behaviors (e.g., Gutwill & Allen, 2010; Jant et al., 2014; Pagano et al., 2020; Polinsky et al., 2017; Willard et al., 2020). However, it is important to keep in mind that the result in the current study is affected by the fact that parents in the prior knowledge questions condition read questions directly from the conversation card and does not solely reflect parents' generation of unique prior knowledge connections.

**Effect of Conversation Card Condition on Children's Retention**

In our study, we asked if the conversation card condition affected children's learning of podcast topics. We found no effect of conversation card condition on children's transfer scores. In other words, there is no evidence that differences in parents' use of prior knowledge did not affected children's ability to transfer concepts learned from the podcast. This result contradicts prior research in museums, which found that prior knowledge connections support children's learning (e.g., Anderson et al., 2002; Jant et al., 2014). Jant et al. (2014) found an effect of parents' use of prior knowledge connections in a museum exhibit on children's ability to transfer concepts between exhibits. However, this study took place in a natural history museum where parents and children interacted with exhibits that displayed different types of shelters (e.g., pueblo). The concepts were more concrete than learning about the abstract processes of the water cycle. Additionally, Jant et al. (2014) counted the times in which children and parents made an association from one exhibit to another as transfer (e.g., "These beds are like the beds we saw in the last exhibit."). In the current study, we defined transfer as applying one of the water cycle processes to a new, given scenario. These differing findings raise the question about the learning outcomes that prior knowledge connections support – do they support the ability to make concrete comparisons, or could they facilitate abstract relational reasoning?

Children scored above chance on transfer questions and their scores did not vary much across the conditions, leading us to consider the possibility that the transfer questions were easier for children. As a reminder, transfer questions were delivered in a multiple-choice format, which may have influenced the relative ease of these questions as children did not have to generate a water cycle process term to answer the questions. A study design in which transfer questions are formatted differently (e.g., open-ended) may yield different effects and should be examined in future studies.

However, we found an effect of condition on children's recall performance. Children in the water cycle questions condition scored higher on recall test questions compared to children in the control and prior knowledge questions condition. The water cycle questions condition encouraged parents to ask open-ended questions about water cycle processes. Prior research has found that when parents were primed to ask critical thinking questions while engaging in a museum exhibit, they in fact did so, and their children produced more of their own explanations and observations, potentially promoting their learning (Callanan et al., 2017). Another study found that parent-child conversation while interacting with gears at a museum exhibit supported children's retention and recall of the exhibit's concepts (Willard et al., 2019). Furthermore, parents have been found to scaffold children's scientific reasoning with explanations and evaluations of evidence (Crowley et al., 2001a). The water cycle questions could have had an effect on children's recall performance by facilitating highly relevant explanations and conversations about the water cycle compared to other conditions.

Because the questions on the water cycle conversation cards reiterated the processes (i.e., evaporation, condensation, precipitation, transpiration) from the podcast, it is possible that the repetition of the names of the processes could have positively supported children's recall performance. However, through a mediation analysis, we found that the number of times parents said the names of the processes did not mediate the effect of conversation card condition on children's recall scores. There could be other factors of the podcast-listening experience that could mediate the significant effect of conversation card condition on children's recall performance. For example, some parents sounded out and spelled the names of the processes for their children, which could make the names of the processes salient. Alternatively, children's own question-asking or naming of the processes could influence their recall performance. The effect of these variables on children's recall performance was not tested in the current study but could be examined in future research.

**Overall Implications**

The current study was the first to examine parent-child conversation while listening to a podcast when a podcast is viewed as a learning resource. Our study design combined conversation card methodology prominent in parent-child interaction studies in museum contexts and aimed to situate podcasts within the JME framework. Our results highlight interesting effects of parent-child conversation on children's learning in the podcast-listening context and raise important questions for future research.

We did find an effect of conversation cards on parents' use of prior knowledge connections corroborating prior research (e.g., Gutwill & Allen, 2010; Jant et al., 2014; Pagano et al., 2020; Polinsky et al., 2017; Willard et al., 2020). This is particularly encouraging because prior knowledge connections have been found to benefit children's STEM learning (Anderson et al., 2002; Morris et al., 2021); however, prior knowledge connections are quite rare in informal learning spaces (Callanan et al., 2017; Land-Zandstra et al., 2020). Interestingly, many parents in our study read directly from the conversation cards and often appeared to use them to review concepts with their children, a behavior not reported in prior research. This finding highlights the interaction of study designs and parents' beliefs about educational content. Parents could have used the conversation cards more deliberately because they knew their children would be tested after the podcast listening session or because they felt their children needed additional support to engage and learn due to the audio-only format of a podcast. Additional research is needed to explore parents' beliefs about learning from podcasted media and the supports children need to learn from an audio-only format.

Even though we found that conversation cards influenced parents' use of prior knowledge connections during the podcast listening session, we did not find an effect of parents' use of prior knowledge on children's transfer learning. This finding raises the question about the role of prior knowledge connections, as defined in the current study, in facilitating relational reasoning to learn higher-order concepts. While studies show that prior knowledge connections benefit children's learning and transfer in informal contexts (Anderson et al., 2002; Jant et al., 2014; Morris et al., 2021), how learning and transfer are operationalized in these studies differ. Future research could examine how to facilitate prior knowledge connections in parent-child conversation that make comparisons more explicit. Explicit and structured prior knowledge connections could aid children's aggregation and decontextualization of concepts to successfully transfer information from one context to the next.

We found an effect of conversation card condition on children's recall of water cycle concepts, but we were not able to conclude in this study the element of parent-child conversation that could have driven this effect. The question of whether parent-child conversation is redundant when paired with podcast media remains open. Therefore, additional research is needed to further examine the role of parent-child conversation on children's learning while listening to podcasts. This study encourages incorporating podcast media in the JME framework to further the understanding of parent-child interaction on children's learning from this media format.

**Limitations**

One limitation of the current research is the limited generalizability of the results to parent-child podcast listening experiences. Parents expected that their child would be tested, and it is likely that parents' behaviors were affected by the study's procedure. Therefore, we did not capture the typical nature of parent-child conversation while listening to a podcast, but rather the nature of parent-child conversation when parents use podcasts as a learning resource. Prior research has examined parent-child engagement and learning with podcasts through surveys (Kids Listen, 2016, 2021) and interviews (Grack Nelson et al., 2021). However, these studies rely on parent self-report which can also introduce bias. Future research could adapt the current study's design by omitting a pretest or not telling parents that their children will be tested after listening to the podcast. Parents' listening behaviors and parent-child conversation may change if there is no pressure of a test after the activity. Future studies could also interview parents about their approach to engaging in conversation while listening to podcasts and their beliefs about learning opportunities (Song et al., 2017) to shed light on some of the unique behaviors (i.e., pausing the podcast so their child could answer questions posed by the podcast host) we observed in the current study.

One of the unique engagement behaviors that we did not anticipate was parents using the sketchpad during the 5-minute interval after the podcast had ended to review water cycle concepts with their child. This behavior introduces visuals to the learning environment that could have influenced children's performance at test. We chose not to exclude these participants from data analysis because this type of interaction could reflect how parents and children generally interact with podcasts. For example, one child took what his parent called "visual notes" while listening to the podcast and they chose to review those notes together after the podcast had ended. However, this behavior is necessary to consider when interpretating the results of the current study because visual information could have affected some children's performance at test. Additional research is needed to holistically examine the effects of children's podcast listening environments on their retention and transfer of concepts presented in podcasts.

Another limitation of our study is the recording quality of our study sessions. We had to exclude a number of participants due to poor video recording quality as well as a number of utterances that we could not reliably transcribe from the videos. When reviewing the videos, we found that Zoom often prioritized the podcast audio playing from the parent's computer and did not capture audio from parent-child conversation. We chose to give parents the link to the podcast audio to play from their own devices so they could control the podcast-listening experience and pause the media when they felt it was necessary. One way to mitigate the competition of audio would be to ask parents to play the podcast audio on a separate device (e.g., a cell phone) while the study session records from their laptop. However, this introduces more logistical hurdles and places a burden on families to monitor and control multiple devices during the study session. Another solution would be to run the study in-person where the experimenter would have control over devices and recording setups.

In the current study, we used the Standard Taxonomy of Dyadic Conversation (Mulwa & Kucker, 2022) to code the content of parent-child conversation. This coding scheme was developed for researchers to annotate parent-child conversation in informal learning contexts like science museums. We adapted this coding scheme to include some categories not in the original taxonomy, such as responding to the podcast host and the source of parent questions (i.e., podcast audio, conversation card, etc.). While coding, the research team noticed some unique behaviors that were not captured by the coding scheme. These behaviors were described in the results section above. Future research could employ a qualitative coding approach to analyze parent-child conversation while listening to podcasts. This data-driven analysis approach could also lay the foundation for developing a coding scheme to characterize parent-child conversation and other listening behaviors while listening to podcasts.

Finally, we defined prior knowledge connections as statements or questions that connect the content of the podcast with children's personal prior experience. Some studies have found that these personal connections support children's learning (Anderson et al., 2002; Morris et al., 2021), but these personal connections have not been studied from the perspective of structural alignment, in which correspondence is explicitly drawn between the two examples, making the common structure more salient (Catrambone & Holyoak, 1989; Gentner et al., 2003). Prior work has shown that explicit comparison of examples is helpful for children to understand the structural similarities, especially when examples are perceptually dissimilar (Gentner & Toupin, 1986; Gentner & Namy, 1999; Gentner et al., 2016). For example, if a child is presented with an example of evaporation from the Earth's atmosphere and an example of evaporation from a pot of water boiling on the stove, it would be beneficial for parents to make an explicit connection between the functional similarities of the stove burner and the sun (i.e., both items heat the water turning the water into water vapor) to facilitate structural alignment and transfer. Future research could define prior knowledge connections that include structural alignment elements. Studies could examine the effect of these prior knowledge connections provided by parents or woven throughout the podcast program on children's ability to transfer concepts learned from the podcast.

**Conclusion**

In the current study, we examined the characteristics of parent-child conversations while listening to a podcast and the effect of conversation cards on prompting parents' use of prior knowledge connections and children's retention and generalization of information presented in the podcast. We found that conversation cards influenced parents' use of prior knowledge connections and children's recall of content presented in the podcast, but not children's generalization of content presented in the podcast. Our study has implications for integrating parent-child interactions while listening to podcasts within the JME framework and the role of prior knowledge connections in facilitating children's transfer abilities.

## General Discussion

The goal of this dissertation was to examine if STEM podcasts and parent-child listening contexts supported children's higher-order concept learning. In Study 1, we examined at the effect of modality on children's higher-order concept learning by comparing children's learning when listening to a science podcast and when listening to a science podcast and viewing related visuals. In Study 2, we examined the effect of conversation cards on parent-child conversation while listening to a podcast and, subsequently, children's learning of science concepts. Overall, the results suggest that children can learn from STEM podcasts with differing effects of listening contexts factors on children's learning performance.

Study 1 aimed to assess the effect of modality on children's higher-order concept learning. Participants were 69 7-and 8-year-olds. Participants were randomly assigned to a condition where they listened to an 11-minute podcast about the water cycle or listened to the podcast and viewed related water cycle visuals. Results revealed no significant differences between children's learning performance; however, children performed above chance on transfer questions in both conditions. Furthermore, a semantic textual analysis showed that children in the audiovisual condition did not appear to use visual information when explaining certain water cycle processes (i.e., evaporation and precipitation). These results suggest that children's science podcasts may independently support children's learning of higher-order concepts, and visual information may not add additional learning benefits. This study invites more research on the effect of modality on children's learning from podcasted media to expand the existing multimedia learning theories.

In Study 2, we examined the effect of conversation cards on prompting parent-child conversation and the effect of parent-child conversation on 7- and 8-year-olds' transfer abilities. Participants were 61 parent-child dyads. Dyads were randomly assigned into three conversation card conditions that provided parents with example questions they could ask their child during conversation (i.e., water cycle questions, prior knowledge questions) or general information about the positive effect of conversation on children's learning (i.e., control). We found that most parents chose to talk while the podcast was playing, when they paused the podcast, and after the podcast had ended. Conversation seemed primarily driven by parents, but we found evidence of reciprocal interaction and engagement between parents and children, generally. Additionally, parents engaged in conversation in unique ways. For example, many parents read questions directly from the conversation cards, and some parents strategically paused the podcast to discuss concepts with their children.

For the effect of conversation cards on parent talk, results revealed a significant effect of conversation cards on parents' use of prior knowledge connections with parents who received the prior knowledge connections conversation card used more prior knowledge in their conversation. However, we found no significant effect of conversation cards on children's performance on transfer test questions. Instead, we found that children whose parents received the water cycle questions conversation card scored significantly higher on recall test questions compared to children in the control and prior knowledge connection questions conditions. Due to the similarity of the water cycle questions conversation card with the podcast content, we hypothesized that the repetition of the water cycle processes could affect children's recall performance. However, we found that the number of times parents stated the water cycle processes in conversation did not mediate the effect between the conversation card condition and children's recall performance. Study 2 highlights the unique conversational behaviors parents chose to engage in with their children while listening to a podcast and the potential effects on children's learning and engagement with the podcast material. It also invites more research on parent-child engagement with podcasts to potentially expand upon the current JME framework.

These studies are a first look at whether children learn from podcast media and the factors that can affect children's learning. One question that was raised in this dissertation was if children's podcasts, on their own, could support children's retention and transfer of complex science concepts. Children's podcasts include learning supports such as explanations, connections, or analogies, and questions and prompts directed to the child listener. It is possible that children do not need additional supports to scaffold their learning from this audio-only format. Results from Study 1 suggest that children were not using visual information to learn about the water cycle. Results from Study 2 found an effect of conversation card condition on children's recall performance, but the question remains if a factor or multiple factors (i.e., number of questions asked by the child, amount of joint talk between parent and child) of parent-child conversation mediates this effect. It is crucial for future research to continue examining the content of children's podcasts and children's podcast-listening environments to understand the effects of podcasts and children's environments on their learning outcomes.

These studies are important for the field because they challenge existing theories on multimedia learning and media engagement to integrate podcasts and audio-only learning into their frameworks. The cognitive theory of multimedia learning poses that information is better learned when presented in more than one modality (Mayer, 1997). However, much of the research conducted from the multimedia learning framework has focused on instructional videos that include PowerPoint slides and narration and with a college student population (e.g., Mayer et al., 1996; Mayer & Johnson, 2008). Narration of PowerPoint slides differs greatly from children's podcasts that include conversational structure and vivid imagery to evoke engagement auditorily. Additionally, the Integrated Model of Test and Picture Comprehension (ITPC) proposes that learners develop a mental model based on the visual information they receive (Schnotz, 2005). The ITPC model does not consider how podcast audio, with its vivid description and sound effects, could help learners build a mental model to process information. Future research should examine the effect of podcast audio on individuals' learning to potentially inform and revise these existing frameworks to include learning from audio podcasts.

Furthermore, the Joint Media Engagement Framework states that shared attention to media and interactions that scaffold children's learning experiences help support learning (Takeuchi & Stevens, 2011). However, podcasts have not been studied using the JME framework. Even though the current studies did not provide conclusive evidence on the effect of parent-child interaction on children's learning while listening to podcasts, it is still an area for future research to investigate if the parent-child interaction provides an additive benefit to learning from podcasts. Additional research is needed in order to situate podcasts in the JME framework.

These findings also have implications for families and the children's podcast community. First, podcasts are a convenient and affordable way to access information. Examining the extent to which podcasts do and do not support learning is important in understanding the diversity of real-world learning experiences and opportunities for the development of cost-effective curricula for families (Grack Nelson et al., 2021). Additionally, this work can inform children's podcast creators about the learning supports they can continue to implement in their podcasts and how they can incorporate opportunities to engage children and their families with their podcasts. For example, a few podcasts encourage additional learning activities children can do at home with their families to further explore the topic of the podcast. Podcast creators could also prompt children to discuss the podcast topic with a family member. Many families reported that their children initiate discussion about a podcast after listening (Kids Listen, 2016), so facilitating these discussions is one way that podcast creators can support parent-child interaction in the podcast listening experience.

**Conclusion**

In summary, these two studies aimed to answer if STEM podcasts and parent-child listening contexts supported children's higher-order concept learning. Overall, these results show that children learn higher-order concepts from podcasts and highlight unique parent-child interactions while listening to podcasts together. These results are informative for existing theories on learning from media and media engagement and have implications for families and podcast creators dedicated to supporting children's engagement with and learning from podcasts.

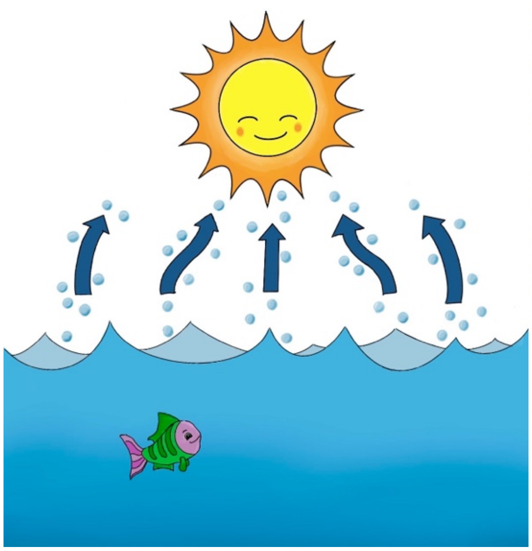
## Appendix A: Definitions of Transfer Types

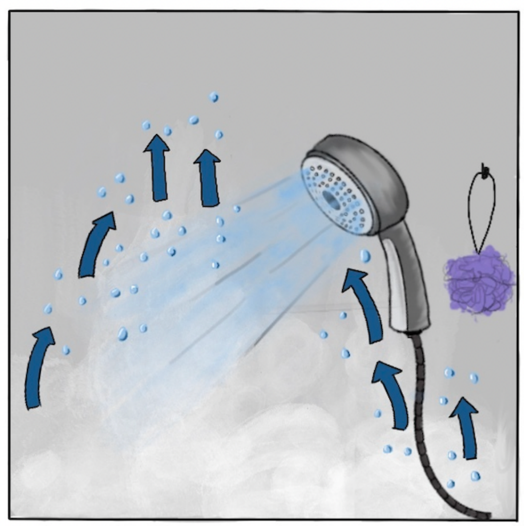
| Type of Transfer | Definition | Example |
|---|---|---|
| *Positive v. Negative* | | |
| Positive | Learning is benefited in the new context | Learning about evaporation in a cooking context (e.g., boiling water) and applying it to the environmental context (e.g., sun heating up the ocean) |
| Negative | Learning is hindered in new context | Learning about evaporation in a cooking context (e.g., boiling water) makes it more difficult to generalize to other evaporation examples |
| *Near v. Far* | | |
| Near | Many similarities between the two learning contexts | Learning about evaporation from different bodies of water (i.e., lake versus ocean) |
| Far | Few similarities between the learning contexts | Learning about evaporation in terms of steam produced by a hot shower and evaporation from a large body of water |
| *Specific v. General* | | |
| Specific | Specific concept transferred to new context | Transferring the concept of evaporation between the cooking context and the environmental context |
| General | General skills transferred to new context | Transferring the understanding of the cyclical nature of the water cycle to other cyclical processes (i.e., nitrogen cycle) |
| *Surface v. Structural* | | |
| Surface | Transfer of the perceptual similarities of the context | Identifying the perceptual similarities between rain and snow when transferring the concept of precipitation to new contexts |
| Structural | Transfer of the underlying functional similarities of the concept | Identifying the similarity between the stove and the sun as heat sources when transferring the concept of evaporation from a cooking context to an environmental context |

## Appendix B: Water Cycle Images (Study 1)

*Condensation Visuals*

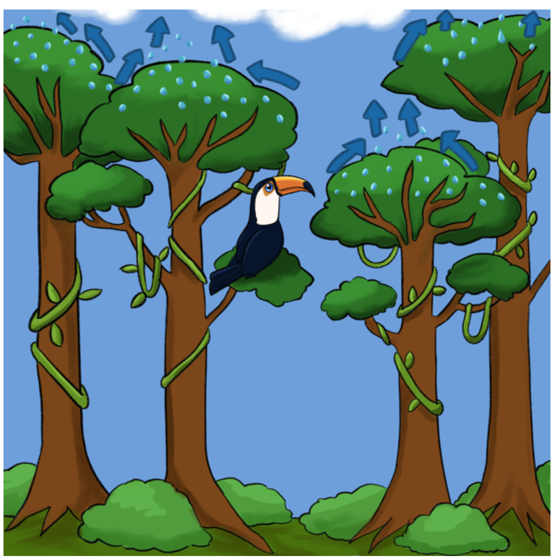
*Evaporation Visuals*

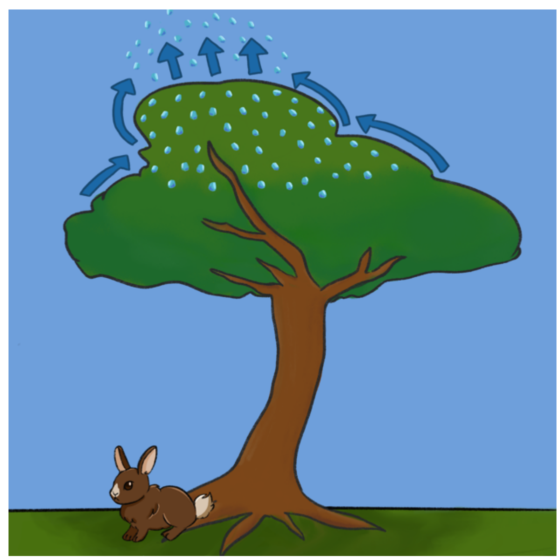




*Precipitation Visuals*

*Transpiration Visuals*





## Appendix C: Engagement Questionnaire (Study 1)

While listening to the podcast: I felt bored.

While listening to the podcast: I felt happy.

While listening to the podcast: I felt excited.

While listening to the podcast: I was daydreaming a lot.

While listening to the podcast: I was focused on the things we were learning most of the time.

While listening to the podcast: Time went by quickly.

While listening to the podcast: I was busy doing other tasks.

While listening to the podcast: I talked to others about stuff not related to what we were learning.

Adapted from Chung, J., Cannady, M. A., Schunn, C., Dorph, R., & Bathgate, M. (2016). Measures Technical Brief: Engagement in Science Learning Activities.

## Appendix D: Test Questions (Study 1 and Study 2)

**Pretest Questions** (Study 2 only)

In your own words, can you tell me what evaporation means?

In your own words, can you tell me what precipitation means?

In your own words, can you tell me what condensation means?

In your own words, can you tell me what transpiration means?

**Post-Test Questions** (Study 1 and Study 2)

*Recall Questions*

What are the three different physical forms of water?

What is it called when water vapor gets cold, turns into a liquid, and then turns into a cloud?

What is it called when clouds get heavy and can't hold anymore liquid water and the liquid water falls to the ground?

What is it called when the sun heats up water, turning the water into water vapor and the water vapor rises into the air?

What is it called when trees release water vapor?

*Transfer Questions*

Of the three bodies of water, ocean, lake, pond, which one would release the most amount of water vapor through evaporation?

When do you think we would most likely see precipitation like rain or snow? On a cloudy day where there are lots of clouds in the sky or a sunny day when there are no clouds in the sky?

When it is hot outside and we are drinking a cold drink from a glass, sometimes water droplets form on the outside of the glass. Is this an example of evaporation, condensation, or precipitation?

When we are cooking pasta, we boil the water first in a pot. When the water is boiled, it creates steam or water vapor. Is this an example of evaporation, condensation, or precipitation?

What would happen to the amount of water vapor in the atmosphere if we cut down a lot of trees?

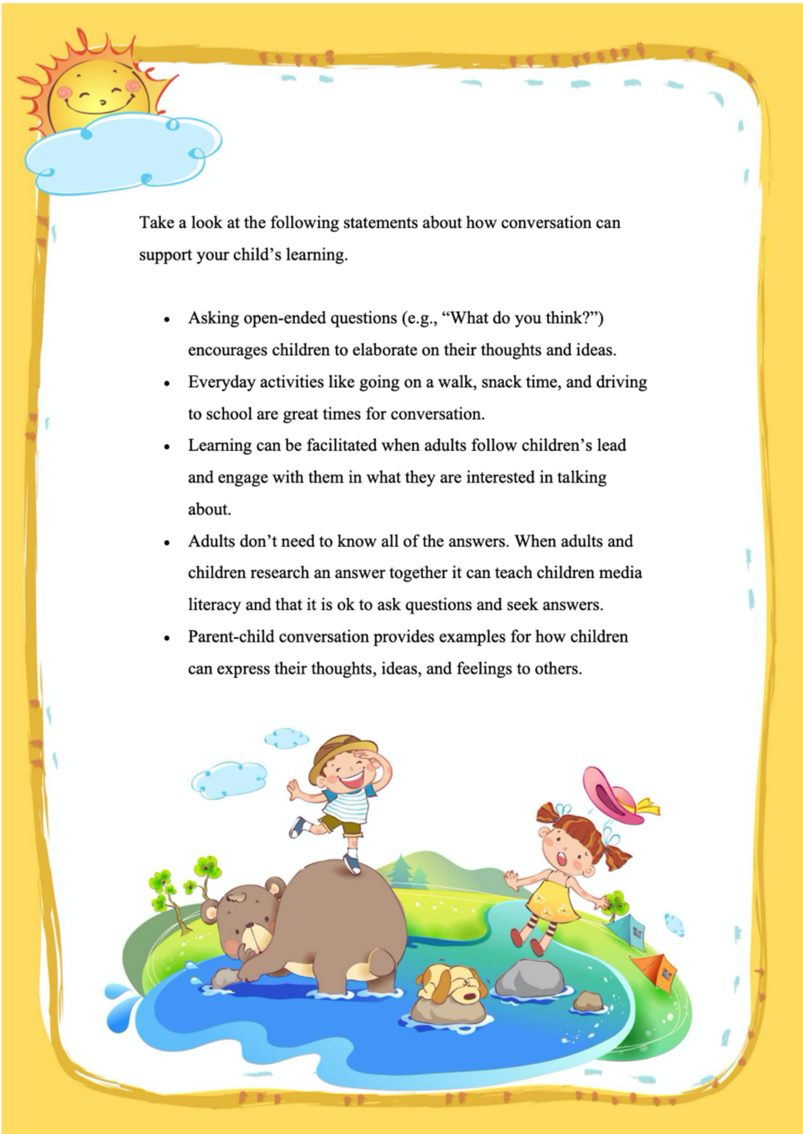
## Appendix E: Test Item Analysis (Study 1)

| | Audio-Only Condition (*n* = 35) | | | Audiovisual Condition (*n* = 34) | | |
|---|---|---|---|---|---|---|
| ***Recall*** | **Full** | **Partial** | **Zero** | **Full** | **Partial** | **Zero** |
| Q1: Water Forms | 14 | 6 | 15 | 17 | 2 | 15 |
| Q2: Condensation | 4 | 0 | 31 | 8 | 0 | 26 |
| Q3: Precipitation | 23 | 0 | 12 | 24 | 0 | 10 |
| Q4: Evaporation | 19 | 2 | 14 | 17 | 2 | 15 |
| Q5: Transpiration | 7 | 0 | 28 | 7 | 0 | 27 |
| ***Transfer*** | | | | | | |
| Q1: Evaporation | 28 | 0 | 7 | 28 | 0 | 6 |
| Q2: Precipitation | 34 | 0 | 1 | 30 | 0 | 4 |
| Q3: Condensation | 13 | 0 | 22 | 13 | 0 | 21 |
| Q4: Evaporation | 26 | 0 | 9 | 23 | 0 | 11 |
| Q5: Transpiration | 12 | 2 | 21 | 15 | 3 | 16 |

*Note.* The values in the columns denote the number of children who received full, partial, and zero credit on each test question.

# Appendix F: Conversation Cards (Study 2)

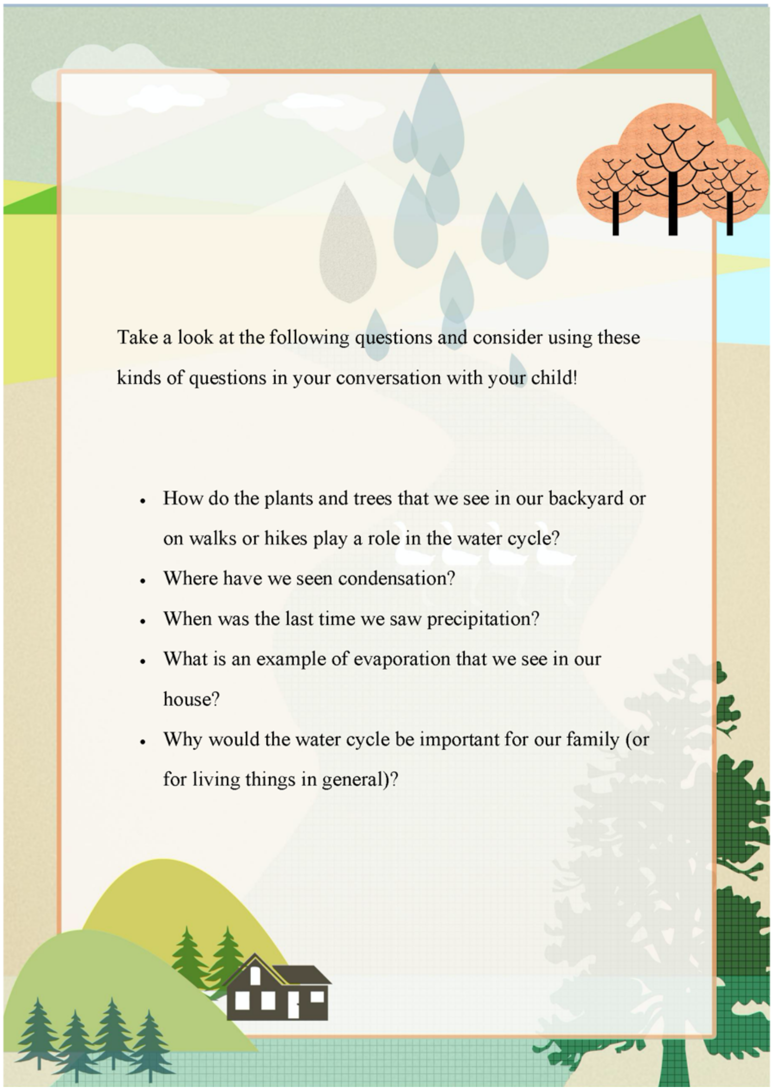
*Control Condition Conversation Card*



Take a look at the following statements about how conversation can support your child's learning.

- Asking open-ended questions (e.g., "What do you think?") encourages children to elaborate on their thoughts and ideas.
- Everyday activities like going on a walk, snack time, and driving to school are great times for conversation.
- Learning can be facilitated when adults follow children's lead and engage with them in what they are interested in talking about.
- Adults don't need to know all of the answers. When adults and children research an answer together it can teach children media literacy and that it is ok to ask questions and seek answers.
- Parent-child conversation provides examples for how children can express their thoughts, ideas, and feelings to others.

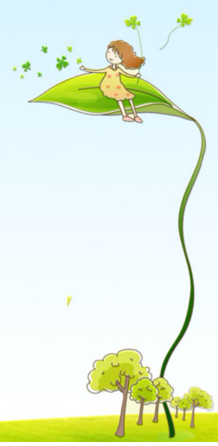
*Prior Knowledge Conversation Card*



*Water Cycle Conversation Card*

Take a look at the following questions and consider using these kinds of questions in your conversation with your child!

- How do trees play a role in the water cycle?
- How is condensation different from evaporation?
- What are the different forms of precipitation?
- Which process transforms water vapor into liquid water?
- Why is the water cycle called a "cycle"?



## Appendix G: Parent-Child Conversation Coding Schemes (Study 2)

**Table G1**

*Parent-Child Conversation Coding Scheme*

| Speech Categories | Coding Symbol | Criteria |
|---|---|---|
| "Wh-" Questions | Qw | An open-ended question that typically begins (or is implied to begin) with "Who", "What", "Where", "When", "Why", or "How"<br>- Include multiple choice and fill-in-the-blank type questions, e.g., ("Do you think it is a dinosaur or a chicken?", "What's that called? Con…")<br>- "Do you have any guesses?" (this example is phrased as a yes/no question, but its intent is to get the child to elaborate so it would be coded as a wh- question). |
| Yes/No Questions | Qy | a closed-ended question in which the answer is likely "Yes" or "No |
| Declarative Statements | S | gives an account of the objects or people in the situation or activity<br>- Count responses to questions as statements unless they are only acknowledged with a mhmm (mhmm = acknowledgment)<br>- Code S (talk code 1 column) + PR (talk code 2 column) when parents or children follow up/provide an explanation about something said in the podcast or comment on the podcast and it is followed by conversation. These statements will usually start with "So she [referring to podcast host] just said…" or "It is saying…" However, S + PR utterances may not be this explicit. Refer back to the podcast script/recording when making these judgments.<br>    - These will most likely happen in conversational turns compared to PR utterances (see definition below). |

| | | |
|---|---|---|
| | | - Sometimes you may see a child response that ends in a question mark (e.g., Ice?). This would count as a statement and not a question as the intent is expressing uncertainty. |
| Commands (Directive Statements) | C | order, demand, or directive of something a subject should do or not do. Intended to initiate or stop a child's behavior<br>- Examples: "Let's see what they say," or "Let's listen" are commands because they are directing the child's attention to the podcast. |
| Irrelevant | I | does not pertain to relevant ongoing activity, objects, or individuals<br>- Mark if the conversation is not related to the podcast (e.g., content, hosts, etc.) |
| Acknowledgment | A | brief verbal response to another's verbalization or behavior that contains no descriptive content (e.g., uh-huh, mhmm, oh, tee-hee/haha) |
| Evaluative (Encouragement) | Ee | statement or phrase expressing approval, appreciation, positive acknowledgment, or praise of effort, attributes, or product.<br>- Do not count "yeah" from a parent following up on a child's response. But "right" or "good job" counts. |
| Evaluative (Criticism) | Ec | statement of phrase expressing disapproval or criticism<br>- Examples: "No, that is not condensation." Nor, that is evaporation." |
| Other/Unknown | U | when a talk item is produced by a target subject, but is not easily classified in one of the above ways or is unintelligible<br>- If any part of the utterance has xx or the entire utterance is xxx, mark with U. |
| Responding to/Repeating Podcast | PR | If the parent or child responds to something said in the podcast then mark this here. These will occur outside of conversational turns. Examples are, "I knew that!" or "That is interesting." |

| | | |
|---|---|---|
| Distancing | D | When the parent or child makes a personal prior knowledge connection. Prior knowledge connections are coded only when we can determine a clear *personal experience* connection. For example, "I read this in my dinosaur book," "Remember when we went to the beach and we saw the rainstorm?" etc. |

Adapted from the Standard Taxonomy of Dyadic Conversation (Mulwa & Kucker, 2022)

**Table G2**

*Source of Parent Questions Coding Scheme*

| **Code** | **Definition** |
|---|---|
| P | The parent asks a question that is clearly a follow up to what was just stated in the podcast. Often parents will say something like, "Did you hear what they just said," or "Have you thought about that?" |
| CW (Water Cycle Condition only) | The parent asks a question *directly from the conversation card* (reading the question off of the card) that they were provided before the study. |
| CP (Prior Knowledge Condition only) | The parent asks a question *directly from the conversation card* (reading the question off of the card) that they were provided before the study. |

## References


Adesope, O. O., & Nesbit, J. C. (2012). Verbal redundancy in multimedia learning environments: A meta-analysis. *Journal of Educational Psychology*, *104*(1), 250–263. https://doi.org/10.1037/a0026147

Aladé, F., Lauricella, A. R., Beaudoin-Ryan, L., & Wartella, E. (2016). Measuring with Murray: Touchscreen technology and preschoolers' STEM learning. *Computers in human behavior*, *62*, 433-441. https://doi.org/10.1016/j.chb.2016.03.080

Alba, J. W., & Hasher, L. (1983). Is memory schematic? *Psychological Bulletin, 93*(2), 203-231.

Alper, R. M., Beiting, M., Luo, R., Jaen, J., Peel, M., Levi, O., Robinson, C., & Hirsh-Pasek, K. (2021). Change the things you can: Modifiable parent characteristics predict high- quality early language interaction within socioeconomic status. *Journal of Speech, Language, and Hearing Research*, *64*(6), 1992–2004. https://doi.org/10.1044/2021_JSLHR-20-00412

Anderson, J. R., & Bower, G. H. (1973). *Human associative memory.* Wiley.

Anderson, D., Piscitelli, B., Weier, K., Everett, M., & Tayler, C. (2002). Children's museum experiences: Identifying powerful mediators of learning. *Curator: The Museum Journal, 45*(3), 213–231. https://doi.org/10.1111/j.2151-6952.2002.tb00057.x

Ari, O., & Calandra, B. (2022). Dual modality effects on college students' comprehension of short texts during a simulated self-study session. *College Teaching*, *70*(4), 433–442. https://doi.org/10.1080/87567555.2021.1971604

Assaraf, O. B. Z., & Orion, N. (2005). Development of system thinking skills in the context of earth system education. *Journal of Research in Science Teaching*, *42*(5), 518–560. https://doi.org/10.1002/tea.20061

Bahrick, L. E., Flom, R., & Lickliter, R. (2002). Intersensory redundancy facilitates discrimination of tempo in 3-month-old infants. *Developmental Psychobiology*, *41*(4), 352–363. https://doi.org/10.1002/dev.10049

Bar, V. (1989). Children's views about the water cycle. *Science Education, 73*(4), 481-500.

Barnett, S. M., & Ceci, S. J. (2002). When and where do we apply what we learn? A taxonomy for far transfer. *Psychological Bulletin*, *128*(4), 612–637. https://doi.org/10.1037/0033-2909.128.4.612

Benjamin, N., Haden, C. A., & Wilkerson, E. (2010). Enhancing building, conversation, and learning through caregiver–child interactions in a children's museum. *Developmental Psychology*, *46*(2), 502–515. https://doi.org/10.1037/a0017822

Bers, M. U. (2007). Positive technological development: Working with computers, children, and the internet. *The Periodical of the Massachusetts Psychological Association, 51*, 5–19.

Bers, M. U. (2010). Beyond computer literacy: Supporting youth's positive development through technology. *New Directions for Youth Development*, *2010*(128), 13–23. https://doi.org/10.1002/yd.371

Bjork, R. A. (1994). Memory and metamemory considerations in the training of human beings. In J. Metcalfe and A. Shimamura (Eds.), *Metacognition: Knowing about knowing* (pp. 185–205). MIT Press.

Blume, B. D., Ford, J. K., Baldwin, T. T., & Huang, J. L. (2010). Transfer of training: A meta-analytic review. *Journal of Management, 36*(4), 1065–1105. https://doi.org/10.1177/0149206309352880

Bobrow, S. A., & Bower, G. H. (1969). Comprehension and recall of sentences. *Experimental Psychology, 80*(3), 455-461.

Boland, A. M., Haden, C. A., & Ornstein, P. A. (2003). Boosting children's memory by training mothers in the use of an elaborative conversational style as an event unfolds. *Journal of Cognition and Development*, *4*(1), 39–65. https://doi.org/10.1080/15248372.2003.9669682

Bransford, J. D., & Schwartz, D. L. (1999). Rethinking transfer: A simple proposal with multiple implications. *Review of Research in Education*, *24*, 61–100. https://doi.org/10.2307/1167267

Broudy, H. S. (1977). Types of knowledge and purposes of education. In R. C. Anderson, R. J. Spiro, & W. E. Montague (Eds.), *Schooling and the acquisition of knowledge* (pp. 1-17). Erlbaum.

Callanan, M. A., Castañeda, C. L., Luce, M. R., & Martin, J. L. (2017). Family science talk in museums: Predicting children's engagement from variations in talk and activity. *Child Development*, *88*(5), 1492–1504. https://doi.org/10.1111/cdev.12886

Callanan, M. A., & Jipson, J. (2001). Explanatory conversations and young children's developing scientific literacy. In K. Crowley, C. D. Schunn, & T. Okada (Eds.), *Designing for science: Implications from everyday, classroom, and professional science* (pp. 21–49). Erlbaum.

Callanan, M. A., Shrager, J., & Moore, J. L. (1995). Parent-child collaborative explanations: Methods of identification and analysis. *Journal of the Learning Sciences*, *4*(1), 105–129. https://doi.org/10.1207/s15327809jls0401_3

Catrambone, R., & Holyoak, K. J. (1989). Overcoming contextual limitations on problem-solving transfer. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 15*(6), 1147-1156.

Chandler-Campbell, I. L., Leech, K. A., & Corriveau, K. H. (2020). Investigating science together: Inquiry-based training promotes scientific conversations in parent-child interactions. *Frontiers in Psychology*, *11*, 1–12. https://doi.org/10.3389/fpsyg.2020.01934

Chakroff, J. L., & Nathanson, A. I. (2008). Parent and school interventions: Mediation and media literacy. In S. L. Calvert & B. J. Wilson (Eds.), *The handbook of children, media, and development* (pp. 552-576). Blackwell Publishing Ltd.

Chi, M. T. (2000). Self-explaining expository texts: The dual processes of generating inferences and repairing mental models. In R. Glaser (Ed.), *Advances in instructional psychology: Educational design and cognitive science* (Vol. 5). (pp. 161-238). Lawrence Erlbaum Associates Publishers.

Chong, S. C., & Treisman, A. (2005). Attentional spread in the statistical processing of visual displays. *Perception & Psychophysics*, *67*(1), 1–13. https://doi.org/10.3758/BF03195009

Chung, J., Cannady, M. A., Schunn, C., Dorph, R., Bathgate, M. (2016). Measures technical brief: Engagement in science learning activities. Retrieved from: http://www.activationlab.org/wpcontent/uploads/ 2016/02/Engagement-Report-3.1-20160331.pdf

Craik, F. I. M., & Lockhart, R. S. (1972). Levels of processing: A framework for memory research. *Journal of Verbal Learning and Verbal Learning, 11*, 671-684.

Crowley, K., Callanan, M. A., Jipson, J. L., Galco, J., Topping, K., & Shrager, J. (2001a). Shared scientific thinking in everyday parent-child activity. *Science Education*, *85*(6), 712–732. https://doi.org/10.1002/sce.1035

Crowley, K., Callanan, M. A., Tenenbaum, H. R., & Allen, E. (2001b). Parents explain more often to boys than to girls during shared scientific thinking. *Psychological Science, 12*(3), 258–261. https://doi.org/10.1111/1467-9280.00347

Crowley, K., & Galco, J. (2001). Everyday activity and the development of scientific thinking. In K. Crowley, C. D. Schunn, & T. Okada (Eds.), *Designing for science: Implications from everyday, classroom, and professional settings* (pp. 393–413). Lawrence Erlbaum Associates Publishers.

Crowley, K., & Jacobs, M. (2002). Building islands of expertise in everyday family activity. In G. Leinhardt, K. Crowley, & K. Knutson (Eds.), *Learning conversations in museums* (pp. 333–356). Lawrence Erlbaum Associates Publishers.

Crowley, K., & Siegler, R. S. (1999). Explanation and generalization in young children's strategy learning. *Child Development*, *70*(2), 304–316. https://doi.org/10.1111/1467-8624.00023

Daniel, D. B., & Woody, W. D. (2010). They hear, but do not listen: Retention for podcasted material in a classroom context. *Teaching of Psychology*, *37*(3), 199–203. https://doi.org/10.1080/00986283.2010.488542

De Koning, B. B., Van Hooijdonk, C. M. J., & Lagerwerf, L. (2017). Verbal redundancy in a procedural animation: On-screen labels improve retention but not behavioral performance. *Computers & Education*, *107*, 45–53. https://doi.org/10.1016/j.compedu.2016.12.013

Deng, W., & Sloutsky, V. M. (2016). Selective attention, diffused attention, and the development of categorization. *Cognitive Psychology*, *91*(December), 24–62. https://doi.org/10.1016/j.cogpsych.2016.09.002

Detterman, D. K. (1993). The case for the prosecution: Transfer as an epiphenomenon. In D. K. Detterman & R. J. Sternberg (Eds.), *Transfer on trial: Intelligence, cognition, and instruction* (pp. 1–24). Ablex Publishing.

Dore, R. A., & Zimmermann, L. (2020). Coviewing, scaffolding, and children's media comprehension. In J. Bulck (Ed.), *The International Encyclopedia of Media Psychology* (1st ed., pp. 1–8). Wiley. https://doi.org/10.1002/9781119011071.iemp0233

Engle, R. A. (2006). Framing interactions to foster generative learning: A situative explanation of transfer in a community of learners classroom. *Journal of the Learning Sciences*, *15*(4), 451–498. https://doi.org/10.1207/s15327809jls1504_2

Ewin, C. A., Reupert, A. E., McLean, L. A., & Ewin, C. J. (2021). The impact of joint media engagement on parent-child interactions: A systematic review. *Human Behavior and Emerging Technologies*, *3*(2), 230–254. https://doi.org/10.1002/hbe2.203

Fender, J. G., & Crowley, K. (2007). How parent explanation changes what children learn from everyday scientific thinking. *Journal of Applied Developmental Psychology*, *28*(3), 189–210. https://doi.org/10.1016/j.appdev.2007.02.007

Fisher, K., Hirsh-Pasek, K., Golinkoff, R. M., & Gryfe, R. G. (2008). Conceptual split? Parents' and experts' perceptions of play in the 21st century. *Journal of Applied Developmental Psychology, 29*,305–316.

Fivush, R., Haden, C. A., & Reese, E. (2006). Elaborating on elaborations: Role of maternal reminiscing style in cognitive and socioemotional development. *Child Development*, *77*(6), 1568–1588. https://doi.org/10.1111/j.1467-8624.2006.00960

Gamer, M., Lemon, J., Fellows, I., & Singh, P. (2022). *irr: Various Coefficients of Interrater Reliability and Agreement.* R package version 0.84.1, https://CRAN.R-project.org/package=irr

Gentner, D. (1983). Structure-mapping: A theoretical framework for analogy. *Cognitive Science, 7,* 155-170.

Gentner, D., Levine, S. C., Ping, R., Isaia, A., Dhillon, S., Bradley, C., & Honke, G. (2016). Rapid learning in a children's museum via analogical comparison. *Cognitive Science*, *40*(1), 224–240. https://doi.org/10.1111/cogs.12248

Gentner, D., Loewenstein, J., & Thompson, L. (2003). Learning and transfer: A general role for analogical encoding. *Journal of Educational Psychology*, *95*(2), 393–408. https://doi.org/10.1037/0022-0663.95.2.393

Gentner, D., & Namy, L. L. (1999). Comparison in the development of categories. *Cognitive Development*, *14*, 487–513.

Gentner, D., & Toupin, C. (1986). Systematicity and surface similarity in the development of analogy. *Cognitive Science, 10*, 277-300.

Gick, M. L., & Holyoak, K. J. (1980). Analogical problem solving. *Cognitive Psychology, 12*, 306-355.

Gleason, M. E., & Schauble, L. (1999). Parents' assistance of their children's scientific reasoning. *Cognition and Instruction*, *17*, 343–378. https://doi.org/10.1207/S1532690XCI1704

Gomaa, W. H., & Fahmy, A. A. (2013). A survey of text similarity approaches. *International Journal of Computer Applications*, *68*(13), 13-18.

Göncü, A., & Rogoff, B. (1998). Children's categorization with varying adult support. *American Educational Research Journal, 35*(2), 333-349.

Grack Nelson, A., Her, C., Van Cleave, S., & Dominguez-Flores, J. (2021). *Children's STEM-focused podcasts as promising learning experiences: Research summary.* Science Museum of Minnesota: St Paul, MN.

Gray, M. E., & Holyoak, K. J. (2021). Teaching by analogy: From theory to practice. *Mind, Brain, and Education*, *15*(3), 250–263. https://doi.org/10.1111/mbe.12288

Greeno, J. G., Moore, J. L., & Smith, D. R. (1993). Transfer of situated cognition. In D. K. Detterman & R. J. Sternberg (Eds.), *Transfer on trial: Intelligence, cognition, and instruction* (pp. 99–167). Ablex Publishing.

Gutwill, J. P. and Allen, S. (2010). Facilitating family group inquiry at science museum exhibits. *Science Education, 94*, 710-742. https://doi.org/10.1002/sce.20387

Haden, C. A. (2010). Talking about science in museums. *Child Development Perspectives*, *4*(1), 62–67. https://doi.org/10.1111/j.1750-8606.2009.00119.x

Haden, C. A., Jant, E. A., Hoffman, P. C., Marcus, M., Geddes, J. R., & Gaskins, S. (2014). Supporting family conversations and children's STEM learning in a children's museum. *Early Childhood Research Quarterly*, *29*(3), 333-344. https://doi.org/10.1016/j.ecresq.2014.04.004

Hanner, E., Braham, E. J., Elliott, L., & Libertus, M. E. (2019). Promoting math talk in adult–child interactions through grocery store signs. *Mind, Brain, and Education*, *13*(2), 110–118. https://doi.org/10.1111/mbe.12195

Harskamp, E. G., Mayer, R. E., & Suhre, C. (2007). Does the modality principle for multimedia learning apply to science classrooms? *Learning and Instruction*, *17*(5), 465–477. https://doi.org/10.1016/j.learninstruc.2007.09.010

Hayes, A. F. (2018). *Introduction to mediation, moderation, and conditional process analysis (second edition): A regression-based approach.* Guilford Press.

Hedrick, A. M., San Souci, P., Haden, C. A., & Ornstein, P. A. (2009). Mother-child joint conversational exchanges during events: Linkages to children's memory reports over time. *Journal of Cognition and Development*, *10*(3), 143–161. https://doi.org/10.1080/15248370903155791

Hiniker, A., Lee, B., Kientz, J. A., & Radesky, J. S. (2018). Let's play!: Digital and analog play between preschoolers and parents. Paper presented at the *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*, Montreal QC, Canada.

Jacoby, L. (1978) On interpreting the effects of repetition: Solving a problem versus remembering a solution. *Journal of Verbal Learning and Verbal Behavior, 17*, 649-667.

Jant, E. A., Haden, C. A., Uttal, D. H., & Babcock, E. (2014). Conversation and object manipulation influence children's learning in a museum. *Child Development*, *85*(5), 2029–2045. https://doi.org/10.1111/cdev.12252

Jeu, N. P., & Mohamad, M. (2014). Effects of redundancy and modality principle in multimedia learning: Concentration on motivation and gender differences among primary school students. *Journal of ICT in Education, 1*, 42-53.

Kalyuga, S., & Sweller, J. (2014). The Redundancy Principle in Multimedia Learning. In R. E. Mayer (Ed.), *The Cambridge Handbook of Multimedia Learning* (2nd ed., pp. 247–262). Cambridge University Press. https://doi.org/10.1017/CBO9781139547369.013

Kennedy, M. J., Hirsch, S. E., Dillon, S. E., Rabideaux, L., Alves, K. D., & Driver, M. K. (2016). Using content acquisition podcasts to increase student knowledge and to reduce perceived cognitive load. *Teaching of Psychology, 43*(2), 153-158. https://doi.org/10.1177/0098628316636295

Kids Listen. (2016). *Kids Listen inaugural survey. The first survey of children's podcast listening habits.* https://bd754cce-d1c0-4397-b737-454f7138e2cd.filesusr.com/ugd/10c540_8056b16c7caa47b091ca25a5cc426176.pdf

Kids Listen. (2021). *Kids Listen. Understanding the kids and family podcast audience.* https://www.kidslisten.org/survey

Knoop-van Campen, C. A. N., Segers, E., & Verhoeven, L. (2019). Modality and redundancy effects, and their relation to executive functioning in children with dyslexia. *Research in Developmental Disabilities*, *90*, 41–50. https://doi.org/10.1016/j.ridd.2019.04.007

Krippendorff, K. (2011). *Computing Krippendorff's Alpha-Reliability*. https://repository.upenn.edu/asc_papers/43

Land-Zandstra, A. M., Hoefakker, K., & Damsma, W. (2020). Reasoning about objects in a natural history museum: The effect of complexity of questions on object labels. *Visitor Studies, 23*(2), 218–236. https://doi.org/10.1080/10645578.2020.1781485

Lauricella, A. R., Barr, R., & Calvert, S. L. (2014). Parent–child interactions during traditional and computer storybook reading for children's comprehension: Implications for electronic storybook design. *International Journal of Child-Computer Interaction, 2*(1), 17–25. https://doi.org/10. 1016/j.ijcci.2014.07.001

Lauricella, A. R., Gola, A. A. H., & Calvert, S. L. (2011). Toddlers' learning from socially meaningful video characters. *Media Psychology, 14*, 216–232. https://doi.org/10.1080/15213269.2011.573465

Lave, J. (1988). *Cognition in practice: Mind, mathematics, and culture in everyday life.* Cambridge University Press.

Linebarger, D. L., & Walker, D. (2005). Infants' and toddlers' television viewing and language outcomes. *American Behavioral Scientist, 48*, 624–645. https://doi.org/10.1177/0002764204271505

Lonn, S., & Teasley, S. D. (2009). Podcasting in higher education: What are the implications for teaching and learning? *The Internet and Higher Education*, *12*(2), 88–92. https://doi.org/10.1016/j.iheduc.2009.06.002

Luna, M. L., & Sandhofer, C. M. (2021). Arbitrary but predictive cues support attention to overlooked features. *Journal of Memory and Language*, *120*, 104251. https://doi.org/10.1016/j.jml.2021.104251

Marcus, M., Haden, C. A., & Uttal, D. H. (2018). Promoting children's learning and transfer across informal science, technology, engineering, and mathematics learning experiences. *Journal of Experimental Child Psychology*, *175*, 80–95. https://doi.org/10.1016/j.jecp.2018.06.003

Márquez, C., Izquierdo, M., & Espinet, M. (2006). Multimodal science teachers' discourse in modeling the water cycle. *Science Education*, *90*(2), 202–226. https://doi.org/10.1002/sce.20100

Mayer, R. E. (1997). Multimedia learning: Are we asking the right questions? *Educational Psychologist*, *32*(1), 1–19. https://doi.org/10.1207/s15326985ep3201_1

Mayer, R. E. (2005). Cognitive theory of multimedia learning. *The Cambridge Handbook of Multimedia Learning*, *41*, 31-48.

Mayer, R. E., & Johnson, C. I. (2008). Revising the redundancy principle in multimedia learning. *Journal of Educational Psychology*, *100*(2), 380–386. https://doi.org/10.1037/0022-0663.100.2.380

Mayer, R. E., Bove, W., Bryman, A., Mars, R., & Tapangco, L. (1996). When less is more: Meaningful learning from visual and verbal summaries of science textbook lessons. *Journal of Educational Psychology*, *88*(1), 64–73. https://doi.org/10.1037/0022-0663.88.1.64

Morris, B. J., Zentall, S. R., Murray, G., & Owens, W. (2021). Enhancing informal STEM learning through family engagement in cooking. *Proceedings of the Singapore National Academy of Science*, *15*(02), 119–133. https://doi.org/10.1142/S2591722621400111

Mulwa, K. W., & Kucker, S. C. (2022). Coding social interactions in naturalistic settings: The taxonomy of dyadic conversation. *Behavior Research Methods, 56*, 172-186. https://doi.org/10.3758/s13428-022-02033-w

National Research Council (2012). Education for life and work: Developing transferable knowledge and skills in the 21st century. Washington, D.C.: National Academies Press.

National Research Council (2013). Next generation science standards: For states, by states. Washington, D.C.: National Academies Press.

Neumann, M. M., Finger, G., & Neumann, D. L. (2016). A conceptual framework for emergent digital literacy. *Early Childhood Education Journal*, *45*(4), 471–479. https://doi.org/10.1007/s10643-016-0792-z

Ocular, G., Kelly, K. R., Millan, L., Neves, S., Avila, K., Hsieh, B., & Maloles, C. (2022). Contributions of naturalistic parent-child conversations to children's science learning during informal learning at an aquarium and at home. *Frontiers in Psychology*, *13*, 943648. https://doi.org/10.3389/fpsyg.2022.943648

Ornstein, P. A., Haden, C. A., & Hedrick, A. M. (2004). Learning to remember: Social-communicative exchanges and the development of children's memory skills. *Developmental Review, 24*(4), 374–395. https://doi.org/10.1016/j.dr.2004.08.004

Pagano, L. C., Haden, C. A., & Uttal, D. H. (2020). Museum program design supports parent–child engineering talk during tinkering and reminiscing. *Journal of Experimental Child Psychology*, *200*, 104944. https://doi.org/10.1016/j.jecp.2020.104944

Palmquist, S., & Crowley, K. (2007). From teachers to testers: How parents talk to novice and expert children in a natural history museum. *Science Education, 91*(5), 783–804. https://doi.org/10.1002/sce.20215

Parish-Morris, J., Mahajan, N., Hirsh-Pasek, K., Golinkoff, R. M., & Collins, M. F. (2013). Once upon a time: Parent–child dialogue and storybook reading in the electronic era. *Mind, Brain, and Education*, *7*(3), 200–211. https://doi.org/10.1111/mbe.12028

Plebanek, D. J., & Sloutsky, V. M. (2017). Costs of selective attention: When children notice what adults miss. *Psychological Science*, *28*(6), 723-732. https://doi.org/10.1177/0956797617693005

Polinsky, N., Perez, J., Grehl, M., & McCrink, K. (2017). Encouraging spatial talk: Using children's museums to bolster spatial reasoning. *Mind, Brain, and Education*, *11*(3), 144-152. https://doi.org/10.1111/mbe.12145

R Core Team (2023). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/

Reimers, N., & Gurevych, I. (2019). Sentence-BERT: Sentence embeddings using Siamese BERT-networks. In *Processing of the 2019 Conference on Empirical Methods in Natural Language Processing.* Association for Computational Linguistics. https://arxiv.org/abs/1908.10084

Reiser, R. A., Tessmer, M. A., & Phelps, P. C. (1984). Adult-child interaction in children's learning from "Sesame Street". *Educational Communication and Technology, 32*(4), 217-223.

Resnick, L. B. (1987). *Education and learning to think*. National Academy Press.

Romeo, R. R., Leonard, J. A., Robinson, S. T., West, M. R., Mackey, A. P., Rowe, M. L., & Gabrieli, J. D. E. (2018). Beyond the 30-million-word gap: Children's conversational exposure is associated with language-related brain function. *Psychological Science, 29*(5), 700-710. https://doi.org/10.1177/0956797617742725

Rowe, M. L., Turco, R. G., & Blatt, J. H. (2021). Can interactive apps promote parent-child conversations? *Journal of Applied Developmental Psychology*, *76*, 101326. https://doi.org/10.1016/j.appdev.2021.101326

Schnotz, W. (2005). An integrated model of text and picture comprehension. In R. E. Mayer (Ed.), Cambridge handbook of multimedia learning (pp. 49 –70). Cambridge, England: Cambridge University Press. https://doi.org/10.1017/CBO9780511816819.005

Schwartz, D. L., & Moore, J. L. (1998). On the role of mathematics in explaining the material world: Mental models for proportional reasoning. *Cognitive Science, 22*(4), 471-516.

Scott, K., & Schulz, L. (2017). Lookit (part 1): A new online platform for developmental research. *Open Mind*, *1*(1), 4-14.

Seger, B. T., Wannagat, W., & Nieding, G. (2019). How static and animated pictures contribute to multi-level mental representations of auditory text in seven-, nine-, and eleven-year-old children. *Journal of Cognition and Development*, *20*(4), 573–591. https://doi.org/10.1080/15248372.2019.1636799

Sheehan, K. J., Pila, S., Lauricella, A. R., & Wartella, E. A. (2019). Parent-child interaction and children's learning from a coding application. *Computers & Education, 140*, 103601. https://doi.org/10.1016/j.compedu.2019.103601

Sheskin, M., Scott, K., Mills, C. M., Bergelson, E., Bonawitz, E., Spelke, E. S., ... & Schulz, L. (2020). Online developmental science to foster innovation, access, and impact. *Trends in Cognitive Sciences*, *24*(9), 675-678.

Shing, Y. L., & Brod, G. (2016). Effects of prior knowledge on memory: Implications for education. *Mind, Brain, and Education, 10*(3), 153–161. https://doi.org/10.1111/mbe.12110

Siegler, R. S. (1995). How does cognitive change occur: A microgenetic study of number conservation. *Cognitive Psychology ,25*, 225−273.

Siegler, R. S. (2002). Microgenetic studies of self-explanation. In N. Franott & J. Parziale (Eds.), *Microdevelopment: Transition processes in development and learning* (pp. 31-58). Cambridge University Press.

Sloutsky, V. M., & Fisher, A. V. (2004). When development and learning decrease memory: Evidence against category-based induction in children. *Psychological Science, 15(8)*, 553-558.

Sloutsky, V. M., & Robinson, C. W. (2013). Redundancy matters: Flexible learning of multiple contingencies in infants. *Cognition*, *126*(2), 156–164. https://doi.org/10.1016/j.cognition.2012.09.016

Song, L., Golinkoff, R. M., Stuehling, A., Resnick, I., Mahajan, N., Hirsh-Pasek, K., & Thompson, N. (2017). Parents' and experts' awareness of learning opportunities in children's museum exhibits. *Journal of Applied Developmental Psychology, 49*, 39-45. https://doi.org/10.1016/j.appdev.2017.01.006

Sternberg, R. J., & Frensch, P. A. (1993). Mechanisms of transfer. In D. K. Detterman & R. J. Sternberg (Eds.), *Transfer on trial: Intelligence, cognition, and instruction* (pp. 1–24). Ablex Publishing.

Strouse, G. A., O'Doherty, K., & Troseth, G. L. (2013). Effective coviewing: Preschoolers' learning from video after a dialogic questioning intervention. *Developmental Psychology*, *49*(12), 2368–2382. https://doi.org/10.1037/a0032463

Strouse, G. A., Troseth, G. L., O'Doherty, K. D., & Saylor, M. M. (2018). Co-viewing supports toddlers' word learning from contingent and noncontingent video. *Journal of Experimental Child Psychology*, *166*, 310–326. https://doi.org/10.1016/j.jecp.2017.09.005

Sun, X., Norton, O., & Nancekivell, S. E. (2023). Beware the myth: Learning styles affect parents', children's, and teachers' thinking about children's academic potential. *Npj Science of Learning, 8*(1), 46. https://doi.org/10.1038/s41539-023-00190-x

Sung, J. (2018). How young children and their mothers experience two different types of toys: A traditional stuffed toy versus an animated digital toy. *Child & Youth Care Forum, 47*(2), 233–257. https://doi.org/10. 1007/s10566-017-9428-8

Sweller, J., & Chandler, P. (1994). Why some material is difficult to learn. *Cognition and Instruction*, *12*(3), 185-233.

Sweller, J., Van Merrienboer, J. J., & Paas, F. G. (1998). Cognitive architecture and instructional design. *Educational Psychology Review*, *10*, 251-296.

Takeuchi, L., & Stevens, R. (2011). The new coviewing: Designing for learning through joint media engagement. New York: The Joan Ganz Cooney Center at Sesame Workshop.

Tessler, M., & Nelson, K. (1994). Making memories: The influence of joint encoding on later recall by young children. *Consciousness and cognition*, *3*(3-4), 307-326. https://doi.org/10.1006/ccog.1994.1018

Thiessen, E. D., & Saffran, J. R. (2003). When cues collide: Statistical and stress cues in infant word segmentation. *Developmental Psychology, 39*, 706–716.

Thorndike, E. L., & Woodworth, R. S. (1901). The influence of improvement in one mental function upon the efficiency of other functions. *Psychological Review, 8*, 247-261.

Toppino, T. C., Kasserman, J. E., & Mracek, W. A. (1991). The effect of spacing repetitions on the recognition memory of young children and adults. *Journal of Experimental Child Psychology*, *51*(1), 123–138. https://doi.org/10.1016/0022-0965(91)90079-8

Tulving, E., & Thomson, D. M. (1973). Encoding specificity and retrieval processes in episodic memory. *Psychological Review, 80*(5), 352-373.

Valle, A., & Callanan, M. A. (2006). Similarity comparisons and relational analogies in parent-child conversations about science topics. *Merrill-Palmer Quarterly*, *52*(1), 96–124.

Vlach, H. A., & Kalish, C. W. (2014). Temporal dynamics of categorization: Forgetting as the basis of abstraction and generalization. *Frontiers in Psychology*, *5*, 1–9. https://doi.org/10.3389/fpsyg.2014.01021

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes.* Harvard University Press.

Wickham, H. (2016). *ggplot2: Elegant graphics for data analysis.* Springer-Verlag. https://ggplot2.tidyverse.org

Willard, A. K., Busch, J. T. A., Cullum, K. A., Letourneau, S. M., Sobel, D. M., Callanan, M., & Legare, C. H. (2019). Explain this, explore that: A Study of parent–child interaction in a children's museum. *Child Development*, *90*(5), e598–e617. https://doi.org/10.1111/cdev.13232

Wooldridge, M. B., & Shapka, J. (2012). Playing with technology: Mother-toddler interaction scores lower during play with electronic toys. *Journal of Applied Developmental Psychology, 33*(5), 211–218. https://doi. org/10.1016/j.appdev.2012.05.005

Yelland, N., & Masters, J. (2007). Rethinking scaffolding in the information age. *Computers & Education, 48*(3), 362–382. https://doi.org/10.1016/ j.compedu.2005.01.010

Yoshida, H., & Smith, L. B. (2005). Linguistic cues enhance the learning of perceptual cues. *Psychological Science, 16*(2), 90-95.

Yue, C. L., Bjork, E. L., & Bjork, R. A. (2013). Reducing verbal redundancy in multimedia learning: An undesired desirable difficulty? *Journal of Educational Psychology*, *105*(2), 266–277. https://doi.org/10.1037/a0031971

Zimmerman, H. T., Reeve, S., & Bell, P. (2010). Family sense-making practices in science center conversations. *Science Education*, *94*(3), 478–505. https://doi.org/10.1002/sce.20374