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Exploring science concepts in everyday interactions with infant-toddlers at home: Caregivers' raised science consciousness through Fleer's Conceptual PlayWorld

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Abstract

Family is the core institution for infant-toddlers' science learning. However, little is known about how caregivers support infant-toddlers' science concept formation at home. The study presented in this paper follows 18 families with infant-toddlers aged 4 to 24 months old (mean age 10 months old) over five weeks in an educational experiment of Fleer's Conceptual PlayWorld (CPW) at home using *We Are Going on a Bear Hunt* story. 46 h of recorded data, including 29 h of Zoom workshops, 5.5 h of the family-collected videos, and 11.5 h of pre-and post-CPW interviews, are analysed from a cultural-historical perspective to explore how families identify and engage science concepts in moments of interaction with infant-toddlers at home. The findings show that with the support of CPW educational experiments, families become more conscious of science possibilities in their everyday lives at home, and they reframe routine activities into enjoyable science learning experiences for infant-toddlers. Three family practices have been identified to draw out science concepts from their moments of interaction with infant-toddlers: 1) creating phenomena central to a science concept using cultural objects such as mirrors for light reflection; 2) drawing infant-toddlers' attention to the salient aspects of a phenomenon through scientific narratives, and 3) creating imaginary play scenarios in CPW or everyday routine activities that require problem-solving actions informed by science concepts. It is argued that by reframing routine activities into enjoyable science experiences and drawing out science concepts, families become more confident and skilful in enriching infant-toddlers' learning in science.

Keywords: family science pedagogy; infant-toddlers; science concept formation; Fleer's Conceptual PlayWorlds; educational experiment

Introduction

High-quality early science experiences are crucial for children's overall cognitive development and their later academic and career interests and achievements in science

(Pattison & Dierking, 2019). Previous research has confirmed that early playful engagement with science concepts can start in infancy and toddlerhood (Fleer et al., 2021; Sikder, 2015). Those early days in life are crucial for laying a solid foundation for the formation of science concepts (Lloyd et al., 2017; Fragkiadaki et al., 2023a). 'Science concepts' refer to culturally and historically developed ideas in science, such as light and shadow, or the classification of animals, their diets, and habitats, that help children make sense of the world in systematic and meaningful ways (Fragkiadaki et al., 2023a). For infant-toddlers (those under 2 years old), family homes are the most important institutional settings where their science concept formation takes place, as rich science opportunities are available in their everyday moments at home (Sikder & Fleer, 2015). The caregiver's role as an adult mediator is indispensable for infant-toddlers to tap into these science opportunities (Sikder & Fleer, 2015; Setioko & Ding, 2022).

However, despite its importance, there is a notable gap in the literature of infant-toddlers' science concept formation with caregivers' support at home, for most of the existing literature on young children's science concept formation focuses on older children in centre-based or community-based settings (Lloyd et al., 2017; Fleer, 2024; Fleer et al., 2024a). This gap has practical consequences, as an insufficient understanding of how to support infant-toddlers' science learning might lead to adults' lack of confidence and misconceptions in supporting the science concept formation of infants and toddlers. When adults lack confidence (Johnstone et al., 2022), hold low expectations of infants' and toddlers' capacities (Fleer, 2024), or do not prioritise science in their interactions (Gustavsson et al., 2016), science possibilities tend to be overlooked. Therefore, researchers (Fleer et al., 2024a; Sikder, 2015; Sikder & Fleer, 2015) call for more research on the science concept formation of infants and toddlers in general, to add more evidence to the existing limited research base. Fleer (2024) advocates for further research on this research problem using study designs

based on the Fleer's Conceptual PlayWorld (CPW) in settings outside of early learning centres. To address the identified gaps, this study aims to explore the formation of science concepts in infant-toddlers with caregivers' support in family settings. More specifically, it attempts to answer two research questions:

- How does Fleer's CPW impact caregivers' science pedagogical practices with infant-toddlers at home?
- How do caregivers identify and engage with science concepts during everyday routines with infant-toddlers under the condition of Fleer's CPW?

This paper starts with a narrative review of caregivers' mediation in infant-toddlers' science concept formation, followed by a cultural-historical conception of concept formation, illustrative data from two participating families, discussions about how the findings sit within the broader existing literature, and a conclusion highlighting new insights regarding how families can better support infant-toddlers tapping into science possibilities in everyday lives and amplifying infant-toddlers' science concept formation at home. It is argued that the nuanced understanding of infant-toddler science pedagogy presented in this study offers families valuable insights into their science pedagogical practices at home.

Caregivers as mediators for infant-toddlers' science concept formation

Caregivers may demonstrate different levels of confidence and involvement in engaging infants and toddlers with science concepts. When adults do not orient towards science, they miss opportunities for science in their interactions with infants and toddlers (Gustavsson et al., 2016). In contrast, when they do, they can effectively support the emergence of science concepts in infants and toddlers through everyday interactions and activities at home (Sikder & Fleer, 2015; Lloyd et al., 2017). Intervention studies targeted at caregivers have been shown to increase their confidence and orientation towards science concepts. This, in turn, improves how they engage infants and toddlers in science-related interactions (Lloyd et al.,

2017; Fleer et al., 2024b). In their educational experiment, Fleer and her colleagues (2024a) find that it is essential for caregivers to become more oriented towards science possibilities during their interactions with infant-toddlers. However, most intervention studies on infant-toddlers' science concept formation occur in centre or community-based settings, and there is a lack of intervention studies in family settings.

Family settings provide rich opportunities for infants and toddlers to encounter science as part of their everyday experiences. Sikder (2015) identifies various science concepts available in infant-toddlers' everyday social situations at home through her naturalistic observations of four Bangladesh families, for example, shaking a rattle (sound), rolling and pressing playdough (force), and mixing ingredients (change of state of matter), to name just a few. She highlights the significant contributions of everyday experiences and interactions yet does not explain how caregivers support infant-toddlers tapping into those available science opportunities. Sikder and Fleer (2015) partially fill this gap by foregrounding the concept of "small science", which highlights the importance of caregivers narrating and engaging with infant-toddlers in science moments. That is, caregivers provide rich scientific explanations related to a phenomenon that accompanies infant-toddlers' physical exploration or problem-solving actions. This unity of doing science and having accompanying conversation about science is also captured in the concept of 'science talk' (Lloyd et al., 2017; Setioko & Ding, 2022). In their interventionist study, Lloyd and colleagues (2017) provided families with prompts to encourage them to ask more questions and engage in conversations related to relevant science concepts when children participated in science activities.

Other studies have also supported the importance of children's actions and adults' words in supporting early science concept formation. Klaar and Öhman (2012) find that infant-toddlers form science concepts through their physical exploration and problem-solving

actions in response to natural phenomena and problem scenarios encountered in a Swedish centre. Adults' words are believed to direct infant-toddlers' attention to phenomena they experience and thus create links between phenomena and scientific terms supporting infant-toddlers' raised scientific consciousness about their everyday world (Fleer et al., 2024a; Fleer, 2024; Sikder & Fleer, 2018). The use of scientific terms should be considered over time, not just in 'moments' (Fleer et al., 2024a). It should not be confined to conversations with children amid observation of natural phenomena but also be used during story narratives which support infant-toddlers to perceive phenomena relevant to science concepts in imaginary situations (Fleer et al., 2021). However, all these studies cited focus either on centre-based settings or on structured science activities or playful science activities. It is still unknown how adults' scientific explanations and narratives unfold in everyday routines for infant-toddlers at home.

Imaginary situations are believed to provide unique, emotionally charged contexts that invite and support infants and toddlers to actively experience and explore science concepts (Fleer et al., 2021). Infant-toddlers should be supported in having more opportunities for sensual experiences through active 'as if' engagement (acting as if the imaginary situation were real, such as pretending to feed a teddy bear as if it were a real bear) and interactions with objects (or props) in their imaginary situations (Fragkiadaki et al., 2023b; Fleer, 2024). Props can serve as pivots for holding scientific meaning for infant-toddlers in imaginary play (Fleer et al., 2024a), and their 'as if' actions around the props gradually shift from orienting towards concrete objects to a shared intellectual space as their scientific understanding and co-imagination develop (Fragkiadaki et al., 2021).

Fragkiadaki and colleagues (2023a) introduce Fleer's CPW using the storybook of the *Possum in the House* into an Australian early learning centre in an educational experiment. During the CPW, they co-created imaginary play situations with infant-toddlers who take

different imaginary roles, such as the Possum who makes various kinds of sounds, such as '*Screech-screech*!' '*Squick-squick*!'. They contextualise the imaginary play by using props like possum puppets and real possum sound recordings. In addition to enacting various sounds within imaginary play situations, they provide infant-toddlers with the experience of playing drums to make more sense of sounds. They also intentionally extend infant-toddlers' understanding of sound by using coloured chalk dust on the drum to make the invisible sound wave visible to infant-toddlers outside the imaginary play. Again, the identified studies on imaginary situations for science learning occurred in centre-based settings, and it remains unknown how imaginary play supports young infants' and toddlers' science concept formation in family settings.

To fill gaps identified in this review, this study introduces the imaginary play-based pedagogical model of Fleer's Conceptual PlayWorld into family settings to generate understandings of science-concept-related imaginary play for infant-toddlers at home, as well as observe how imaginary play, children's exploration and problem-solving actions, and adults' verbal narration and explanation unfold in infant-toddlers' everyday routines. In the next section, we examine a cultural-historical perspective on concept formation.

Cultural-historical conception of concept formation

Vygotsky (1987, 1994) conceptualises concept formation as a higher mental function that develops through socially mediated processes. Before a concept becomes an intrapsychological function, it first exists on the social plane through interpersonal interactions. Adults play a vital role in creating these conditions by guiding children's attention to essential features of objects and phenomena and introducing concepts that shape what children learn (Hedeggard et al., 2008; Bodrova & Leong, 2006). Through interpersonal

interactions, children learn what to notice and how to act upon these features, which lays the foundation for their conceptual development.

Concrete sensual experiences, actions, and *words* are necessary for concept formation (Vygotsky, 1987). Vygotsky (1987) argues that *"...for the child in particular, the concept is linked with sensual material, the* ***perception*** *and transformation of which gives rise to the concept itself."* (p.121). Early understandings of how things work gained through concrete sensual experiences are conceptualised as '*potential concepts*', which arise very early in children (Vygotsky, 1987). Since infants think in action (Vygotsky, 1998), potential concepts often take the form of "*habitual actions*", serving as a precondition for the appearance of intellect (Groos, 1916, p.196 as cited in Vygotsky, 1987, p.157). At this stage, perception and action are "*undifferentiated*" and "*connected through affect*" (Vygotsky, 1998, p.225). Infants perceive the whole situation before they perceive the parts; for example, when an infant perceives a room, initially '*everything seems as an undivided whole*' for them (Vygotsky, 1998, p. 291). Gradually, perception becomes more differentiated, enabling children to recognise objects and actions separately (Vygotsky, 1998). During this process, adults' actions and moving objects attract attention earlier than static objects (Vygotsky, 1987; 1998), and infants' own physical manipulation deepens understanding of objects and phenomena (Bodrova & Leong, 2006).

Language also plays an essential role in this process. Words mediate perception by directing attention to certain aspects of a perceived situation and "*breaking it down to objects and actions*" (Vygotsky, 1998, p.87). This linguistic mediation supports more meaningful perception and action (Vygotsky, 1987). Children encounter words in the adult speech from an early age, and their concepts develop alongside their understanding of word meanings (Vygotsky, 1987). In other words, adults' language reorganises children's perceptions and support concept formation.

Potential concepts support everyday concepts when children's word meanings develop through adult mediation in daily interactions (Vygotsky, 1987), and their perception develops from nonverbal to verbal (Vygotsky, 1998). Everyday concepts form the foundation for scientific concepts, which are introduced systematically through verbal definitions in formal schooling (Vygotsky, 1987). Without everyday concepts that are rooted in concrete sensual experiences and everyday interactions, scientific concepts risk becoming empty verbalism. As Vygotsky (1987) states, "*The development of everyday concepts must reach a certain level for the child to learn scientific concepts and gain conscious awareness of them*" (p. 219). Therefore, adults' mediation in everyday interactions is essential for helping infants and toddlers realise their conceptual potential. This involves providing rich sensual experiences, opportunities for problem solving, and supporting links between concrete '*sensual materials*' and culturally and historically accumulated science concepts in everyday situations.

Study design

This study adopts Hedegaard's (2008a) educational experiment design to systematically introduce Fleer's CPW as a planned intervention into family institutional practices. Families are positioned as co-researchers and competent educators who generate meaningful data relevant to family science pedagogy for infant-toddlers (Yu et al., 2024).

There are five theoretically justified characteristics in CPW (Fleer, 2019): 1) selecting a storybook characterised by drama that provides a shared narrative to support children entering imaginary play situations. The storybook selected for this study is *We Are Going on a Bear Hunt* by Michael Rosen (2016). 2) designing and creating imaginary spaces with supports of props that provide contextual support for young children to enter the collective imagining. 3) planned signs for indicating the entry into and exit out of PlayWorld, for example, putting on the binoculars indicates entering the bear hunt imagination. 4) planning

an imaginary problem situation that needs to be solved using a concept; this study focuses on science concepts. 5) planned pedagogical positioning of adults in the collective imaginary play.

A total of eighteen families from Melbourne, Victoria were recruited through an expression of interest and engaged in the educational experiment via ten Zoom sessions conducted over a five-week period. Each Zoom session included storytelling using props to support the imaginary situation, followed by mini-workshops where families discussed challenges, shared videos, and explored further ideas for implementing CPW at home. Detailed session designs, the structure of pre-CPW interviews, the nature of family-researcher interactions, and a brief description of resources provided to families are available in Yu et al. (2024). Each of the participating families had an infant-toddler aged between 4 and 24 months (mean age of 10 months). The study was conducted in two rounds, each with nine participating families: one in March and the other in July 2021. Each round consisted of three small groups scheduled at different times, allowing families to choose the session that best suited their availability. Multiple sources of data have been collected, which include 5.5 hours pre-CPW interviews with individual families, 6 hours post-CPW interviews with families, 29 hours of Zoom workshop and storytelling sessions, 5.5 hours of visual observations collected by families of their CPW, and email communications with families. So, there is a total of around 46 hours of digital data.

The data analysis was conducted by the first author, with feedback from co-authors during manuscript preparation. Guided by Hedegaards' (2008b) three-layer analysis approach, validity and reliability were ensured through explicit theoretical framing and systematic interpretation in three layers (see Table 1), in which the categories we identified from the literature and cultural-historical theory provide us with analytical lens, consistently

guide us on what to pay attention to, and support us in formulating the relations among patterns we notice in the data.

Table 1: Data analysis process

Analysis processes	Research question 1	Research question 2
Step 1: Commonsense interpretation	All pre- and post-interview transcripts were reviewed to highlight where families shared differences that they noticed in their science pedagogical practices. (e.g. "*I would never have thought of giving him a mirror to do that*)	Digital data are revisited to identify 'science moments', where features of a phenomenon central to a science concept are drawn to the child's attention through adults' actions or words (e.g., when cooking porridge, a parent draws her son's attention to the detailed features of matter changing processes of oats; for instance, she uses terms like '*thickening*', '*it's getting thicker and thicker*', '*gluey texture*'). Those data pieces are labelled across the dataset.
Step 2: Situated practice interpretation	Categories identified in the literature regarding 'contact with phenomena central to science concepts', 'everyday versus imaginary scenarios', 'adults and children's actions around objects',	We examine patterns of how adults create phenomena or draw the child's attention to important aspects of phenomena that are

	'adults' words', and 'adults' science consciousness' are used to support further identifying patterns of changes noticed by families.	central to science concepts using actions, objects, and words.
Step 3 Thematic interpretation	Vygotsky's conception of an adult's mediating roles is used to further examine the relations between the patterns of changes noticed by families.	Cultural-historical conceptions of 'potential concept' and 'perceptions' are used to understand how actions, objects, and words work together to help children raise awareness and form understanding of the key aspects of a phenomenon that are central to a science concept.

Findings

In this section, illustrative data from several families with children of different ages are briefly introduced (see Table 2). The purpose of presenting these additional data is to show that the science pedagogical shifts at home discussed in the paper were identified across the wider dataset, rather than being derived solely from the two focal families. This overview provides analytic grounding for the two illustrative cases by indicating that the patterns elaborated in the vignettes recurred across multiple families.

Table 2: Illustrative data from multiple families and data sources

Mum's Pseudonym	**Child's Age**	**Data Examples from different sources**

Daisy	4 months	Daisy expressed her uncertainty about whether her baby was too young for the study [Pre-CPW Interview]. She engages her son in bear hunt imaginary play, brings in various toy animals for the imaginary forest and river, observing and describing the animals for him [Video]. Later, Daisy excitedly shared that her son had developed strong interests in the wild animals she introduced [Post-CPW Interview]
Lyla	6 months	In the bear hunt story's imaginary dark forest, the researcher introduced a *Walking in the Forest* song to enrich the scenario, prompting children to listen and guess animal sounds [Zoom session]. This sparked Lyla's interest in exploring sound with her daughter, leading her to borrow *Baby Loves Hearing* form library and read the book with her daughter [Video]. Later, the father introduced various musical instruments and talked about pitch (high/low), volume (soft/hard), and tempo (slow/fast). For example, he demonstrated slow and fast drumming, and interestingly the baby imitated these movements, and Lyla commented, 'She is actually mirroring your hands with the slow and fast' [Video].
Sienna	12 months	In Week 4, Sienna reflected on changes in her interactions with her son: "My interaction is different from before, as I am allowing longer time to observe Zane and let him response to a new introduction of toys and concepts. Sometimes, I find it difficult to remain silent and sometimes I don't know how to narrate a science concept". In response, the researcher shared baby science picture books recommended by other families [Email]. Later, Sienna shared "We went for a walk… we watched the sky, the birds, and the sun. It was sunset, and I said, '…when we come home from the bear hunt it will be the evening...'" [Post-CPW interview]
Sasha	24 months	Sasha shared that she had never considered introducing new concepts, such as light. After seeing about other families introducing light and shadows in the Zoom session, she began exploring lights, shadows, and rainbows at home. One day, she noticed her four-year-old was creating a light projector for their ceiling using a recycled box with cut-out holes and a lantern underneath, with his 2-year-old sister, all on their own [Post-CPW Interview].

Detailed illustrative data will be presented from two families: Sally with her 10-month-old Ryan, and Rhea with her son Henry, who was 8-month-old upon entry, and 9 months in the data. These two families were selected as information-rich cases that exemplified analytic

patterns identified across the wider dataset. These cases were not selected as exceptional or extreme, but because they offered dense, interconnected data that allowed the analytic processes to be shown in detail. We begin with two vignettes illustrating how Sally created phenomena of light, darkness, and light reflection with the dark, gloomy cave of *We Are Going on a Bear Hunt* story for Ryan on 1st and 3rd April 2021. Prior to these vignettes, singing and imaginary play had occurred repeatedly for two weeks.

Vignette 5.1 *Dark, gloomy cave*!

Vignette 5.1.1

Sally and Ryan are in front of a dark cave made from a big blanket, tied between the child's safety fence and a living room itself. Inside the cave sits a toy panda. Ryan looks at the cave as Sally begins singing, "*We are going on a bear hunt!*". Hearing the song, Ryan moves his body to the rhythm. Sally continues singing, "*We're gonna catch a big one. We're not scared! We're not scared! Look, a cave! A dark, gloomy cave!*" Ryan glances at the bear, then becomes fascinated by light reflected on the wall. He tries to pull himself up against the shelf but fails. Sally sings on: "*We cannot go over it. We cannot go under it. Oh, no, we have to go through it. Oh, what's that?*" Sally pauses for two seconds, and Ryan looks at the bear. Sally raises her tone: "*Big wet nose! Two big furry ears! Big googly eyes! It's bear!*" Ryan looks at Sally, who pretends to scream in fear, "*Ahh!!!*"

Vignette 5.1.2

In front of the same dark cave, Sally holds a small mirror, reflecting light into the cave. She gently shakes the mirror, making the light dance across the toys. Ryan watches intently for 13 seconds, observing the light's movement, then turns to notice the mirror in Sally's hand. His expression changes and he seems puzzled. He starts crawling toward the moving light but

suddenly changes direction, crawls toward Sally with excited babbling "*Huhahh, ahh*", and climbs onto Sally moving towards the mirror in Sally's hand.

The above vignettes offer a glimpse into the *We Are Going on A Bear Hunt* CPW at home. Two problem scenarios are present: the innate problem of how to find the bear in the story regarding how to find the bear (science concepts: bear and bear habitat), and the cave being too dark dramatised by Sally (science concepts: light, light reflection and darkness). Ryan's movements to the song, glances at the bear, attempts to crawl into the cave and exciting grabbing of the bear alongside Sally's singing indicates emerging understanding and engagement with imaginary scenario of hunting for a bear. In vignette 5.1.2, Sally introduces a mirror as a new play object and problem-solving tool. She models the more advanced problem-solving actions by using the mirror to reflect light into the cave, solving the problem of the cave being too dark. Ryan notices the moving light and Sally's actions of reflecting the lights and shaking the mirror. He initially appeared confused before associating the light with the mirror. This aligns with Vygotsky's (1987; 1998) argument that young children perceive actions earlier than objects and are more likely to notice moving objects. Sally's culturally meaningful actions with the mirror and light reflection support Ryan's emerging understandings of mirror's properties. Here, Sally draws on the mirror's affordances (light reflection) and transform it into a cultural object that enables problem-solving within the imaginary scenario. The contrast between concrete sensual experiences of the dark cave and the illuminated cave supports Ryan's enhanced consciousness of the absence and presence of light and thus supporting Ryan's everyday concept of light, reflection, and darkness. Here, Sally does not introduce scientific terms such as "light" or "light reflection". Rather, she sensitively allows Ryan to be present in his moments of wonder and allowing his indulgence in the sensual experiences. This is likely because the light reflection is introduced for the very

first time. Here, the importance of allowing children to be in the moment of concrete sensual experiences is highlighted.

Interview Response 5.2 *Mirror and Shadow play*

Rhea's family also introduce a mirror into play not into CPW settings but as part of their daily bath routine. They further embedded shadow play in their bedtime routine, as described in their post-CPW interview:

Rhea: *... like when we were in the bath, we were using the mirror to reflect the light everywhere. Henry was actually doing it. He noticed it and then was doing it. I would never have thought of giving him a mirror to do that.*

Here, Rhea's comment, "*He noticed it, and then was doing it*", shows that her introduction of the mirror as a play object and her actions of using the mirror to reflect light support Henry to enhance his consciousness of the light-reflecting property of a mirror. Henry is encouraged by Rhea to physically manipulate the mirror, which aligns with Bodrova and Leong's argument that infant-toddlers' physical manipulation and exploration are important in their concrete sensual experiences (Bodrova & Leong, 2006). Henry's increased understanding of the mirror as a cultural object is demonstrated through his actions of using the mirror to create light reflection himself, for Vygotsky (1987, p.184) argues that children "*give meaning to or comprehend the object earlier than the action*", and in return, Henry's meaningful actions around the mirror to reflect light is believed to support him to further enhance his understanding of the unique properties of the mirror as well as the characteristics of light. In addition, Rhea's comment of "*he loves it*" shows that those playful science learning experiences are enjoyable for Henry.

This interview response also showcases a shift in Rhea's belief and practices regarding appropriate play objects and experiences for 9-month-old Henry; for example, she

said, "*I would never have thought of giving him a mirror to do that*", or she would never have thought to create shadows with Henry. This shift enriches Henry's opportunities in his everyday bathing and waking-up routines to engage in concrete science sensual experiences of light reflection and shadow. Everyday routine activities are reframed and turned into opportunities for science engagement.

Interview Response 5.3: *Science is everywhere.*

Interview Response 5.2 illustrates how Rhea reframes routine activities as opportunities to create phenomena with infant-toddlers using cultural objects such as mirrors to generate phenomena of light reflection. However, it does not address phenomena already present in the everyday environment. Therefore, another interview response from Sally is included to demonstrate how families use scientific language to draw infant-toddlers' attention to naturally occurring phenomena.

Researcher: Has participation in the CPW contributed to your home practices? If so, can you give a few examples?

Sally: "*Yes, with different activities we do during the day, like feeding. When I was cooking porridge the other day, I was holding Ryan, and he was looking into the pot. As I was stirring it, it was getting thick. So, I was explaining to him that the heat changes the composition of the oats and the milk so that it becomes a gluey sort of texture. I wouldn't have thought to explain that to him, but you know, he's watching it. I'm like, 'Oh, he's actually really interested in watching this'. Then I started it too, as it was thickening, kept getting the spatula, and showed him how it dropped off the spatula, and it got thicker and thicker. So, he was just watching really intensely as I was doing it. That was quick oats, so it happened really quickly. It was about two to three minutes, And I was just happily holding him, and he was happily watching. So, yeah, like that, it was just like a fun activity. And it was just, you*

know, making breakfast. We have porridge for breakfast every morning, but I'd never thought to pick him up and show them to him."

The phenomena of matter state change in the change of oats are always part of their breakfast cooking routine, and weather changes such as the clouds, wind, and rain are always present in Ryan's environment. However, these phenomena were not made conscious for Ryan. With the educational experiment, Sally develops a scientific orientation, becoming more conscious of science learning opportunities in their everyday routine, enabling her to transform those routine activities into shared science engagement opportunities with Ryan. For example, "*We have porridge for breakfast every morning, but I'd never thought to pick him up and show them to him*." We can also see from this interview that when Sally co-observes the changes in oats, she takes the lead to draw Ryan's attention to the salient features of the changes by providing rich scientific narrative such as "*becomes a gluey sort of texture*", "*it got thicker and thicker*". This aligns with Vygotsky's (1998) argument that adults' words mediated their perception for words "*directs attention to a certain aspect… It automatically analyses what is perceived…*" (p.87). In addition, Sally's comments that "*I was just happily holding him, and he was happily watching. So, yeah, like that, it was just like a fun activity*" show that science learning can be an enjoyable experience for infant-toddlers. According to Vygotsky (1998), this positive affect will support young children's perception of the phenomena they experience and thus support their science concept formation.

<u>Interview response 5.4: *Taking the lead*</u>

Interview Response 5.3 suggests that Sally takes the lead to draw Ryan's attention to the salient features of the phenomena they co-experience. Rhea also highlights this pattern of taking the lead in her reflection in the post-CPW interview.

Rhea: "*...when we went on that bear hunt where we went for that big long walk (Rhea and her partner took Henry for a walk in a park one weekend and turned it into a Bear Hunt imaginary play). Then, we're* ***taking the lead*** *on that to explain how things are, like how the bear lives, where the bear lives, and what he likes to do. But yeah, that is* ***more from us taking the lead than just seeing his reaction***."

Fleer et al. (2024a) also highlights this pattern of taking the lead and generating science interest in infant-toddlers rather than just responding to their science noticing.

Vignette 5.5: *Morning tea picnic with Bear and Bunny*

One previously highlighted pattern is that families reframe routine activities into science moments. The following vignette provides further evidence of this pattern, introducing a different dramatisation strategy in which Rhea transforms their everyday morning tea routine into imaginary play. This play requires the use of knowledge of what bear and bunny eat, that is the *everyday concept of animal diet*.

Rhea: "*OK, Henry, so you can carry the lunchbag. Should we go and find some food for Bunny and Bear? We have a look in the fridge.*" Rhea carries Henry to the fridge while he holds the lunchbag. She opens the fridge and says, "*Oh, we have some lettuce. Shall we take that for Bunny? We put that in here? And we have some rocket leaves, and Bunny will definitely like that. Should we take the rocket?*" Rhea holds the rocket bag in front of Henry and waits for his response. Henry reaches out and Rhea squeezes it into the lunchbag. "*And lettuce?*" She adds that too. "*Now, what does bear like to eat? Nuts, honey, and fruit. And that doesn't go in the fridge. So, it goes this way.*" She moves Henry to the cupboard. "*So, we get a Kiwi?*" Henry reaches for the fruit, and Rhea says, "*Can you put the Kiwi in?*". Henry puts it in his mouth instead, and Rhea laughs: "*Ohh, bit furry the skin…"* "*What else did he like? Honey? ... And we got some nuts. ..."* They gather honey and nuts, and Rhea encourages

Henry to put them in the lunchbag. She zips the lunchbag, and adds, "*And we will just get the blanket. And then we are ready to go for a picnic! It's exciting, isn't it? You're excited about the picnic?*" In the backyard, Rhea sets up the blanket with bunny, teddy bear, water and milk bottles, and the lunchbox for picnic. Rhea offered Henry water, and she suggests: "*Shall we see if the bear would like to have some milk?*" Rhea makes a sound in her mouth, pretending the bear drinks the milk bottle. When Rhea puts the milk bottle down, Henry also puts his water bottle down. Rhea gently shakes the teddy bear and says, "*Thanks, Henry.*" Later, Rhea hands Henry a box of walnuts and suggests, "*Do you want to feed this to a bear?*". Henry observes the box, and Rhea opens the box and pretends to feed the teddy bear with some walnuts.

In her post-CPW interview, Rhea reflected: "*Like the teddy bear picnic, for example, I never would have done that, especially not to such an extent*."

This vignette illustrates how the imaginary play scenario condenses concrete experiences of finding and packing food for different animals (e.g. bear, bunny), providing opportunities for Rhea to share cultural knowledge about animal diets while Henry explores various food. Rhea supports Henry's perception of the concrete imaginary morning tea experience through modelled actions such as picking up food, packing it in the lunchbag, and encouraging Henry to participate by placing food in the bag and feeding the bear. This aligns with Vygotsky (1998), who argues that perception and action are connected for young children, with actions supporting perceptions. Rhea also models and encourages Henry to engage in pretend or as-if actions, such as 'pretending the bear drinks the milk bottle' while Henry drinks his water or pretending to 'feed the bear'. According to Vygotsky (1966), pretend actions use actions as pivots for holding the meaning of certain real actions, which is argued to support Henry's becoming more conscious of the real meanings of those actions. While we do not claim Henry fully understands pretending here, the presence of advanced

pretend actions in the social situation is argued to support his development. In addition, Rhea's words support naming the different kinds of food such as *lettuce*, *socket leaves*, *nuts*, and actions related to the morning tea picnic activity such as pack up food, '*carry*' the lunchbag, '*put the walnut box into*' the lunchbag, '*drink*' water from a water bottle, or *'eat'*, and *'feed'* the bear. These words, combined with actions and cultural objects (e.g., lunchbag, water bottle, milk bottle), form a meaningful scientific narrative for Henry. This scientific narrative, according to Vygotsky (1998), supports Henry's perception moving from the undivided and undifferentiated impression of the whole situation to objects and actions, which support Henry's raised consciousness of the fact that animals eat food and different animals (including human beings) eat different kinds of foods (e.g. bunny eats lettuce, socket leaves; bear eats nuts, honey, milk, kiwi fruits; Henry eats cracker and milk) and thus lead to gradual development of the *everyday concept of animal diet*.

Discussions

This section discusses key findings from the broader existing literature in relation to the two research questions.

6.1 Changes in families' science pedagogy with the support of Fleer's CPW

This study shows that, with the support from the mini-workshops within educational experiment, most participating families developed a scientific orientation and become more conscious of science opportunities in everyday life with infant-toddlers, although the extent of this development varied across families, with some demonstrating more substantial shifts than others. These findings align with Lloyd et al. (2017), who report that their intervention supports families becoming more oriented towards science in interactions with children, and with Fleer et al. (2024b), who find that CPW educational experiments raised educators' scientific consciousness, thereby supporting infant-toddlers' science learning. Families' raised scientific consciousness enables them to seize and create science moments enriching

infant-toddlers' science learning. For example, in Interview Response 5.3, Sally reflects that, with the support of CPW educational experiment, she became more aware of opportunities to use scientific language and intentionally draw Ryan's attention to everyday phenomena, such as clouds, rain, explaining how clouds and rain form. For another example, in Interview Response 5.4, Rhea reflects that she starts to '*take the lead*' to '*explain how things are*' rather than simply responding to infant-toddlers' noticing. This pattern of adults initiating science interests is also noted by Fleer et al. (2024a; 2024b) in centre-based settings. In addition, several families (10/18) also shifted expectations about appropriate play objects and experiences for infant-toddlers. For example, in Interview Response 5.2, Rhea brings in play objects such as a mirror, which she would not normally consider as play objects for infant-toddlers, for Henry to reflect lights. This shift is argued to create enriched developmental conditions at home for infant-toddlers. Fleer et al. (2024b) also identified that under the conditions of CPW educational experiment, educators change their beliefs regarding science experiences and science play resources.

This study also shows that, across many participating families (14/18), everyday routine activities were reframed as enjoyable science experiences for infant-toddlers during the CPW educational experiment, with researcher-led mini-workshops providing conceptual tools and examples that supported this reframing. For example, in Interview Response 5.2, Rhea transforms the bathing routine into an enjoyable light-reflecting mirror play experience for Henry, and she mentioned that Henry enjoyed the experience. For another example, in Interview Response 5.3, Sally starts to seize the science opportunity in their everyday breakfast cooking activity, and she engages Ryan in the fun experience of observing the oats change. Also, in Vignette 5.5, Rhea turns the morning tea activity into imaginary problem-solving using science knowledge. This is something new that this study has discovered. Empirical evidence in existing literature suggests that when adults do not orient

towards science, science possibilities and opportunities could be missed in interactions (Gustavassn et al., 2016). However, it was unclear what happens when adults approach routine activities with a science orientation. This study shows that a science orientation can support adults in reframing routine activities as science engagement opportunities.

6.2 Drawing science potentials out from moments of interactions with infant-toddlers

The following themes illustrate how families, supported by the CPW educational experiment and researcher-facilitated reflection, enacted science-oriented practices in their everyday interactions with infant-toddlers. First, many families (15/18) in this study provided evidence of creating phenomena using cultural objects that provide concrete sensual materials for the formation of science concepts for infant-toddlers. For example, in Vignette 5.1, Sally creates the phenomena of light reflection and movement using the cultural object of mirror. This is supported by several studies that argue the importance of direct contact with phenomena in concrete everyday situations (Klaar & Öhman, 2012; Sikder, 2015) or imaginary situations (e.g. Fleer et al., 2021; Fragkiadaki et al., 2023a) for infant-toddlers' science learning. However, what is new in this study is that it demonstrates how families can enrich infant-toddlers' science experience by creating phenomena using cultural objects, such as mirrors. During direct contact with phenomena or cultural objects, families model exploration and problem-solving actions and encourage infant-toddlers to engage in exploration or problem-solving through their actions. For example, in Vignette 5.5, Rhea not only models how to put various kinds of food into the lunchbag but also encourages Henry to put food into the lunchbag himself. For another example, in Interview Response 5.2, Rhea encourages Henry to reflect light using the mirror himself. This finding aligns with other studies that highlight the importance of adults' modelling of actions in supporting infant-toddlers' engagement in science activities through their own physical exploration or problem-solving actions (e.g. Klaar & Öhman, 2012; Sikder, 2015; Fragkiadaki et al., 2023a, 2023b).

Second, evidence from several families in the dataset demonstrates that carers drew infant-toddlers' attention towards the salient features of the phenomenon through rich and meaningful scientific narratives. For example, in Interview Response 5.3, Sally provides the example of how, with an increased science orientation developed within the CPW educational experiment, she draws Ryan's attention to the detailed features of matter changing processes of oats; for instance, she uses terms like '*thickening*', '*it's getting thicker and thicker*', '*changing composition*', '*gluey texture*', and she shows how it drops off the spatula differently as it gets thicker and thicker. For another example, in Vignette 5.5, we see the meaningful scientific narrative Rhea creates with Henry through lots of naming of different foods and actions of packing up food and feeding bear in the imaginary play scenario to support Ryan's emerging understanding of different animals including people might eat different types of food. The importance of using scientific terms, language, and narratives has been highlighted in several studies (e.g. Sidker, 2015; Lloyd et al., 2017; Fleer et al., 2024a; Fleer et al., 2021). Yet, this study provides a more nuanced understanding of how scientific terms can draw infant-toddlers' attention to salient features of a phenomenon, and how scientific narratives can be created through naming and actions in meaningful concrete and imaginary situations. This study also shows that scientific language was intentionally withheld in some situations by some families in the dataset. For example, when infant-toddlers were engaged in moments of wonder, intense observations of phenomena, or focused exploration with play objects, families tended to allow infant-toddlers to remain in these moments rather than distracting them through talk. In Vignette 5.1, Sally remains quiet and allows Ryan to stay in his moment of wonder of the moving light when a novelty phenomenon is introduced for the child for the first time. This does not contradict with the existing literature regarding the importance of using rich scientific language (Lloyd et al., 2017; Fleer et al., 2024a) because in Interview Response 5.3, Sally shares examples how she

uses rich scientific narratives to draw Ryan's attention to reoccurring phenomena in their everyday life.

Third, evidence from several families also shows that they dramatise routine activities, transforming everyday routine activities into engaging imaginary problem scenarios that require science knowledge for problem-solving. For example, in Vignette 5.5, Rhea turns the everyday morning tea activity into the problem scenario of finding and packing up food for the bear and bunny, and to solve this problem, they need to use their knowledge of what the bear and bunny, like to eat for problem-solving. This strategy of using dramatisation to transform routine activities into fun and playful science-concept-related imaginary play represents a novel contribution of this study, emerging through families' participation in the CPW educational experiment and researcher-supported exploration of imaginary situations.

Conclusion

The findings of this study show that with the imaginary play practices and orientation towards science concepts brought into family institutional settings through Fleer' CPW educational experiment, participating families become more conscious of infants' potential for science concepts and science possibilities in their everyday lives at home. Families raised science pedagogical consciousness support their reframing of daily routine activities (e.g. bathing, morning tea, breakfast cooking) into enjoyable science learning experiences. Three pedagogical practices support families' reframing of everyday moments of interactions into science moments, which include: 1) creating phenomena using cultural objects such as mirrors, 2) drawing infant-toddlers' attention to the salient aspects of the phenomenon through naming and scientific language, and 3) creating imaginary scenarios within the CPW or everyday activity settings and engaging their infant-toddlers in problem-solving actions

that are informed by science concepts. These findings are significant, for the existing literature shows that adults' orientation towards routine tasks or safety issues could lead to missed science opportunities in interactions in educational settings (Gustavassn et al., 2016). However, it was not clear how adults might draw science concepts out from their moments of interactions during routine activities at home. This study fills this gap and provides a nuanced understanding of how caregivers, when supported through the CPW educational experiment, drew out infant-toddlers' potential science concepts by transforming routine activities into science moments. It is argued that this new understanding supports families' confidence in enriching infant-toddlers' science learning and amplifying infant-toddlers' science concept formation at home. The illustrative data presented in this study also provide empirical evidence that, through participation in a CPW educational experiment, adults were supported to create conditions in which science learning can be enjoyable for infant-toddlers, and infant-toddlers can become more conscious of key features of the phenomena they perceive, indicating the realisation of their potential for science concepts. However, given the study's focus on pedagogy, what remains under-explored is how infant-toddlers' potential for particular science concepts is taken up and sustained over time through continuing caregiver support in collaboration with researchers, and whether this leads to increasing consciousness of phenomenon related to specific science concepts. This forms an important focus for another paper.

Statements and Declarations

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Contributions

Suxiang Yu was responsible for data collection, formal analysis, conceptualisation, and both drafting and editing of the manuscript. Marilyn Fleer and Prabhat Rai, as Yu's PhD supervisors, provided supervision of the research

project, including guidance on the selection of methodology and study design, and they also commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Ethics declarations

This study is approved by Monash University Human Research Ethics Committee (Project ID:19788).

Conflict of interest

The authors declare that they have no conflict of interest.

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