



Working paper number 52 –

<https://www.monash.edu/education/research/projects/conceptual-playlab/publications>

This is an article published in the *International Journal of Science Education*

on 30 May 2024, available online:

<https://www.tandfonline.com/doi/full/10.1080/09500693.2024.2354075>

Article DOI: 10.1080/09500693.2024.2354075

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Fleer, M., March, S., & Suryani, A. (2024). Contradictions and roadblocks: a cultural-historical study of educators' beliefs and practices in the teaching of science concepts to infants and toddlers. *International Journal of Science Education*, 1–29.

<https://doi.org/10.1080/09500693.2024.2354075>



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To cite this article: Marilyn Fleer, Sue March & Anne Suryani (30 May 2024): Contradictions and roadblocks: a cultural-historical study of educators' beliefs and practices in the teaching of science concepts to infants and toddlers, International Journal of Science Education, DOI: [10.1080/09500693.2024.2354075](https://doi.org/10.1080/09500693.2024.2354075)

To link to this article: <https://doi.org/10.1080/09500693.2024.2354075>



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Published online: 30 May 2024.



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Contradictions and roadblocks: a cultural-historical study of educators' beliefs and practices in the teaching of science concepts to infants and toddlers

Marilyn Flear , Sue March and Anne Suryani 

School of Educational Psychology and Counselling, Faculty of Education, Monash University, Melbourne, Australia

ABSTRACT

Whilst there is a body of emerging literature related to science education for children aged 3 years and above, less is known about educators' beliefs when planning for the teaching of science concepts to infants and toddlers in group settings. This paper discusses how educators working with children under 18 months of age talk about and plan for the teaching of science concepts. We undertook an educational experiment with 6 educators and 11 infants aged 1.1–2.0 years (mean 1.6 years). An analysis of the digital data of 18.1 h (5.2 h of adult-researcher data; 12.9 h of observations) revealed both roadblocks and contradictions in educators' beliefs and practices when planning for infant and toddler learning of science concepts. Initial contradictions for educators include focusing on activities not concepts, following interests and not introducing science content, and a belief associated with developmental restrictions regarding if science concepts and science resources are relevant/safe for this developmental period. These were genuine blocks in shifting educators' beliefs towards planning for the learning of science concepts. We found under the conditions of an intervention, these roadblocks were resolved, giving more opportunities for infant-toddler engagement in science learning.

ARTICLE HISTORY

Received 16 August 2023
Accepted 5 May 2024

KEYWORDS

Concepts; infants; cultural-historical

Introduction

The problem that this paper seeks to address is centred on educator beliefs and potential roadblocks to teaching science to infants and toddlers, as identified through how they plan for and talk about teaching concepts when preparing and implementing their programmes. As an under-researched area (Klaar & Öhman, 2012; Lloyd et al., 2020; Sikder, 2015; Sikder & Flear, 2015), we were interested to learn more about how educators plan for infant learning of concepts, and how they conceptualise what is an appropriate science concept for this early period of development. We know from the broader

CONTACT Marilyn Flear  marilyn.flear@monash.edu  Faculty of Education, Monash University, Peninsula Campus PO Box 527, Level 3, Building A, McMahons Road, Frankston, Victoria 3199, Australia

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science education literature, that many researchers have oriented their efforts to preschool children (see O'Connor et al., 2021) where arguments about beginning early in science education abound. However, less attention to what educators do and believe about the teaching of science concepts to infants and toddlers is evident in the literature. Yet children under three years of age are in early childhood settings, where educators are charged with designing learning programmes for them too. This appears to be both a research and practice gap, that this paper seeks to contribute to filling.

In this paper, we use the terms teachers and educators interchangeably. In the Australian early childhood education context, teachers refer to staff with a university degree while educators refer to staff with diploma or certificate qualifications. Teacher beliefs are defined as philosophical principles or belief systems that guide teachers' expectations about child behaviour and the decisions they make in their teaching (Vartuli, 1999). These may include beliefs about their knowledge and ability to plan and deliver lessons as well as to address children's questions (Jamil et al., 2018). Teachers' planning and presentation of new curricula and pedagogical approaches are also influenced by how the new practices align with their pre-existing beliefs (Lee & Ginsburg, 2007). These dimensions of teacher beliefs supported how we understood the problem of this paper, where we studied educator beliefs in introducing conceptual learning in science to infants and toddlers.

We begin this paper with an overview of what is known about science education generally in early childhood, specifically for infants and toddlers, followed by the details of our study design and results. We discuss the implications of the findings in relation to cultural-historical theory (Davydov, 2008; Vygotsky, 1987) and address the challenges associated with the delivery of science education programmes for infants and toddlers. We conclude with recommendations for future research and argue that there is a need for understanding the roadblocks faced by educators that we identified through researching teacher beliefs and practices. We also suggest more attention be directed to the genesis of science education, where teachers and educators design science programmes for infants and toddlers.

Early childhood science education: what do we know about educators' beliefs and practices in the teaching of science?

We began our review by examining studies related to the teaching of science in early childhood settings, where we identified research that was focused on the content of science learning by preschool children, such as the nature of science (Akerson et al., 2011), ecology (Allen, 2017), fossils (Borgerding & Raven, 2018), magnetism (Constantinou et al., 2013; Smolleck & Hershberger, 2011), force (Forman, 2010), matter (Krnell et al., 2005), density (Smolleck & Hershberger, 2011), and electricity (Solomonidou & Kakana, 2000). We also found studies that researched the process of concept formation by preschool children across a broad range of concepts, such as emotional connections with a science concept (Fleer, 2013), the imagining of concepts (Fleer, 2019a, b), drawing representation of science concepts (Fragkiadaki & Ravanis, 2015; Fragkiadaki et al., 2019, 2021) and peer and or teacher interactions (Adbo & Carulla, 2020; Pramling & Samuelsson, 2001; Siry et al., 2012; Siry & Max, 2013). However, because we were interested to know about educators' beliefs about the learning of science, we closely examined

the literature and identified in our review those studies related to the pedagogical practices of teaching science concepts and noted that they primarily focused on 5- and 6-year-old children, where we found a broad range of approaches, such as inquiry-based didactic methods (Dejonckheere et al., 2016), planned science activities (Dogru & Seker, 2012), structured hands-on activities with resources (Hadzigeorgiou, 2002; Hannust & Kikas, 2007; Nayfeld et al., 2011; Zacharia et al., 2012), responsive teaching and explicit instruction (Hong & Diamond, 2012), picture story method (Kalogiannakis et al., 2018) with narratives (Peterson, 2009) and drama (Walan & Enochsson, 2019), and the use of precursor models (Kambouri-Danos et al., 2019; Ravanis et al., 2004). With the exception of one study that showed a direct link between teacher philosophy and the richness of science learning by children (Fleer, 2009), the literature on preschool science primarily centred on the learning of concepts by children under the conditions of a specific model or approach. These studies did not look at teacher beliefs in relation to the models or approaches to teaching science to preschool children. We then wondered if and how these practices by educators could be relevant for those designing programmes in science for infants and toddlers. Based on this broad understanding of early childhood science education, we continued with a more focused review of those studies related to science for infants and toddlers to identify what is known about educator beliefs for infants and toddlers in science education.

We initially narrowed down from our previous scoping review of all studies related to early childhood science education (O'Connor et al., 2021), those studies which included children younger than 3 years of age in their sample and then examined what had been published since then. We reviewed each study closely to identify common themes directly related to teaching practices and beliefs about infants and toddlers learning of science. We noted that most studies including our own previous research, tended to focus on older infants and toddlers when studying science education (1.1–2 years). Because we were interested in science concepts for this particular age period, and educators' beliefs and practices when planning for conceptual learning of such young children, we sought to specifically examine each study in relation to enabling and constraining practices and beliefs regarding teaching science concepts. We knew from previous studies more broadly, that this age period is under-researched generally, and has limited professional learning resources when compared with educators who work with children older than 3 years of age (O'Connor et al., 2021). Therefore, we assumed that we would find few studies directly related to teachers' beliefs about the teaching of science concepts to children under 3, but thought we might find some general pedagogical practices and themes associated with planning for the teaching of science.

As expected, there was a limited number of studies into infant and toddler learning of science (Klaar & Öhman, 2012; Lloyd et al., 2020; Sikder, 2015; Sikder & Fleer, 2015). Therefore, we looked more broadly at the context of the studies for specific beliefs and practices that enabled or limited educators focusing on science concept formation.

We were able to identify two major patterns related to the pedagogical practices for supporting the conceptual development of infants and toddlers that were related to educators' practices and beliefs, which we thought could guide our study and better inform our discussion of our results. They were:

1. Contradictions in beliefs and practices associated with the role of the adult in introducing and explaining science concepts
2. Intervention studies where educators are actively encouraged to plan pedagogical practices to support science learning in imaginary play situations

Contradictions in beliefs and practices associated with the role of the adult

All of the studies reviewed showed that science concepts tended to emerge in teaching programmes as part of the everyday concrete practices of educators. We noted everyday life situations where adults were present but with a limited role in developing children's conceptual thinking in science. For instance, Klaar and Öhman (2012) noted in their research the practical and physical meaning-making of toddlers, stating that rather than a conceptual and verbal expression of concepts in everyday practices, toddlers embody them. For example, when encountering a slippery icy slope in their outdoor play, they adjust their actions to solve the problem of the experienced friction. Interacting with nature without educator input is thought to afford the learning of science. Similarly, Sikder (2015) discussed how infant and toddler environments afford possibilities for science learning. But she noted that parents' science conversations took place in everyday situations at home, in the park, and when visiting family and friends. Sikder (2015) named these as *age-related conversations* where parents' explanations about nature featured, such as when gardening, discussing the watering of plants, or noticing and discussing the butterflies in the garden. In the former study by Klaar and Öhman (2012), the teacher was not present in the toddler-child interactions, but in the latter study by Sikder (2015), a parent was physically present. It was noted by Sikder (2015) that the parent's role was not to introduce science concepts but rather to respond to the situation with an explanation. In both kinds of studies, the toddlers' interactions with nature were theorised in relation to the science learning affordances.

We also found in our review everyday interactions at home between infants, toddlers, and parents, which were named as *small science* (Sikder & Fleer, 2015). Small science is a simple scientific narrative that can occur in everyday situations, where moments of scientific explanation could present themselves. Sikder and Fleer (2015, 2018) suggested that a special form of narrative by the adults was identified, and families took account of their child's perspective in relation to everyday practices when supporting their thinking in science-related experiences. Four affordances were conceptualised by Sikder and Fleer (2015): First, there were everyday practices that occurred regularly, such as snack times, which afforded a narrative or science explanation (multiple science opportunities). Second, there were occasional moments, such as mirror play, where it was possible for a parent to name the part of a toddler's body (discrete moments of science). Third, there were embedded situations, such as night and day, which were the natural routine of living in the world. Fourth, there were also counterintuitive moments, such as observing a sunset, where what was observed could not be understood without a scientific explanation.

The key role of the educator in the imaginary situation for supporting conceptual learning in science was reported by Fleer (2024) and Yonzon et al. (2023). Their studies showed a series of pedagogical practices that were important for supporting

scientific concept formation in imaginary situations. Named by Fleer (2024) as a *Conceptual PlayWorld for infants-toddlers*, educators planned an imaginary situation through reading a children's book, designed an imaginary space where the infants and their teachers jumped into the imaginary story, and met problems that they solved using science. The infants co-experienced the science concept with their teachers as part of the role-play. Unique to infants and toddlers were the use of props to support the imaginary situations (Yonzon et al., 2023) and the intentional teaching of the science concept to build content that could be embodied and expressed through role-play (Fleer, 2024). In these two studies, teachers' beliefs about their role in the imaginary situations were deemed pivotal in supporting responsiveness to infants in their learning of science concepts.

We also noted in our review other contradictions in teachers' beliefs about their role. For instance, whilst Gustavsson et al. (2016) observed challenges in following a child's lead for children older than three years, they noted that for toddlers, the teachers tended to focus more on including everyone in the imaginary play activity, rather than exploring the science possibilities. They showed how teachers invite toddlers into the activity by playing alongside them. Teacher belief in the *inclusion of all* was deemed to be the goal in the play activities, rather than the learning of specific science concepts. The focus on doing the activity, rather than learning the science has been challenged by Sikder and Fleer (2015), who brought forward the significance of the adult in making conscious the science concepts for infants and toddlers in everyday life experiences. They found that parents considered the toddler's perspective by engaging in special kinds of science-informed conversations with them during imaginary play and in everyday life. These studies give attention to the key role educators play in drawing attention to science concepts in play and everyday life, but only when educators believe they have a role to support concept formation.

Most of the studies reviewed showed that infants and toddlers have opportunities to develop early forms of the scientific method. Whilst a scientific method can be conceptualised as science process skills, scientific practices, or scientific reasoning skills, in the literature longstanding researchers have also identified scientific reasoning, scientific discovery, and scientific thinking, across a broad set of studies (Zimmerman, 2000). Scientific reasoning of infants and young children has been the focus of Goddu and Gopnik (2022) who theorised that there are scientific reasoning synergies between the infant and the expert scientist when engaged in a scientific process because they both 'fundamentally involve identifying and manipulating causally relevant variables and observing the changes that result (or do not) in a surmised effect variable' (p. 312). However, we found for infants and toddlers the studies identified many different forms and ways in that teachers conceptualised a systematisation of an exploration of a phenomenon by such young children – reflecting teachers' beliefs in relation to how they introduce or support a systematic exploration. For instance, Fragkiadaki et al. (2023) showed how an educator supported the early learning of the scientific method through a systematic exploration of the concept of sound through placing different objects on a drum and observing vibration. The scientific method was modelled by the educator, with early forms of trial testing of different objects' sound waves on the surface of the drum. The educators' actions were intentional and systematic in relation to introducing the concept of sound to infants and toddlers, and the infants and toddlers in turn co-

explored with their educator different vibrations. Similarly, Lloyd et al. (2020) noted in their *stay and play sessions* with parents and teachers that they could also engage in early forms of the scientific method. Their approach focused on the preparation of specific prompts and questions to support families to engage in scientific talk and explore with their toddlers floating and sinking, the properties of materials, force in the playground, and living things through exploring plants. It was through these *stay and play* sessions that an early form of the scientific method was being prompted, and toddlers had opportunities to engage with the science concepts of materials and their properties, living things, and force. In contrast to the teacher planned and prompted sessions for supporting early forms of the scientific method (Lloyd et al., 2020; Fragkiadaki et al., 2021, 2024), Klaar and Öhman (2012) noted that everyday interactions in the playground between toddlers with no teacher present gave opportunities for developing early forms of scientific exploration. Through a detailed case study of a toddler (22 months) playing in the outdoor area, they brought forward how toddlers' practical actions changed in the processes of everyday problem situations. They argued that learning becomes evident when there is an extension of the practical actions, such as when making adjustments in their actions when trying to walk up a muddy slope. Klaar and Öhman (2012) argue that toddlers do not make verbal conceptualisations of natural phenomena, but their actions and adjustments in problem situations, show they are making meaning in science, and these actions could also constitute early forms of the scientific method. When taken together the scientific method for infants and toddlers was variously described as early forms of trial testing that were modelled by educators (Fragkiadaki et al., 2023), or simply as observed and analysed by educators in the iteratively changing practical actions of toddlers in the processes of everyday problem-solving situations (Klaar & Öhman, 2012). Although there were few studies on what educators believed might be a scientific method for infants and toddlers, we expected in our study that educators would have different beliefs and practices about their role when planning a scientific method for infants and toddlers to support science learning.

What these studies collectively highlight is the variability in adult practices and educator beliefs about their role in introducing concepts or a scientific method to infants and toddlers with some believing the environment alone will afford the learning of science concepts or give rise to a systematic scientific approach, whilst others create narratives, explanations and play situations in support of science learning.

Intervention studies where educators are actively encouraged to plan pedagogical practices to support science learning in imaginary play situations

We identified a group of intervention studies into the learning of science concepts by infants and toddlers where teachers were encouraged to develop imaginary situations to support the imagining of the science concept. The studies collectively showed a set of specific pedagogical characteristics and beliefs that helped infants and toddlers in science learning. A key finding across these studies was teachers' beliefs in the importance of using props for supporting infant and toddler learning of concepts. For example, Yonzon et al. (2023) were able to show how educators used a series of differentiated props to support the development of imaginary situations in which science learning of concepts could be supported. The props acted as important placeholders for the

science concept and also the imaginary situations gave contextual and playful actions for the children. They found that over time, the educators transitioned the infants and toddlers from using props as placeholders for science meaning (concept), to using props as pivots to support a special scientific narrative related to the concept. In a related study, Fleer (2024) found that the teachers iteratively created conditions in their centre for infants and toddlers to build a relationship with a science concept through including books, props, and posters into the centre. The study showed how a toy snake in the jungle (part of the story being read) was role-played, and this brought forward the need to learn about the characteristics of the snake – so that the infants and toddlers could find the toy and imagine a snake in their play environment. The study also found that science was always conceptually accessible when introduced through a prop, such as a snake.

We also found studies that featured imagination and showed how teachers of infants and toddlers supported a sense of togetherness, learning to work as a collective in support of science concept formation. This was deemed as an important practice that was planned for and actively discussed with the researchers, suggesting teachers' beliefs in supporting collective learning in science with infants and toddlers. For instance, Fragkiadaki et al. (2021) identified that the imaginary situation of a storybook gave a collective orientation towards common imaginings of the science concept, which then supported a sense of collective action in solving a scientific problem. The imaginary situations took the form of a collective orientation to the specific science concept, exploration in pairs, and whole group action. The collective orientation to the science concept supported a sustained action within one session and over time. Teachers' practices supported an imaginary situation that gave the possibilities for revisiting the science concept, deepening the scientific understanding of the concept, and using the science concept in embodied play. Like Yonzon et al. (2023), this practice in turn supported a shift from physical objects and towards a shared intellectual and abstract space for exploring science concepts.

Consistent with Sikder and Fleer (2015), Fragkiadaki et al. (2023) identified in their study that teachers of infants and toddlers were consistently using scientific language, introducing relevant analogies to intentionally make science visible, and bringing forward in everyday practices science learning opportunities when in an educational experiment of researchers and teachers planning STEM programmes together. Both the prop and the science concept were considered in the practices of the educators (e.g. drum/sound). The latter was also noted in the study by Fleer (2024), where the use of a prop, such as a toy snake was iteratively explored in relation to an early form of an ecosystem – the structural characteristics of the snake in relation to how it moved, where it lived, and what it ate. This research showed how educators' beliefs can and do intentionally support infants and toddlers build a relationship with a scientific concept and make consciousness of the concept in both the traditional areas of the centre (e.g. reading couch) and through imaginary situations in play (e.g. looking for snakes in an imaginary jungle).

Collectively, these intervention studies show how imaginary play as a valued practice tradition in early childhood, was used by educators to plan and implement the learning of science, where teachers actively created conditions in which props could act as pivots in support of a special scientific narrative related to the concept, and play enabled a

collective orientation towards common imaginings of the science concept. Both pedagogical practices emerged because educators had a strong belief in play and the use of objects to support infant and toddler learning of science concepts.

When all the studies of infants and toddlers learning of scientific concepts are considered, they show two broad themes where educators' beliefs and practices shape if and how infants and toddlers learn science concepts. One theme is associated with the variability in beliefs related to the role of the educator in teaching science concepts to infants and toddlers. The other theme is associated with intervention studies that support educators in bringing the learning of science concepts into infant and toddler play. Knowing more about educators' beliefs about the teaching of science to infants and toddlers has the potential to inform what is an under-researched area in science education. Other than Sikder and Fleer (2015), we could not find studies that explicitly researched beliefs in relation to the teaching of science concepts to infants and toddlers, or what might be the enabling practices or roadblocks in beliefs for the planning and teaching of science to such young children. It seems we only know a small amount about the beliefs and practices of educators in supporting the learning of science in early childhood settings, and knowing more about potential roadblocks and enablers could better support educators generally with teaching science to infants and toddlers. The study reported in this paper seeks to contribute to filling this gap.

Study design

The overarching research questions of our study were:

1. What are educators' beliefs about teaching science concepts to infants and toddlers?
2. What are the contradictions and the roadblocks associated with planning and teaching of science concepts to infants and toddlers?

To study these, we set up an educational experiment with the intervention of a Conceptual PlayWorld in which we examined how educators planned for the teaching of science concepts for infants and toddlers, how they talked about what would be a science concept relevant for this early period of development, and how their beliefs and practices changed through being involved in an educational experiment.

An educational experiment

An educational experiment is a collaboration between researchers and teachers interested in solving a theoretical problem, not just a problem of practice (Hedegaard, 2008). Our theoretical problem was centred on the focus of our study but presented through the shared activity (educators and researchers) of planning and implementing a programme to support infant and toddler learning of scientific concepts. This meant explicitly discussing educators' beliefs about what are the science concepts to be taught to infants and toddlers and what are the pedagogical practices that enable this to happen.

Guided by previous extensive experience in educational experiments, we introduced the intervention of a Conceptual PlayWorld to the educators. Based on prior research with preschool children (Fleer, 2019a, b), a Conceptual PlayWorld has been shown to

create motivating conditions for the learning of science in play-based settings. But we did not know much about how a Conceptual PlayWorld as an intervention would enable the teaching and learning of science concepts for infants and toddlers.

There are 5 characteristics of the model that have been shown to support the learning of preschool children: (1) Selecting a children's book with a dramatic storyline or the potential to create drama that will engage children in wanting to help the characters from the storybook; (2) Designing an imaginary play space, where children jump into the story and become the characters solving problems; (3) Planning a routine for entry and exit into the imaginary situation of the story; (4) Introducing a scientific problem that the children will be motivated to solve so that the science concepts become personally meaningful; and (5) Teachers become players with all the children in the same imaginary situation solving the problem. We add to these 3 more characteristics that were found relevant for infant-toddler learning of science (Fleer, 2024). They were:

- *Planning for building knowledge as play content to resource infant and toddler imagining and role play.* When infants know more, they have more to draw on and use when pretending to be a character.
- *Planning role development is graduated over time.* Role development is from self, to self as a player, to self as co-experiencing 'as if' imaginary play.
- *Planning transitions from the real world to the imaginary world before the problem in the Conceptual PlayWorld is introduced.* Establishing routines related to entering and exiting imaginary play situations supports infants with being oriented towards collective imagining.

Theory guiding the study

The intervention of a Conceptual PlayWorld and an educational experiment are both informed by cultural-historical theory (Vygotsky, 1987). This theory foregrounds the person and the practice of social relations as the source of a child's development. Two guiding and interrelated concepts framed our cultural-historical study design: Davydov's (2008) concept of a core concept, and Mariane Hedegaard's conception of a double move (Hedegaard & Chaiklin, 2005). The former is focused on how a concept is culturally developed, and the latter is oriented to how a concept guides the beliefs and practices of teachers to support conceptual learning in social practice.

Core concept: To understand teachers' beliefs about the teaching of science concepts, we had to consider the historical need for the formulation of the concept, if educators were to determine how infants could build a relationship with the concept to guide their actions (Fleer, 2024). Davydov (2008) has argued that to achieve an understanding of a core concept, we need to understand that concepts are historically developed in response to human needs, and they become culturally formulated as valued societal knowledge to help the human condition, such as learning about microscopic organism as foundational for wound care, or how to stay safe using basic physics in the playground as part of playground design. It is in this context that specific subject domains, like science, develop. Understanding that subject-matter content in science has its roots in the historical development of societies and is formulated as a specific form of knowledge

to solve human needs is theoretically complex. In our educational experiment, we had to consider how historically formulated subject-matter could become personally meaningful for infants. That is, the researchers and educators had to conceptualise what might be the authentic problem to be solved by the infants, in lieu of historically formulated human needs in which the development of the concept emerged. To create these conditions in relation to the scientific concept, such as an ecosystem, a personally meaningful context of the narrative was needed in the educational experiment. As will be shown later, in our study the educators chose the storybook of *The March of the Ants* for designing imaginary play situations. This gave a common practice context and narrative in which researchers and teachers planned, and which infants and educators experienced as an early form of an ecosystem in their imaginary play.

Double move: The motives that sit under an early childhood educator's planned activities are hidden from the infants. To bring out the concept in the practice, Hedegaard and Chaiklin (2005) have shown in their *double move approach to instruction* for school-age children, that the general relations in a core model bring forward both 'the children's ways of formulating questions and their interests in the specific substance of the activities' (p. 71). They suggest that in a dual conception of person and practice. This is consistent with what we learned from Sikder and Fleer (2015). Hedegaard and Chaiklin (2005) suggest that teachers are expected:

1. To analyse the subject-matter so that the teaching is based on a core model of the central concept relations of the subject-matter area,
2. To have knowledge of the children's interests and background,
3. To create tasks and problems, so that the core concepts are illuminated (p. 71).

Hedegaard and Chaiklin (2005) have suggested that in this formulation and use of core models:

The teaching objective in this phase is to support children to formulate their own core models. The teacher can guide this appropriation by presenting the pupils with key examples and tasks where oppositions and conflicts between phenomena are accentuated, thereby accentuating core relations (p.76).

In our educational experiment, the researchers and educators worked together to explore the core concept of an ecosystem, but also the teaching practices that could enable conceptual learning in science by infants and toddlers. It was through dialogue that we expected educator beliefs would emerge and where potential roadblocks for the teaching of science could be explicitly discussed. While infants and toddlers are unlikely to develop a core model of a concept, the Conceptual PlayWorld with its narrative of the phenomenon and orientation to science concepts, gave a way to enable teachers to systematically plan (Jamil et al., 2018) for the development of children's early learning of aspects of a scientific concept. This provided a rich context in which teachers' beliefs about what informs their practices (Vartuli, 1999) could be realised and expressed as part of the planning sessions. We expected that this would also bring forward potential contradictions and roadblocks (Lee & Ginsburg, 2007), but also enablers for realising meaningful and relevant science education programmes for infants and toddlers.

Sample

Six educators participated in our educational experiment, and pseudonym names were utilised in this study. Karen is the room leader with 35 years of teaching experience. She has a Diploma of Children's Services and has a European heritage background. Mya has just completed her Diploma of Early Childhood and is a fluent speaker of Mandarin and English. She has 4 years of experience and has a Chinese heritage background. Four other educators work part-time in the infant room and have Bosnian, Bangladeshi, and European heritage backgrounds. The two main educators, Karen and Mya, had previously participated in the planning of a Conceptual PlayWorld for toddlers.

Eleven infants aged 1.1-2.0 years with a mean of 1.6 years participated in the study. Six boys and 5 girls with diverse cultural heritage backgrounds (4 Australian-Chinese, 2 Australian-Colombian, 1 Australian-Indonesian, 1 Australian-Irish, 1 Australian-Indian, 1 Australian-European, and 1 Australian-Thai).

Procedure

Three periods of data collection framed the procedure.

Period 1: The educational experiment was established as a joint collaboration, and the theoretical problem of how to plan for science teaching/concepts was discussed with the educators, and the teaching was planned as an intervention. To support this, the researchers implemented a one-hour session of supported planning of the 5 characteristics of a Conceptual PlayWorld through Zoom (see [Figure 2](#) below). In this planning session, the researchers and Karen (educator) planned a Conceptual PlayWorld using the children's book *The March of the Ants* by Ursula Dubosarsky and Toby Riddle (2021). The researchers supported the educators planning by circling back and forth between the concept to be taught (with information) and the authentic problem for the children to solve. This brought out educators' beliefs about the relevance of what might be a scientific concept for infants and what might be the imaginary play situations to design and resource with support from the researchers. The session was digitally recorded.

Period 2: Educators implemented the planned intervention over 10 sessions (3 weeks). The planned Conceptual PlayWorld sessions were recorded digitally, and at regular intervals, the researchers made suggestions as well as asked educators to reflect on the surprises, challenges, and curiosities they had. These questions gave possibilities for understanding educators' beliefs. The educators were interviewed in situ at the end or the beginning of their planned science activity. All interviews were recorded, and field notes were documented.

Period 3: In the post-implementation, the educators attended a 2-hour reflection session where they shared their implemented plans and practices and discussed explicitly their beliefs about the teaching of science concepts to infants and toddlers. This session was digitally recorded. A post-semi-structured interview of 1-hour was also undertaken.

Data collection

Digital video recordings of teaching practices: Two cameras were used to record a total of 8.4 h of educators' practices over ten sessions. One camera was on a tripod gathering data on the whole room. The second hand-held camera followed the educators and the infants

during the implementation of their planned Conceptual PlayWorld of The March of the Ants.

Digital video-recorded interviews: A total of 3.2 h of interviews were conducted. Audio files were extracted and the post-interviews were transcribed.

Digital video recorded educators-researchers planning sessions: A total of 2 h of digital video data resulted.

This resulted in a total of 18.10 h of digital video data.

Analysis

The analysis followed a 4-step process that is theoretically in line with Hedegaard's (2008) cultural-historical analysis. *First*, all digital files were placed into folders for a particular recorded session. Each folder had separate folders for planning documents, photos, transcribed interviews, and digital videos.

Second, each digital folder of videos was logged in relation to the camera, the context, the length of the digital recording, the time and date, and who was recording the session. This was accompanied with summaries of the content of that particular video, as is shown in (see Figure 1).

Third, the data were then iteratively viewed, and digital files were copied and cut into video clips of practices associated with the focus of the research and placed into discrete folders of video clips and labelled, such as, the particular science concepts being discussed, the planning for the teaching of the concepts, the educators' comfort with the concepts, and the educators' beliefs about planning for and evaluating the conceptual learning of infants and toddlers. Patterns across digital folders were noted.

Fourth, the data were then examined in relation to the research questions, and a summary set of data was prepared according to the categories that emerged in the third step of the analysis. The summaries were formed in relation to the categories that emerged from the literature review that were directly related to teacher beliefs

MCFC 2022 Room 2 (infants) CPW											
		Total minutes of data		771		Notes: Entries in red are on-the-spot interviews recorded during CPW implementation included here for context (minutes are not included in CPW data count). They are recorded in Planning and					
		Total hours of data		12.9							
		Total minutes of		593							
		Total hours of filming		9.8							
APD interview starts 8m30s into clip. Interview lasts 1m30s.											
85	MC069 H4 ni	20221208	8/12/22	2.20-4.30pm	1	Y	VX1-5	Handheld	Sue	Sue	Discussed P being focussed on real world of ants.
CPW DAY 9											
87	MC070 T1	20221209	9/12/22	2.20-4.30pm	21	Y	GHS - 1	Tripod	Sue	Sue	Tripod was set up to record afternoon tea then moved to observe the CPW, but K decided to go with the children's spontaneous play and to explore outside (she was very tired after the PD at EB) the previous evening. Handheld camera observed afternoon tea from a different angle near the display table as there had been changes.
89	MC071 T2	20221209	9/12/22	2.20-4.30pm	21	Y	GHS - 1	Tripod	Sue	Sue	
90	MC072 H1	20221209	9/12/22	2.20-4.30pm	5	N	VX1-5	Handheld	Sue	Sue	I began filming afternoon tea that was already in progress. K said she had rearranged the posters after taking them to the PD yesterday. She had put the story posters from the book in the display table area, along with some books about ants and the rubber and pipe-cleaner ants. K said that just moving things around in the room renewed the children's interest as much as introducing new things.
91	MC073 H2	20221209	9/12/22	2.20-4.30pm	23	N	VX1-5	Handheld	Sue	Sue	After finishing afternoon tea, P went to the display table and brought a pipe-cleaner ant to the afternoon tea table where the other children were still eating. She put it on the floor. K linked it to the ants marching and P looked down on it as she does the real ants outside. K gave her a piece of watermelon from afternoon tea to feed the ant. P took it and the ant to the display table and tried to feed the ants. K came and swapped the real watermelon for toy fruit (wiping P hands) and named each fruit as P pretended to feed the model ants. Other children joined in. P expressed excitement when she saw the A is for Ant book. K sat down and read it to P. A and O discussing the images on each page, and engaged with the children's interests (e.g. in the badges she wears on her cardigan). P later went to the door and K decided they could all go outside and look for ants. https://docs.google.com/document/d/1nEnc80p6Hoe0G5aGdMh0v8Tn1n1erLFFhkgavv0NksdI7uacqsham_link
92	MC074 H3	20221209	9/12/22	2.20-4.30pm	23	N	VX1-5	Handheld	Sue	Sue	P ran out first to the area by the steps, joined by O. They looked in the usual places for ants and squealed and pointed when they saw one. K emphasised to be careful not to step on them. Z pointed out an ant he had found, and they went to look. K said she was amazed he was so young but had still identified an ant by himself. M came and said she had found ant holes in another area of the yard and they went to look at these, then by the shed. (One child from another room joined – W – no consent, but mostly filmed from the back or avoided). When we came back, M was with other children at the slide and the children ran off. K talked to camera about how she was amazed at P's keen interest in the ants.

Figure 1. Snapshot of a video log.

(e.g. the role of the educator), as well as roadblocks and enablers in planning and teaching of science concepts to infants and toddlers. Changes in educators' beliefs over time were also tagged. The resulting data sets were then examined further in relation to two cultural-historical concepts guiding the study – Davydov's (2008) concept of a core concept, and Mariane Hedegaard's conception of a double move (Hedegaard & Chaiklin, 2005). These concepts supported us to better understand and theorise how educators who work with infants and toddlers, formulate their beliefs about planning for the learning of scientific concepts, and also how they deal with any contradictions in their beliefs and practices when implementing science learning for this early period of development.

Results

In this paper, we primarily present examples from the planning session (Period 1) and the post-implementation interviews (Period 3) between Karen (educator), Ruth (researcher), and Sophie (researcher) to illustrate the findings. Specifically, we draw on typical as well as contextual data taken from across the three periods of the study. We draw two major conclusions from the results. First, and not surprisingly, educator beliefs presented through how they talked about planning for the science learning of infants and toddlers dramatically changed between periods 1 and 3. Second, the teaching practices of introducing science concepts to infants brought forward a series of ideological roadblocks that were hidden in the first period, but through implementation of their planned science programme (Period 2), surfaced explicitly and were strongly critiqued by the educators from an evidence-informed position in Period 3.

1. What are educators' beliefs about teaching science concepts to infants and toddlers?

We begin the presentation of the results with its focus on the beliefs and practices of educators by showcasing how educators talked about the relevance of teaching science to infants and toddlers in Period 1, where their initial struggles with formulating what might be a science concept appropriate for infants dominated their planning. This is followed by details of Period 3, where educators formulated a core concept (Davydov, 2008) in relation to an authentic problem that was meaningful to infants and toddlers. The challenge of talking about what is a science concept appropriate for infants and toddlers, foregrounded teacher beliefs and highlighted contradictions. Some of these had previously been identified in the literature as related to their role, such as planning activities and not explaining concepts, or observing children and responding, rather than planning to orient children to science concepts.

How educators talked about the relevance of teaching science to infants and toddlers

Period 1: In the first period, Karen initially questioned the relevance of STEM for infants:

Karen: We wouldn't normally be thinking about STEM and babies. Where is it going? We are so used to having an endpoint in mind.

Ruth: What's the end?

Karen: You know when you plan things, you set out a goal. But with this, because as you say it's research, it's new. We are doing stuff with children, that we would not normally do. We wouldn't be thinking of STEM and babies. We would be going, 'No that's for when they are older'. So it felt a bit awkward. We had to go and sit with the book (*The March of the Ants*). Mya did the same. We had to feel comfortable with the book. As educators, we rush to the doing. But we have got to slow down.

Being part of the educational experiment gave time to consider beliefs and practices associated with teaching science to infants and toddlers, where expectations that science is not for babies emerged ('No that's for when they are older'). To challenge this belief, we brought into the discussion a model of teaching (Conceptual PlayWorld for infants) with a particular concept (living things) to discuss as part of a core concept of an ecosystem. A planning template with a focus on an ecosystem was introduced by Ruth through Zoom as shown in [Figure 2](#).

Ruth: We would like you to stick with the template. We can share the screen and look at the template together. Sophie, can you highlight the concept (on the shared Zoom – see [Figure 2](#) Conceptual PlayWorld proforma)?

Ruth: So that's the concept we put right up front. Whilst it is sort of a science concept, and it might seem a bit too abstract and heavy for infants and toddlers, we were thinking about, 'What would that look like in the everyday experience of the infants and toddlers?'

Karen hesitates, pulls her head back, and appears shocked at the suggestion of the concept being presented and highlighted above the table in the first part of the proforma. Sophie and Ruth notice the hesitancy of Karen, and Sophie jumps in to give some practical examples as a contribution to exploring what a concept of an ecosystem might look like in practice in Karen's centre.

Sophie: The parts of the ant's body. Being an ant. So now that you have said they [infants] are closer to 1, we have to think about how that [highlighted concept in proforma] would work, but we would imagine they would be thinking about being an ant, having antennae, having 6 legs, what's it like to have 6 legs. Living in a colony. We think for that age, the idea of a home is really engaging ...

[Enthusiastically,

Karen responds]:

Ruth continues:

Because there is a whole bunch of stuff we want them to have exposure to, so how can we make that exciting for them to notice, or to imagine ... a Conceptual PlayWorld is how can we create motivating conditions for children.

[Karen repeats and writes in her notebook]:

How can we motivate children?

Ruth opens up a discussion on learning a particular science concept (ecosystem), even though Karen's non-verbal expression appears to signal a belief that questions the relevance of an ecosystem for infants (appears shocked), suggesting that the learning of complex science is not appropriate for infants. However, the concept is then discussed in relation to working out how to create motivating conditions for infants learning about the ecosystem of an ant. This is consistent with those studies that showed that it

Planning a Conceptual PlayWorld in STEM

Five Characteristics of a Conceptual PlayWorld to support imaginary play and Science, Technology, Engineering and Mathematics (STEM) thinking and learning

Concept: Living things - 1. Ants have an important role in the ecosystem, e.g. in breaking down matter into smaller parts and recycling nutrients back into the ecosystem 2. Ants have basic needs such as food, water and shelter (they live in nests and colonies).

Pedagogical characteristics & planned practices	Conceptual PlayWorld in action	Planning ideas & notes
<p>Selecting a story for the Conceptual PlayWorld</p> <p>Story: The March of the Ants</p>	<ul style="list-style-type: none"> This story is about a team of ants and the important roles they play. It brings forward the concept of Living things (ants' role in the ecosystem, ants have basic needs such as food, shelter) Develop the drama in the story e.g. going on an expedition, with all of the different ant characters. They have a long way to march. Did you know that 	<ul style="list-style-type: none">

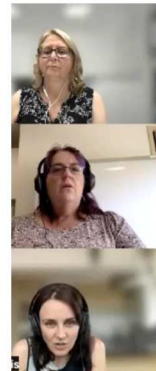


Figure 2. An educational experiment – being introduced to the intervention via a Conceptual PlayWorld planning proforma.

was important for toddlers to build a relationship with aspects of a science concept (Fleer, 2024). At this point, teachers' beliefs about relevance begin to slightly change when the concept is made more concrete, as was shown when Karen becomes engaged with the concept of anatomy through imagining the programme in action (Fleer et al., 2021). A co-sharing of practice and concepts emerges and comes to fruition when there is a discussion about the physical structure of the ants, their habitat, and their food source.

We suggest that teacher beliefs about the relevance of teaching science to infants and toddlers could be seen through how the educators narrowed down the core concept of an ecosystem into the structure of the organism – as seen when Karen and the researchers discussed focusing on the anatomy of an ant.

As was also identified by Yonzon et al. (2023), the educators in our study considered the relevance of a science programme for infants in relation to the appropriateness of resources and how they could make the science programme more concrete for infants and toddlers. But as is shown in the segment below, educators' beliefs about relevant resources for infants and toddlers were problematic because of their beliefs about infant development (Figure 3).



Figure 3. How to represent mandible action to infants.

- Ruth: So really thinking about the anatomy of an ant. Do you think they may like looking at some posters do you think?
- Karen: Definitely! We are really into things like that, because we have done that with the birds. Looking at insects is so amazing. ... Posters are really great for the children to return to things. **I have got to find a big ant.**
- Ruth/Sophie: We can help with the resources.
- Karen: I have got some little ants. Like all of my life-size plastic ants. **But they are no use to babies ...**

Karen's limited view about resourcing was focused on the longstanding belief in early childhood that educators cannot give small objects to infants and toddlers, because they will choke, and this belief emerges when she says, 'But they [ant models] are no use to babies ...' However, Ruth pushes the idea of the anatomy further, by introducing new content and the language of anatomy as a way of enriching and challenging Karen's thinking and beliefs about the use of props:

- Ruth: Sophie and I were also interested to find out about their jaws. That's really important when thinking about the anatomy of the mouth. How they eat. Because that is part of their decomposition. So even though you won't be talking about decomposition to the children, but just starting to think about what sort of things will expose them to that. Just the beginnings of it.
- Sophie: ... jaws or mandibles are sort of a scissor action. They go sideways. Would they imitate that? Would they pick things up like that?
- Karen: Yes, you could do that. Oh, do you know what I just realised? We have got these tongs we use to pick things up from the floor, that you can open sideways.

As the discussions between educators and researchers converge in relation to ant anatomy and mandible action, we found solutions to representing mandible action are brought forward, as Karen linked the content of the concept being discussed with the way infants could engage with the ideas through symbolic forms of the mandible action. The educators and researchers imagine new kinds of pedagogical practices for different aspects of the science concept through gestures (Fleer et al., 2021), and in the example above, the use of a model of the special kind of action of a set of tongs. This is in keeping with previous research in infant-toddler learning of concepts in concrete situations (Fleer, 2024; Sikder, 2015; Yonzon et al., 2023), and where props are important for supporting the transition from the object to the science concept. The discussion about the props is reflective of teachers' beliefs about using science resources to support infant and toddler learning (see further below, Figures 4–6), but also it surfaces restrictions on what props are developmentally appropriate for infants and toddlers.

Period 3: In Period 3 after implementing a Conceptual PlayWorld on The March of the Ants, educators' beliefs about the teaching of a science concept to infants, such as an ecosystem, were discussed quite differently:

- Karen: Well, we started looking at the concept that we were going to teach which was ants and their ecosystem and their anatomy and the foods they eat ... (MC T1 post int Karen 20221214 GH5-1 P1022230)



Figure 4. Metal ants.



Figure 5. Rubber ant.



Figure 6. Pipe cleaner ants.

The educators' beliefs about the relevance of teaching science were no longer their focus. Rather, we found that the educators spoke authoritatively about the concepts (ants, their ecosystem, anatomy, and the foods they eat), as well as how to plan for the teaching of

science concepts. For instance, Mya determined that they needed to break down the concept into its essence:

Mya: We need to break them down [the concept] into tiny ones, like we start from little, and as they grow [their understandings] they can gain more relevant knowledge. Just like starting from little things ... gain that concept, we can build on ... little by little. I think that's the thing we did to make it work (MC T4 post int Mya 20221214 GH5-1 P1022233).

Breaking down the concept into its essence is in keeping with the idea of small science introduced by Sikder and Fleer (2015). Educators developed new ways of planning, where they identified that they needed to research the concept. For example, with increased knowledge, the educators modified their practice when implementing the co-designed programme, as Mya explains:

Mya: It's like maybe like get prepared like do a lot of background information research, but like starting from little like and also always to use reflective practice and to see what worked what didn't work and then kind of modify your plan, and it's doable, yeah. (MC T4 post int Mya 20221214 GH5-1 P1022233).

Our study found that the educators' beliefs about the relevance of teaching science to infants changed through their research. We also saw how they came to embrace what were the big ideas in science surrounding an ecosystem (Zangori et al., 2020).

Mya: Because like, children [are] still young ... like they need to learn ... maybe how things work how like you know, it's co-living things like we human and other living creatures like we should have that concept, so it's a good point. Like we start from tiny little things and then we can introduce other creatures as well (MC T4 post int Mya 20221214 GH5-1 P1022233).

Mya in conceptualising the big idea of an ecosystem, showed how the concept sat within valued forms of societal knowledge, but also this showed that she now held a belief that it was relevant for infants and toddlers.

In summary, we found a positive shift between Period 1 and Period 3 in educators' beliefs and practices about the relevance of teaching science concepts to infants. We determined this through how they talked differently about a concept such as an ecosystem. In the first period, the educators (and the researchers) initially found it difficult to imagine the essence of the concept or its relevance to infant-toddler's everyday practices. But as both Mya and Karen illustrated in Period 3, the universal big idea of the system (co-living) was considered at the same time as planning the practice context that was more individual (ants). This was where the idea of 'tiny concepts' (e.g. the structure of the ant) emerged and this has synergy with previous research (Sikder & Fleer, 2015), and research where the role of an adult was deemed critical for making conscious conceptual learning (Fragkiadaki et al., 2024). We suggest that educator beliefs moved from a focus on relevance to deep thinking about planning for concepts where Mya and Karen appeared to theorise that it was through the universal big idea (ecosystem) and the individual tiny science concepts (ant anatomy), that a relational system of concepts was forming in the practice of teaching science using the storybook of *March of the Ants*.

2. What are the contradictions and the roadblocks associated with planning and teaching of science concepts to infants and toddlers?

The study also found that educators held beliefs that appeared to be roadblocks to the teaching of science to infants and toddlers, and which seemed to prevent them from even considering planning for the learning of science concepts. They were:

- Beliefs about developmental restrictions associated when using science props
- Traditional beliefs about planning an interest-led programme narrowed the content of the programme
- No expectations for infants to learn STEM concepts in early childhood education

Beliefs about developmental restrictions associated when using science props

In Period 2 Karen had to think differently about the props she was providing. As discussed above, initially she found it difficult to find appropriate materials to support the science programme being implemented:

Karen: Well, it was really interesting because it's very easy with older children I suppose to think about resources or think about things that you can use. A bit more challenging with babies.

Karen suggested that there is an expectation that because infants will put things in their mouths, as their developmental approach to experiencing materials, providing small resources (which most ant models were found to be) would be unsafe:

Karen: I thought that would become a big issue because it's a thing that babies do which is mouth. They mouth things.

Karen found a large metal ant in a gardening centre which she gave access to under supervision. Karen eventually found a soft ant that could be mouthed. However, it did not have the anatomical features of small ants (Figure 7) that she later introduced. She introduced pipe cleaner ants to support play and the exploration of the legs (Figure 6). Whilst the pipe cleaner and small plastic ants initially worried her, she found the infants did not mouth the pipe cleaner ants or swallow the small ants:

Karen: They're allowed to mouth the other ones (Figure 5), but they don't mouth the little pipe cleaner ones (Figure 6), and they were really curious to watch them being made. Which I found really interesting. Was that they were very, very interested and brought, you know, accepted that they were ants, even though they may not look perfect, it's the child can imagine better than we, and they don't need it to be perfect. They just need it to be enough to give them that, that imaginative, imaginative sort of option (MC022 H1 int 20221129 Ebony S1170001).

The educators' beliefs on child development (resources suitable for infants) were challenged in the practice of providing materials that traditionally are deemed to be unsafe. This finding has not been previously discussed in the literature, yet it is important for knowing how to introduce objects as transitions (Yonzon et al., 2023) into practices of science teaching of infants and toddlers.

Traditional beliefs about planning an interest-led programme narrowed the content of the programme



Figure 7. Small plastic ants.

Child-led programmes feature in the literature for older children (Lewis et al., 2019; Sikder, 2015). This also emerged in our study of infant-toddler learning of science. We found that both educators identified that they held different beliefs to the profession about how to conceptualise what ‘interest’ actually meant in an interest-based programme. The educators both discussed how interest-led programmes in early childhood education become the vehicle for the content. But through the educational experiment, where science concepts were featured, the Conceptual PlayWorld became the vehicle for the science content, and they found that the infants became oriented to the concepts because of their interest in the ants. As Karen explains:

Karen: ... the interest is just the vehicle to the knowledge of whatever that knowledge may be, and so in a way, it's like the PlayWorld is, it's the vehicle to the knowledge. Cause when it's not about 'do they like ants?' It's about learning about an ant as a creature to then develop a love or respect, a value for it, and so we're using a book or we're using songs, or we're using implements or tools or resources, but it's really the knowledge that we're teaching and that can be anything and its STEM-based (MC022 H1 int 20221129 Ebony S1170001).

A shift in the educators' beliefs about an interest-based programme to planning a STEM programme to generate interest and motivate infants to science was reported. This is supportive of research which shows that interest-led programmes for preschool children limit science learning possibilities (see Gustavsson et al., 2016), but shows how blocks towards reciprocity between concept and child could emerge because of a belief of simply following whatever science could be afforded through the environment (Klaar & Öhman, 2012), rather than a planned introduction of science concepts for infants and toddlers (Fleer, 2024; Yonzon et al., 2023).

No expectations for infants to learn STEM concepts in early childhood education

Overwhelmingly, both Karen and Mya identified through the educational experiment that the profession held low expectations of infants. Their views were changed because of the focus on science concepts for infants.

Karen: Yeah, we expect more. We teach more, we teach deeper sort of concepts because we understand that children will be interested in those deep concepts, and we have higher expectations for the babies than previously (MC T1 post int Karen 20221214 GH5-1 P1022230).

Taken together, the educators identified that their traditional beliefs on child development with a correspondingly low, or no expectation of learning science concepts, and the dominant practice of following children's interests, had been challenged. Traditional views on child development as expressed in this section, were deemed to be significant roadblocks to the teaching of science to infants and this gives greater insight into why some teachers do not plan for the teaching of science concepts to infants and toddlers (Klaar & Öhman, 2012) or do not extend the conceptual learning associated with a science narrative (Sikder, 2015).

Discussion

Our educational experiment sought to study teacher beliefs and practices and to determine if there were contradictions or roadblocks when planning a science programme for infants and toddlers. We found that by participating in our educational experiment with the intervention of a Conceptual PlayWorld, where educators discussed the relevance of science concepts for infants and toddlers (Figure 8, category 1), this brought forward a set of child development contradictions, that had to be resolved before the science problem could be solved (see Figure 8 category 2). The contradictions were more ideological than pedagogical. We found a belief in an interest-led programme (Lewis et al., 2019), no expectation that infants could learn science concepts, foregrounding the activity rather than the concept (Klaar & Öhman, 2012), and developmental considerations when bringing science props into the teaching. It was during the implementation of the science programme, that the contradictions were resolved and new beliefs and practices about the nature of infant learning emerged (Figure 8, category 3). In contrast to the literature, in the post-implementation interviews, we found higher expectations of infant learning, greater insights into teacher planning for the teaching of science concepts, and a new perspective on infant development that changed teachers' practices.

These findings presented in Figure 8 show the resolution of the contradictions and thereby extend what we learned from the literature regarding teacher beliefs and their associated practices in supporting infants' and toddlers' learning of science concepts. However, we were curious about the enablers and motivated conditions for the change in teacher beliefs between Periods 1 and 3. We found through the educational experiment, that the educators came with a deep knowledge of the infants they were planning programmes for, and the researchers brought to the planning process a new demand of introducing a sophisticated concept of an ecosystem to infants. Neither the researchers nor the educators initially knew how to solve the problem of the relevance of science

concepts for infants and toddlers, as was evident when Ruth read out the concept populated in the planning proforma, to which Karen rightly responded with a look of shock and disbelief (later confirmed in the post-implementation interviews):

Concept: Living things – 1. Ants have an important role in the ecosystem, e.g., in breaking down matter into similar parts and recycling nutrients back into the ecosystem. 2. Ants have basic needs such as food, water, and shelter (they live in nests and colonies).

Ruth opened up the theoretical problem (Figure 8, category 1) further by inviting Karen to consider what might be the motivating conditions for learning the concept. Under the agreed banner of research where the solution is not yet known, Karen immediately scribed the question of ‘what are the motivated conditions’ as ‘motivating children’, whilst Sophie provided practice examples of an authentic problem to bring forward what the motivated conditions might look like in practice for infants: ‘... they would be thinking about being an ant, having antennae, having 6 legs, what’s it like to have 6 legs. Living in a colony. We think for that age, the idea of a home is really engaging ...’

In keeping with Vygotsky’s (1987) conception of everyday and scientific concepts, Hedegaard (2008) has argued that the development of children’s relations to the world has to be seen as a cultural rather than a natural process. The cultural activities of schooling bring forward the development of motives and competences through specific subject-matter learning, such as science (Hedegaard & Chaiklin, 2005). In our study, we had to find the ways of creating new motivating conditions for infants to become oriented to

Theoretical problem:

- # What do we mean by a science concept?
- # What is an authentic problem to motivate infants to learn science concepts?

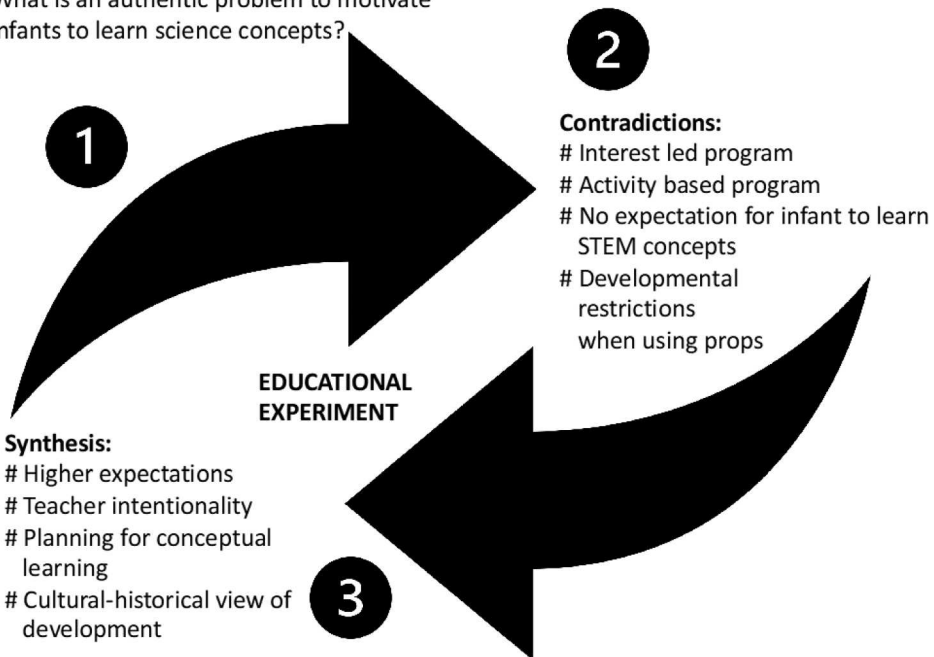


Figure 8. An educational experiment of infants learning science concepts in group settings.

scientific concepts through an authentic and meaningful problem, and this challenged the educators' beliefs and practices. Collectively the educators and researchers had to conceptualise the concept (theoretical knowledge) and the teaching activity together, in order to bring out the core relations (structure, habitat food source) within the subject area (Hedegaard & Chaiklin, 2005) of the ecosystem of the ant. This was deemed different from a practice problem of how to teach a science concept to infants. Theoretical knowledge and thinking are determined more broadly as a move from 'motive orientation and interest to theoretical concepts and back to qualify their interest and develop their learning motive' (Hedegaard, 2020, p. 55). This formulation was foundational for the essence of the theoretical problem of our educational experiment that Karen, Ruth, and Sophie were engaging in when considering the relevance of teaching and learning of science concepts by infants.

But to understand the change in teacher beliefs from Period 1 to Period 3, we determined that the essence of the concept of an ecosystem had to be conceptualised for infants in a way that was personally meaningful. But to do this, the educators and researchers had to first understand the core concept themselves and consider it in relation to the cognitive load being placed on infants. Broad definitions of the concept were provided in the planning proforma (Living things: Ants have an important role in the ecosystem). In the science education literature, we knew that the essence of an ecosystem brings forward a relational system (Zangori et al., 2020) that depends on concepts of animals and plants, food sources, photosynthesis, decay, matter, conservation of matter, and energy transfer. Longstanding studies collectively show that young children take an egocentric view through anthropocentric or human-centred reasoning and only when older do they understand a broader system and relationship model of an ecosystem (Almeida et al., 2013; Leach et al., 1995). Whilst young children think in terms of individual organisms such as pets and zoo animals, older students consider more broadly populations of organisms in the wild. Interdependence within an ecosystem is directional, such as caring for an individual pet in the case of young children, whilst older children have the capacity to manipulate food chains and food webs (Allen, 2017; Leach et al., 1996). Yet no research in relation to teaching an ecosystem has been undertaken with infants and toddlers, and therefore the researchers and the educators were on new ground when discussing if the teaching ecosystem was relevant. For a change in educator beliefs, the educational experiment had to consider what might be the core relational elements of an ecosystem relevant for infants and toddlers where an authentic problem could motivate the needed conceptual learning. This brought forward the relevance of the concept for infants and toddlers, and introduced the idea of *leading concepts* (Mya called *little things*) which were relationally explored by infants with their educators through an authentic problem from the storybook of *The March of the Ants* (*How to care for the baby ants? Where do they live? How do they eat?*). This had the potential to support leading concepts becoming personally meaningful.

Based on the previous literature with preschool children (Fleer, 2019a, b), we expected that when the teachers implemented their planned programme, the infants and toddlers would want to help the characters solve the problem in the imaginary play situations. When several *leading concepts* are each explored through personally meaningful problems under the motivated conditions of the drama of the story (e.g. caring for the baby ants, how to feed the baby ants, where they live), it was found to develop a

motive orientation to the core concept, as was explained by Karen ‘looking for ... the places where ants live’.

In the post-implementation interviews, we noted how finding the motivating conditions helped solve the problem of the relevance of learning science concepts for infants and toddlers. This in turn meant that Karen and Mya were able to identify and dismiss their original beliefs that were roadblocks or restrictions in prop use due to child development expectations of infants mouthing them, low expectations in learning science concepts, science not something considered relevant for infants, and a belief in an interest-led programme where educators responded rather than actively introduced content to lead learning and development.

Conclusion

Learning in science does not just begin in school. Educators work in diverse settings, such as early childhood settings, where infants also experience science education programmes. But there is such a dearth of studies in science for this age period (Klaar & Öhman, 2012; Lloyd et al., 2020; Sikder, 2015; Sikder & Fleer, 2015), and few focus on the nature of the infant learning science concepts in group settings (Fleer, 2024; Fragkiadaki et al., 2021, 2023; Lloyd et al., 2020; Sikder & Fleer, 2015; Yonzon et al., 2023) or study the beliefs and practices of educators in relation to enablers or constrainers of opportunities for learning science concepts by infants and toddlers. We contribute to filling this gap through the results of our educational experiment. Like Gustavsson et al. (2016) we also found that educators originally believed that during the infancy period, the focus is on the activity, rather than on conceptual learning. However, our research showed that through the educational experiment, the educators changed their practices from planning activities to planning for the infants’ conceptual learning which we suggest is a change in teacher beliefs about the relevance of teaching science to infants and toddlers. We also noted that whilst Gustavsson et al. (2016) found problems in planning science learning in interest-led programmes for preschool-aged children, this was also initially a stumbling block for the educators in our study working with infants. An interest-led programme was shown through the post-implementation interviews in our study to have originally limited, rather than enriched, the learning experiences of the infants. This adds to the research of Gustavsson et al. (2016) by showing that the challenges of interest-led programmes for science learning are also relevant to infant programmes.

While Gustavsson et al. (2016) found problems with activity-based science programmes for infants because the focus was primarily on including infants rather than considering the science learning possibilities by the educators, our study showed why this might be the case. We identified that originally, the educators had low expectations of the infants and were surprised in the post-implementation how much conceptual learning of science could be achieved under the motivating conditions they created. In addition, our research identified that educators originally did not consider science concepts relevant for infants (‘We wouldn’t normally be thinking about STEM and babies’), and this helps explain why in studies that focus on the possibilities of science affordance, they do not find adults drawing on the opportunities for science teaching (Sikder, 2015) but rather believe their role to respond to situations without explanation (Klaar & Öhman, 2012; Sikder, 2015). In contrast to these studies, there are other studies of

infants and toddlers learning science as a result of interventions, such as the *stay and play* programme reported by Lloyd et al. (2020), and those studies also used an intervention to bring forward more science teaching in imaginary play situations (Fragkiadaki et al., 2021, 2024). Our research is consistent with the studies that show the possibilities of teaching science. But what our study adds to these studies, is what are the struggles or contradictions faced by the educators when shifting from a *response pedagogy* to *planning* for infant conceptual learning in science. The contradictions of low expectations, interest-led programmes, activity-based pedagogy, and a developmental view of the restricted use of science props, are all genuine blocks in shifting towards planning for the learning of science concepts by infants and toddlers.

The study reported in this paper contributes to a better understanding of a key educational setting that has had limited research attention, and where the unique developmental nature of the infant learner and the educator's role in planning for the learning of science concepts has not been well understood. However, further studies are needed that go beyond an intervention in one setting with 6 educators and 11 infants (1.1–2.0 years). Further research would give more confidence in the applicability of the results for other educators who work with infants and toddlers. Importantly, using other methods and approaches when studying teachers' beliefs and practices associated with the learning of science concepts by infants and toddlers could give different results. We recognise that an educational experiment with an intervention of a Conceptual Play-World gives guided support to educators, and whilst it appears to break the low expectations of learning concepts for the earliest educational period in a child's life trajectory, most educators are expected to plan for the learning of science concepts on their own. We further suggest that educational experiments such as the one described in this paper, could support a genuine change in teacher beliefs and practices to enable rich learning of science for our very youngest citizens – infants and toddlers.

Acknowledgments

Special thanks to the teachers who engaged in an educational experiment, with support from the Conceptual PlayLab team (Dr Rebecca Lewis).

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This paper is funded by the Australian Research Council FL180100161 Scheme.

Ethical approval

Ethics approval and permission were granted by the Human Ethics Committee of Monash university, and the Victorian Department of Education, Ethics approval number: 19778. Consent for images and words of children and adults was given.

ORCID

Marilyn Fleer  <http://orcid.org/0000-0002-1224-5510>

Anne Suryani  <http://orcid.org/0000-0002-5338-2052>

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