Science Concept Formation During Infancy, Toddlerhood, and Early Childhood: Developing a Scientific Motive Over Time

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Abstract
A substantial number of empirical studies in the field of Early Childhood Science Education have explored science concept formation in early childhood educational settings. Most of these studies focus on the process of science concept formation during a teaching intervention or a school year period. However, less is known about how children form science concepts over the first years of their lives. This longitudinal study aimed at studying the process of science concept formation during the first five years of children’s life within educational settings. Following a cultural–historical approach, the study explored how children develop a science motive from infancy, toddlerhood, and into early childhood and how teachers create the conditions for the development of a motive orientation towards science over time. A cohort of 50 children in Australia participated in the study. Indicative case examples are presented. The research design drew on the Conceptual PlayWorld model, a collective form of practice for learning and development through imagination and play. Digital visual methods were used for data collection and analysis. The findings illustrated that a science motive is developed when the motive of play and the motive of learning in science are dialectically interrelated over time. It was also shown that teachers create a motive orientation towards science by introducing, maintaining, and transforming an ideal form of science in the children’s environment and by stimulating children to interact with mature forms of science. The study concludes with insights into early childhood science education research methodology, and implications that inform practice are discussed.

Keywords science · concept formation · motives · infants · toddlers · preschoolers · early childhood
Science Concept Formation in Early Childhood

Empirical research in young children’s engagement, learning, and development about the natural and technical world has a long history. The vast literature in the field covers a wide range of points of interest. Firstly, there has been a focus on exploring children’s ideas, representations, (pre-)conceptions about natural phenomena such as thermal phenomena, optical phenomena, properties of matter, phenomena associated with electricity and solar energy, and meteorological phenomena (e.g. Christidou et al., 2009; Fragkiadaki et al., 2019, 2021; O’Connor et al., 2021; Saçkes et al., 2010). What we have learned from these studies is that from the very early beginning of their lives, children form multiple and complex understandings about the surrounding natural and technical world based on their everyday experiences across diverse institutional settings such as family, community, and educational settings. These understandings might complement or may even be contradictory to each other and may or may not be compatible with the scientific models depending on the form of the child’s experience in science. Several studies have also suggested teaching interventions and pedagogical practices that advance science learning and promote conceptual change during the early years (e.g. Kähler, Hahn & Köller, 2020; Solomon & Johnson, 2000; Vosniadou et al., 2001). These studies identify educational frameworks that promote early scientific literacy and support young learners in starting to think systematically about science concepts and phenomena by developing basic science methodology skills such as making predictions, confirming or not their predictions through observations, inquires and experimentations, and coming to conclusions. Many studies have also examined the critical role of the teacher and the importance of child’s and adult’s interactions during science learning in early childhood settings (e.g. Fleer, 2009; Gustavsson & Pramling, 2014; MacDonald et al., 2020; Siry, 2013; Vellopoulou & Papandreou, 2019). This type of study informs us about the significance of creating a rich in opportunities environment where children and teachers can learn and explore science together. In an environment like that, teacher’s mediational role, participatory practices and play-based learning approaches that involve teacher engagement are foregrounded. Special attention is also given in the literature to the communication and discursive practices used by the teachers during science activities (e.g. Fridberg et al., 2019, 2020; Siry et al., 2012; Vartiainen & Kumpulainen, 2020). These studies have highlighted the dynamics of using an expansive science-related language, introducing precise and sufficient terms, crafting science narratives as well as incorporating these aspects of language into daily communications with children to promote science understandings. The context and factors that affect and promote young children’s scientific thinking such as multimodality, emerging technologies, material tools and objects, books, and accompanying talks, the affective and enactive aspects of science learning have also extensively been explored (e.g. Fragkiadaki & Ravanis, 2021; Fridberg et al., 2018; Hadzigeorgiou, 2001; Hansson et al., 2020; Vartiainen & Kumpulainen, 2020).

As Sundberg, Areljung, and Ottander (2019) argued, multidimensional science education in preschools that includes dimensions such as fantasy, play, embodiment, empathy, aesthetic modes of expression, and storytelling does have the potential to advance early childhood science education.

By reviewing the relevant literature, two main points are revealed. First, despite the extensive corpus of literature about how preschoolers engage, learn, and develop in science, limited knowledge is gained for children under the age of three. This is surprising given that recent ground-breaking research shows that science begins in infancy and infants and toddlers are capable and active learners in science (Byrne et al., 2016; Fleer et al.,...
What is important in this body of research is the shifting of focus from what infants cannot do in science to what they can do. Taken together, the evidence from the studies in the field suggests that science concept formation and systematic science learning start in life as early as infancy (O’Connor et al., 2021). Everyday experiences such as household routines and real-life interactions such as child—parent interactions are the initial source of a child’s early formation of science concepts and conscious realization of the world (Sikder, 2015; Sikder & Fleer, 2014, 2018). As Siry and Max (2013) point out, from the very early years children have the capacity to ‘conduct investigations, explain their observations and plan new investigations’ (p. 899). Basic scientific methodological skills such as integrating information and drawing conclusions (Keil, 2011) or forming abstract and causal structures (Gopnik, Meltzoff and Kuhl; Gopnik & Wellman, 2012) can be developed early allowing the child to systematically explore and make sense of the surrounding world. Inquiry-based learning requirements, such as wondering, experimenting, gathering evidence, and using evidence to draw conclusions can also be achieved during infancy (Byrne et al., 2016). As Dueschl et al. (2007) highlight, even pre-verbal children can form basic reasoning as they engaged with science. The existing literature in the field gives us an insight into the multiple and significant capabilities of young learners in science. However, more research has to be done to explore what teaching and learning science in early infancy looks like in everyday educational practice and what science concepts can be taught in infants’ classrooms. The second point in reviewing the literature is that most of the studies unpack science concept formation in different cultural age periods but do not explore the process of science concept formation over time as the child makes transitions from infancy to toddlerhood, and then into the early childhood period. It is noted here that the cultural age of the child is a cultural—historical conception that captures and understands development in dialectical interrelation to societal values, institutional practices, and the developmental conditions these values and practices create. This is different from biological conceptions of human development which attribute the age of the child to predetermined biological stages (Hedegaard, 2019). The current body of studies provides us a wide and deep empirical and evidence-based understanding of the process of science learning, the intellectual outcomes of this process, as well as the context within which this process occurs (O’Connor et al., 2021). What is absent in the broader literature is how science concepts are formed and supported across different cultural age periods within early childhood educational settings. The transitions children make in their science experience as they move from one classroom to the other, the new practices and demands that they face, and the personal pathways they shape as learners in science are yet to be studied, interpreted, and understood.

Given the dearth of research, this paper seeks to explore how children develop a science motive across infancy, toddlerhood, and early childhood and how teachers create the conditions for the development of a motive orientation towards science over time. The paper begins by introducing the cultural–historical concepts of science motive and science motive orientation and the interrelated concepts of real and ideal forms of scientific development. This is followed by an illustration of the methodological choices that determined the study. Empirical data were collected during the implementation of Conceptual PlayWorlds (CPWs) (Fleer, 2017, 2018, 2019), that is, a play-based model for conceptual learning through play and imagination. The process of generating and gathering the visual data in one early childhood centre in Australia is presented in detail. A discussion of how the dialectical–interactive method (Hedegaard, 2012) was used for the data analysis
then follows. The findings revealed that a science motive is developed when the motive of play and the motive of learning in science are dialectically interrelated over time. It was also shown that teachers create a motive orientation towards science by early introductions, actively sustaining, and gradually transforming an ideal form of science in the children’s environment and by consistently stimulating children to interact with mature forms of science concepts. The paper concludes with insights into how the findings can advance a research methodology for studying conceptual development in science over time and with a discussion of how the findings can be translated into educational praxis.

The Development of a Science Motive and Science Orientation

Following a holistic perspective on researching children’s development Hedegaard (2008, 2014) offers an analytic heuristic that shows ‘action in activities are nested within institutional practices which are influenced by broader cultural expectations and traditions’ (p. 188). Central to this framework is the concept of motives and demands. Motives here are not seen as located in the person or social situation, they are culturally and socially determined (Hedegaard, 2002). It can be analytically discerned ‘in particular substantive relations in which persons are engaged’ (Chaiklin, 2012, p. 209). From a cultural–historical perspective, motives develop through participation in institutional practices. Hedegaard highlights the dialectical relation between the person and their environment. Institutional practices with their objectives create demands on children and thus shape/influence children’s actions. Demands are conceptualized here as the conditions that the child faces and the expectations they are called to meet as part of their participation in specific situations such as activity settings. What is important to note is that demands are placed upon the child by the institutional practices but, at the same, the child puts new demands on the activity setting and the individuals they participate with. Negotiations between institutional demands and a child’s initial motives lead to changes in motive orientation or ground for the development/expression of new motives. In line with this conceptualization, a science motive is the dynamic relationship between the child and social and cultural practices related to science concept formation and science learning. A science motive reflects what is personally meaningful and important for a child as they experience and interact with the surrounding natural and technical world as well as the child’s interest in scientific explorations and understandings. Gomes and Fleer (2019) have also defined science motive as the child's interest and engagement in learning science concepts. They argue that during the early years a science motive can be developed in the child’s play and support science concept formation. The young child develops a science motive through participation in science-based activities (e.g. experimentations) or science-related and science-oriented everyday practices (e.g. hanging cloths to the airer to dry or washing hands to remove microbes) at or across institutional settings such as home or early childhood settings. Respectively, a science motive orientation reflects the child’s science motive in a specific situation such as a science-based activity or a science-oriented/science-related activity. It indicates that as the child participates within the activity becomes oriented towards developing science competence. The child’s science motive orientation is expressed through the child’s intentions and positioning with the activity setting, the child’s understanding of the demands of the activity setting as well as the new demands the child puts on the other participants and the relations they develops with them. Hedegaard’s dialectical interactive approach offers analytical tools, especially the concept of activity setting that helps to unpack dynamic
negotiations that happen as children develop new motives/motive orientations. To make the dynamic process of children’s learning and development visible it is necessary to analyse ‘person’s (child’s) motive orientation and her demands on others when participating in activities in actual settings that may be analysed in relation to the demands directed at them’ (Hedegaard, 2014, p.194).

Vygotsky (1994) theorized the role of environment in children’s development not in an objective fashion but in a relative yardstick based on the given stage of child’s development. This theorization is further developed by highlighting the dialectical interrelation between the real and the ideal forms of development. The end result of the developmental process, i.e. ideal form or mature/developed form of the practice, exists in the child’s environment and creates demands on the child’s motives of engagement from the very beginning. The ideal form thus offers a model that can be achieved at the end of the developmental process, to offer a singular trajectory of development where this ideal form which is available from the very first step of development and is in ‘direct reciprocal action with the child’s first steps along the road of development of this rudimentary or primary form’ (Vygotsky, 1994, p. 349). The real forms of development are conceptualized as the current or actual level of a child’s development at the beginning of a developmental process. The concepts of real and ideal forms are described and used by Vygotsky (1994) as a unit, that is, as being in constant relation with each other. This dialectical relationship between the ideal and real form is critical as the environment from the very beginning influences, orients, and guides the developmental process, and acts as a source of development rather than merely a setting or context.

Also critical to the interpretation of the empirical data presented in the present study has been the concept of collectiveness. Collectiveness is conceptualized here ‘as the essence of young children being aware of, joining in, participating in, and contributing to an activity setting in a way that reflects shared meanings and understandings, constantly negotiated and converging intentions and motives as well as commonly accepted rules and roles’ (Authors, in press). The importance of the early introduction and the emergence of a sense of collectiveness in group cultures within early childhood settings has been widely highlighted in the field (Avgitidou, 2001; Fleer, 2013, Fleer, 2010; Goulart & Roth, 2006, 2010; Verba, 1994). Evidence shows children’s agency to be involved within group culture from the cultural age of infancy (Howes & Phillipsen, 1992; Shin, 2010). In the context of the present study, we drew upon the concept of collectiveness, expressed as collective character, collective aspects of the science experience, and/or collective intellectual space. In line with Hedegaard’s (2002) conceptualization about the social character of motives, we argue that the development of a science motive and a science motive orientation within early childhood educational settings can be more systematically studied and understood when seen in dialectical interrelation with the diverse forms of collective science experiences the child experiences within the settings.

The concepts of motives, ideal and real form, and the concept of collectiveness are central in the present study as analytical tools to theorize how teachers create motive orientation in the CPW for science learning in early childhood settings. CPW offers an ideal form of practice that can dialectically engage with children’s primary ways of functioning (real forms) and offers the opportunity for teachers to create demands of science learning in the imaginary situation. Within this framework, we formed the following research questions:

1. How do children develop a science motive across infancy, toddlerhood, and early childhood?
2. How do early childhood teachers create the conditions for the development of a motive orientation towards science over time?

**Methodological Framework**

**Study Design**

As an educational experiment (Hedegaard, 2008), the study was a collaboration between teachers and researchers. A group of teachers was followed over ten weeks as they created the motivating conditions for the formation of science concepts in different classrooms of one early childhood centre in Australia. The teachers were supported by the research team for implementing CPWs (Fleer, 2017, 2018, 2019). CPW is a play-based model for conceptual learning through play and imagination. The model involves five key characteristics: (a) selecting a story that engages children and introduces a problem situation regarding a concept or a set of concepts, (b) designing a space to allow children to explore the concepts in different ways, (c) entering and exiting the imaginary space creating collective experiences, (d) planning several inquiries, based on the stories plot, to form the concepts and (e) planning teacher’s role as they join the imaginary space to support children in concept formation.

To explore a set of science concepts, the teachers along with the researchers firstly created a CPW based on the children’s book *Possum in the House* written by Jensen. The plot of the story is about a possum (an indigenous Australian mammal) that entered a house and caused mischiefs such as creating loud noises. A problem situation emerged; how to get the possum out of the house? A wide range of science concepts related to the possum’s biological nature was introduced: (a) *external biological characteristics* (i.e. fur, marsupial), (b) *heredity* (i.e. same external characteristics), (c) *basic biological needs* (i.e. nutrition, self-protection), and (d) *conditions of living* (i.e. habitat, nocturnal living). Additional science concepts such as sound (i.e. diverse materials produce different types of sound) were also explored.

As a longitudinal study, the teachers and the children were followed one year after the first implementation for an additional period of five weeks. At this phase, the teachers along with the researchers implemented a CPW based on the children’s book ‘*We’re going on a bear hunt*’ written by Rosen. The story describes the experiences of a family as they go through several sites and locations such as a river or a forest in search of a bear. A problem situation emerges; how to walk through these sites and locations? A wide range of science concepts was introduced. The concepts were the (a) *biological external characteristic of a plant and a bear*, (b) *plants’ circle of life*, (c) *hibernation*, (d) *ecosystem*, (e) *floating and sinking*, and (f) *light and shadow*. Science concepts were approached differently in each classroom based on children’s interests and cultural age.

**Participants and Data Collection**

In the overall study, we follow 130 children from 4 childcare centres in Australia. In this paper datasets generated within one centre are presented. The empirical data generated in the centre was the first complete data set collected among the centres and thus analysed in this preliminary study. For evidence related to the infancy data of 13 infants, 8 girls and 5 boys, and 1 teacher are analysed. The teacher had a Certificate qualification and up to 5
years of teaching experience. The infants were aged between 0.5 (6 months) and 2 years with a mean age of 1.2 (1 year and 3 months). For evidence related to the toddlerhood data of 20 toddlers, 11 girls and 9 boys, and 1 teacher are analysed. The toddlers were aged between 1.7 (1 year 9 months) and 2.7 (2 years 8 months) years with a mean age of 2.1 (2 years and 1 month). The teacher had a Diploma qualification and up to 5 years of teaching experience. For evidence related to early childhood data of 17 preschoolers, 7 girls and 10 boys, and 1 teacher are analysed. The preschoolers were aged between 3.9 (3 years 11 months) and 5.1 (5 years 2 months) with a mean age of 4.5 (4 years and 6 months). The teacher had a degree qualification and 11 to 20 years of teaching experience. For evidence related to early childhood data of 17 preschoolers, 7 girls and 10 boys, and 1 teacher are analysed. The preschoolers were aged between 3.9 (3 years 11 months) and 5.1 (5 years 2 months) with a mean age of 4.5 (4 years and 6 months). The teacher had a degree qualification and 11 to 20 years of teaching experience. From the total of the 50 children from the centre that participated in the current study, the cohort of the children from the infants’ classroom was additionally followed during the following school year to map the children’s personal trajectories in science over time. Data from the longitudinal case study of one child from the infants’ room in the combination of cross-sectional data of the larger longitudinal data set from infant’s, toddlers’, and preschoolers’ rooms are illustrated in the present study. The focused child was named with the pseudonym Megan. Based on a longitudinal design (Cohen et al., 2017), the development of Megan’s science motive was documented and studied over time through two waves of empirical data. As an infant, Megan was followed at the age of 1 year and 2 months. Turning into a toddler the following year, Megan was followed at the age of 2 years and 3 months. The longitudinal nature of the study provided us an insight into Megan’s personalized pathway in science during the first two years of her school life. Based on a cross-sectional design (Cohen et al., 2017), data sets from the three different cultural age groups within the centre were also documented and analysed. The diverse way teachers created motivating conditions for the development of an orientation towards science during infancy, toddlerhood, and early childhood was studied. The cross-sectional nature of the study gave us a better understanding of the interrelation between the institutional demands, the cultural age of the children and the development of a science motive. Combining these two types of empirical data was critical for the holistic and meaningful analysis of both the dynamic and transforming nature of science motives as well as the diverse pedagogical qualities and the unique conditions that allow and promote the development of a science motive orientation. Visual methods were used for digital data collection and analysis. Empirical qualitative data arose from the video recordings during the implementation of the Conceptual PlayWorlds in each classroom. The visual data captured children’s imaginary play within the Conceptual PlayWorld. The data were used for the analysis of the process of science concepts formation and the development of science motives by the children. The data collection process was held by the research team and research assistants. Cameras were placed strategically in each classroom with one camera on a tripod to capture the main activities in the main area of the classroom. Another camera in each classroom was hand-held and followed the children more closely as they engaged with each other and with the educators within the Conceptual PlayWorlds. A total of approximately 30.65 hours of digital video observations were collected during the first (2019) and the second (2020) year of the study from all the cultural age groups of children in the centre. The following table (Table 1) illustrates the total time of video data collected each year of the study from each cultural age group and the focus child. It is noted that due to the pandemic restrictions and the following suspension of research in Victorian early childhood centres during 2020, the total length of data collected in the second year of the study is shorter than the first year.

Digital video data collection was chosen as it captures, apart from children’s narratives, additional dynamic aspects of children’s play such as gestures, body positioning, and movements. Digital data collection enabled the researchers to continuously revisit and deepen
their interpretation of the empirical data sets. Field notes, detailed logs, and research protocols were prepared after each data collection visit. Ethics approval was granted from Monash University Human Ethics Committee and the Victorian Department of Education and Training. Parents’ voluntary and informed consent was given to video-record children’s participation within the CPWs and the data to be used for scholarly purposes. Parents and teachers were encouraged to explain to the children that photos and videos of them will be taken while they are playing so we can learn more about how children play. Children were asked if it is okay to film them. Teachers’ voluntary and informed consent were also given. All participants were named with pseudonyms. For participants not wanting to be videoed, the researchers and teachers avoided filming them, and their images were removed or pixelated in cases they were inadvertently filmed. Collected data were stored in accordance with Monash University research data storage principles and only accessed by the researchers. All electronic data were recorded and stored in a secure, durable, and appropriately referenced form. Data management complied with the Monash University data protection and privacy procedure, including the Privacy and Data Protection Act 2014 (Vic).

**Data Analysis**

Three different levels of data analysis, as formulated by the *dialectical–interactive method* (Hedegaard, 2012) were followed. The first level of analysis was common sense interpretation based on the researchers’ comments on children’s and teachers’ experiences. The focus was on viewing all the raw data and extracting single moments where the emergence of a science motive was evident. For example, the moment that an infant hit a drum making some chalk dust move and then, another infant places a toy duck on the drum and the teacher suggests testing if the duck could move because of the vibration and the acoustic waves (Vignette a) or the moment that the toddlers discuss and start thinking systematically about the concept of the ecosystem (Vignette b). All examples were noted, logged, and digitally copied into folders. This analytical process enabled us to organize single data into a series of interrelated data regarding children’s engagement with science within and across the activity settings of the CPW. The second level of analysis involved situated practice interpretation based on the emergence of conceptual links and correlations between the results obtained from the analysis at the first level. All those moments of the emergence of a science motive were clustered to highlight practices related to the emergence of a science motive. At this level of the analysis the emerging patterns were related to (a) the ideal and real forms of science learning and development, (b) forms of children’s engagement with the science concepts, (c) forms of collective spaces and collective science experiences, and (d) the role of the ‘object’ within the collective science experiences. Thus, the multiple data sets tagged at the common sense interpretation level were brought together into different digital folders and categorized under the above new categories. For example, the category ‘a’ involved cases such as the example one of a toddler introducing to

| Year of the study | Infants’ classroom | Toddlers’ classroom | Preschoolers’ room | Focus child |
|-------------------|--------------------|---------------------|--------------------|-------------|
| 1st year (2019)   | 17.80 hours        | 7.15 hours          | 4.73 hours         | 17.80 hours |
| 2nd year (2020)   | Not applicable     | 0.97 hours          | –                  | 0.97 hours  |
the other toddlers’ environment the property of transparency (Vignette d), category ‘b’ involved cases such as experimentations and hands-on experiences (Vignette a) or team discussions (Vignette b), category ‘c’ involved cases such as building with blocks a community of possums following a set of criteria (Vignette c), and category ‘d’ involved cases such as materials and objects manipulation (Vignette d) or changes in the meaning of the ‘object’ within the collective science experiences (Vignette d). The third level of analysis was the interpretation at a thematic level. At this level, a theoretical analysis was carried out to find a conceptual pattern that explains how children develop a science motive over time and how teachers supported this process. Following children as they entered the imaginary situation of the CPWs, we analysed how children formed their personal pathways in science in relation to their play and to what was personally meaningful and important to them. We also explored how teachers created motivating conditions for the children’s engagement with science bringing play and learning together. The social and cultural character of science learning in early childhood settings was also unpacked. The cultural–historical concepts of the motive and motive orientation, the concept of the dialectical interrelation between ideal and real form, and the concept of collectiveness were used as analytical tools. This set of concepts enabled us to theorize the empirical data as organized at the second level of analysis. For example, vignette d shows how the child takes the initiative to explore the property of transparency, although this was not the goal of the activity setting, and how she stimulated the other toddlers to also explore this new aspect of the material. Drawing upon the theoretical concept of science motive and science motive orientation as well as the concept of the interrelation between real and ideal forms, we analysed how the child developed her science motive within the activity setting and how she motivated her peers towards new actions by creating new science demands on them and the teacher. The analysis also revealed the way the child introduced into the group of toddlers an ideal form of development that oriented the children towards science and motivated her peers to expand their explorations. More detailed examples of how the theoretical concepts were used to interpret the data are given in the four vignettes presented in this paper.

Findings

The study found that children developed a science motive across infancy, toddlerhood, and early childhood, and teachers created motivating conditions for the development of an orientation towards science over time. However, this was not straightforward or seen as a linear progression. The findings revealed that a science motive was developed when the motive of play and the motive of learning in science were dialectically interrelated over time. Teachers created a motive orientation towards science by introducing early, actively maintaining, and gradually transforming an ideal form of science in the children’s environment and by consistently stimulating children to interact with this form.

We present these findings through a set of three vignettes illustrating examples of infants, toddlers, and preschoolers, experiencing science in everyday early childhood settings. We also showcase this more deeply through a fourth vignette by presenting the case of one child, Megan, experiencing science over time and as she moves classrooms from infancy to toddlerhood.
Infancy

In vignette 1, two infants, Anna and Amy, and the teacher, Mei, are within their imaginary play inspired by the story ‘Possum in the House’. The story focuses on the diverse sounds created when the possum interacts with different objects. Mei places some coloured chalk dust on a drum suggesting making the dust ‘dance’ by creating sound waves. The infants closely watch Mei’s actions. Mei taps the drum making the chalk jump because of the vibration caused by the acoustic wave (Figs. 1, 2, & 3). At the same time, Mei crafts a narrative about sound waves and how they are transmitted through the air (e.g. ‘Different sounds coming from the book, from different objects. How can we hear those sounds?’). Gilly, another infant, that stands nearby makes loud sounds. Mei continues crafting the narrative around the sound waves (e.g. How can we hear Gilly talking? Because of them (the sound waves) transmitted through the air!’). Anna moves closer focusing on the action. Mei expands her narrative by consistently describing the activity (e.g. ‘Look, it is dancing!’). Mei suggests infants hit the drum. Anna has a turn (Fig. 2). Amy places a toy duck on the drum. Mei suggests testing if the duck could also move. Mei taps the drum, and the duck moves. Mei suggests expanding the exploration by testing other objects too such as a ball (Fig. 3). The infants and the teacher continue exploring different objects for a while placing them on the drum and creating acoustic sounds to make them move.

This vignette illustrates infants’ early engagement with specific aspects of the concept of sound such as acoustic waves and vibration. The teacher introduces into the infants’ environment an ideal form of development to illustrate a core dimension of the concept of sound. This ideal form is an explanation about the phenomenon that comes in line with the aspects of the scientific concept of sound used in early childhood education, that is, the sound is transmitted through the air like a wave, and the acoustic waves can generate kinetic force. The teacher introduces the ideal form in a twofold way. Firstly, she initiates a science-oriented experience for infants and incorporates this experience in infants’ imaginary play (Figs. 1). Secondly, she consistently crafts a scientific narrative to describe and explain the science-oriented experience. The teacher’s scientific narrative is multimodal. It includes the teacher’s wording, gesturing, and body positioning dialectically interrelated to dynamically and effectively communicate the essence of the science concept and support infants to engage with and approach the concept. The data shows evidence that the infants can recognize and respond to the invitation to be in a process of scientific development introduced by the teacher. They focus on the science-oriented
experience (Figs. 1), engage with objects and materials (Fig. 2), and participate for a long
time in the experience (Fig. 3). They initially imitate the teacher’s activity by tapping the
drum and gradually make meaning of the teacher’s activity as they start exploring new
objects themselves. Three main forms of engagement with the experience are noted: (a)
observer of the phenomenon, (b) embodiment of the experience, and (c) imitation of
the teacher’s and peers’ actions. What is also important is an early form of collectiveness
that emerges between the infants. The natural object, that is the drum, orients the infants
to join the science-oriented activity and to orient to each other. The infants begin to share
a collective intellectual space (Fragkiadaki et al., 2021a, b). This abstract sharing is sug-
gestive of a precursor situation of collectiveness that is a precondition and lays the foun-
dations for more complex collective science experiences in the future when the child will
be in a different cultural age period.

Additional evidence of the way infants began to form the science concept of sound
within the ‘Possum in the House’ Conceptual PlayWorld was also revealed from the analy-
isis of Megan’s, the focus child’s, experience. For example, being within the activity setting
of the Conceptual PlayWorld as an infant, Megan was captured joining her peer Olin in
creating diverse sounds by using a set of plastic bowls and spoons and a metallic sauce-
pan (Authors, work in progress). In this vignette, Megan initially appears to observe Olin
while he is creating sounds by using the available objects. In a while, Megan orient herself
towards the objects with the intention to handle them. She grasps, holds, and begins hit-
ing the objects between them creating diverse sounds. Joining the two infants, the early
childhood teacher suggests cooking an imaginary soup. Joining the imaginary play, Megan
begins imitating Olin. She pretends to stir the imaginary soup creating new types of sounds
by using the plastic spoon and the bowl differently. The two infants stay engaged with the
objects and participate in the experience for a long time. In line with the example presented
above, the natural object, a set of a spoon and a bowl in this case, appears to orient the
infants to join the science-oriented activity and to orient to each other sharing a collec-
tive intellectual space. Similarly, in another example, Megan as an infant is captured using
props such as a log, a hammer, and a pot with Mei and her peer Anna to explore together
the sound as if being naughty possums themselves (Fragkiadaki et al., 2021a). In this
vignette, the infants are oriented to the ‘Possum in the house’ story. They use a set of props
creating diverse sounds. Mei introduces to the infants’ environment other materials such
as paper, expanding infants’ imaginary play and enriching their science-oriented experi-
ence. Megan, Anna, and the teacher continue to be oriented to each other as well as to the
props, to share the same imaginary situation, and to stay engaged with the group activity
exploring diverse materials and different sounds together. This example is also suggestive
of an early abstract sharing and an emerging form of collectiveness that constitutes a pre-
condition of more complex collective science experiences later in the child’s school life.
A detailed presentation of the development of Megan’s science motive is presented in the
following subsection d.

**Toddlerhood**

The toddlers are familiar with the story after participating in the CPW for two weeks. The
teacher introduces four boxes to the toddlers. The boxes are handmade models represent-
ing four diverse ecosystems: the ocean, the desert, the forest, and the city. The boxes are
covered with an image from each ecosystem. Inside the box, 3D images represent the flora
and the fauna of each ecosystem. The teacher introduces a problem scenario by posing the inquiry of finding an appropriate place to relocate the possum. She stimulates the toddlers to observe the boxes, describe the external figures of each box, and make predictions about what animal might live in each box (e.g. ‘The dessert kangaroo can live in the dessert!’). She encourages the toddlers to recall the biological needs of the possum already discussed previously within the CPW (e.g. diet, habitat) (e.g. ‘Possums can’t live in the water!’). The teacher supports the toddlers to discuss the appropriateness of the environment for a possum before opening each box. The toddlers open one box at a time (Figs. 4, & 5) to confirm or not the adequacy of the environment (e.g. ‘I can see a possum!’). The toddlers conclude that the possum must be relocated to the forest since this environment can address its needs (Fig. 6).

This vignette highlights toddlers’ engagement with the science/biology concept of ecosystem. As in vignette 1, the teacher introduces into the toddlers’ environment an ideal form of development about the concept. In this case, she introduces the form differently. Firstly, she uses a cultural artefact with a symbolic meaning. The models of the different ecosystems stimulate toddlers to share an abstract intellectual space where they can use their imagination to start forming their understanding and wonder about the concept. Secondly, she uses an early form of scientific method. She supports the toddlers to start thinking systematically about the concept by (a) posing a set of criteria about the adequacy of each ecosystem, (b) making predictions about each environment, (c) confirming or not their predictions, and (d) coming to a conclusion. Toddlers recognize and respond to the invitation to develop scientific thinking related to the concept. Toddlers contribute to the conversation led by the teacher by expressing their understandings and sharing their ideas and thinking with their peers. Three main forms of engagement with the experience are noted: (a) observation, (b) verbal communication (description, predictions, argumentation), and (c) use of imagination. What is also critical is the way the physical object, that is the box, encourages the emergence of a sense of collectiveness between the peers. This comes in line with the role of the object described in vignette 1. An early form of a collective science experience is noted.

**Early Childhood**

Preschoolers and Andrianna, the teacher, read the book. Andrianna stimulates children to pretend to be possums by wearing fur tails and constructing new habitats for themselves.

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"What is this place? It is hot during the day and cool during night."

"Have you seen a possum living in an ocean? Why is that?"

"Is there any food or water for the possum?"

Figs. 4, 5, & 6  Science concept formations during toddlerhood
Andrianna encourages children to think about what materials are needed to make ‘possum homes’. Andrianna encourages children to wonder by using their knowledge from everyday life at home (Fig. 7). She supports them to use the knowledge and the information gained through the story and the conversations the team previously had about possums characteristics, habits, and way of living. Ideas such as fridge, hammer, and kitchen are presented by different children. Andrianna orients the children to think about specific criteria such as keeping the possum warm and dry, the availability of materials for the possum, and the properties of materials. Children express their thinking (e.g. ‘Leaves could be their blanket!’, ‘We can use bamboo like we do for a tree house…’, ‘We can use some sticks to hold it right there…’). In several areas of the room, different groups of children begin building their possum homes (Fig. 8). They build individual homes connected to create a community of possums. The children share ideas and outcomes (e.g. ‘I am pretending this is a blanket to stay warm.’, ‘We need sticks and wood.’, ‘I used fabric for the roof.’). The next day Laureen, the other teacher, invites some of the children to design the process of building a possum house (Fig. 9). Laureen uses an iPad to orient the children to the designing process. The children begin to draw the habitat they created. They craft a narrative explaining the process and the criteria used for the decisions made during the process (e.g. ‘I put a log so the possum can lay and sleep… and stay warm.’, ‘I am making a big house for a possum family’, ‘I made a barrow with leaves and paper in it (for hibernation period).’).

This vignette maps preschoolers’ engagement with the science (biology) concept of environmental conditions in relation to engineering concepts such as stability, tightness, and strength of materials. The teacher creates the conditions for the criteria for constructing a proper possum habitat to be derived from children. She poses some pivots of wondering and allows children to search and find a solution. She consistently attempts connections between everyday and scientific knowledge to support children’s thinking about the constructing and designing process. Emphasis is given to the collective aspects of the science experience. Preschoolers appear to be confident in using symbolic forms of expressing and documenting their thinking such as language, 3D constructions, and drawings as they start thinking scientifically about the concepts. Alternations between collective experience and individual action between the preschoolers are noted. What is also important here is that the preschoolers can share an abstract intellectual space independently from the physical presence of the object and the proximity to it. The above elements are indicators of a collective science experience.

“A roof in order not to get wet, something soft so they can sleep on, some sticks to hold the beds.”

“A possum community!”

“Let’s draw the house we made!”

Fig. 7, 8, & 9 Science concept formation during early childhood
From infancy to toddlerhood

To better understand scientific conceptual development over time, we now present a case example of one child, Megan. Vignette 4 illustrates how Megan experiences science as an infant and her science experiences as she becomes a toddler the following year. As an infant, Megan participates in the CPW ‘Possum in the House’. Within this group activity setting the teacher introduces the concept of properties of matter. Emphasis is given to basic properties such as the property of creating sounds. The teacher makes available to the children a set of diverse materials and objects such as pieces of paper, saucepans, and fabrics and encourages infants to interact with the materials to create and listen to different sounds. Megan stays close to the materials and objects, she observes and pays attention to them and to the way her peer engages with them (Figs. 10). She grasps, holds, shakes, and taps on them creating diverse sounds. She repeats the activity several times. The following year, as a toddler, Megan participated in the CPW ‘Going on a Bear Hunt’. This group activity setting aimed at familiarizing toddlers with differences between diverse ecosystems such as the lake and the forest. The teacher introduces the concept of the ecosystem within toddlers’ imaginary play by representing the diverse ecosystems within the indoor space of the classroom and crafting accompanying science narratives related to the diverse characteristics of each ecosystem. Megan enters the imaginary space. She explores the surroundings and begins interacting with the available materials and objects. She notices some transparent ribbons representing grass. Megan picks up the ribbons and explores the material. She shakes the ribbon to create sounds and observes the ribbons closely. The teachers encourage toddlers to shake the ribbons to imitate the sounds made by the grass in an imaginary pasture. Toddlers continue their imaginary play and the teacher places one ribbon close to Megan’s eyes asking her: ‘What color is the ribbon?’. Megan notices that some of the ribbons are transparent. She picks one ribbon and places it close to her eyes to see through it. She repeats the action, staring through and away from the ribbon. She refers to the teachers asking: ‘What?’. The teacher begins crafting an early scientific narrative to explain the phenomenon (e.g. ‘It is green colour. It makes the light green.’). Although the educator does not go further in explaining that it is only the green light that can pass through the cellophane (something beyond toddlerhood), she brings attention to important preconceptions in understanding light because her focus is in relation to a more concrete conception surrounding materials. Megan explores her surroundings looking through the ribbon. She picks up another ribbon, she places it close to her eyes. When she realises it is not transparent, she throws it away. She finds again a transparent ribbon and continues...
looking through and away from it. The other toddlers notice Megan’s initiative and begin imitating Megan (Fig. 11). The group activity setting now focuses on exploring transparency as a property of the materials.

The vignette highlights the different ways the child engages with and explores science concepts over infancy and toddlerhood. In both phases, the child explores the concepts as part of her imaginary play. What is different in each phase is the degrees of freedom in the child’s interactions with the surrounding physical, technical, and social world. As the child grows up, the degrees of freedom in her interactions increase. Compared with the infant period, a toddler develops more advanced motor skills that allow her to search, find, and explore the surroundings based on her pace and intentions. The child is also more capable of verbal interactions and this capacity enables her to pose basic questions to the teacher and respond to the scientific narrative. The above conditions enable the child to initiate and participate in more complex and deep explorations. What is also important here is that being a toddler, the child takes the initiative to change the orientation of the joint science-oriented experience and put new demands on the teacher and her peers, e.g. other toddlers also begin to explore the property of transparency. This evidence is suggestive of the way the toddler can introduce into the group of toddlers an ideal form of development that motivates her peers to expand their explorations.

Discussion

In this paper, the cross-sectional and longitudinal aspect in forming science concepts during the early years is elaborated. The development of a science motive was studied in different cultural age groups of children. From infancy to toddlerhood, observing the same group of children, the development of a science motive was presented through the case of Megan. As Gomes and Fleer (2019) stated, ‘A scientific motive goes beyond explaining just a moment in a child’s development, but explains the relationship across institutional practice and the relationships over time where an interest in learning science develops’ (p. 629). Exploring how the dialectical interrelations between institutional practices, children’s cultural age, and the social situations created within different science experiences key characteristics were noticed. The characteristics were related to the institutional practices, children’s personal learning pathways in science and the collective character of the science experience. These are discussed in turn.

We learned that the teachers appeared to use the dominant motive of play to orient the children to science and support them to develop a science motive through their play. Firstly, following the new practice tradition of the CPW, they created the conditions for children’s imaginary play (e.g. stimulating the children to stay in role while exploring the science concepts). Secondly, they introduced in children’s imaginary play the ideal form of the science concept (e.g. crafting a scientific narrative or posing a set of criteria to reach a conclusion). Thirdly, they kept the ideal form actively present in the child’s environment throughout children’s play (e.g. continuing crafting a scientific narrative throughout the science experience). Fourthly, they consistently stimulated children to interact with the ideal form (e.g. posing questions to engage children with the scientific narrative). These findings are consistent and support previous findings in the literature (e.g. Fleer, 2009; Gustavsson & Pramling, 2014; MacDonald et al., 2020; Siry, 2013; Vellopoulou & Papandreou, 2019) that highlight the critical mediating role of the teacher in the child’s science learning and development. What was different in each
cultural age period was the degrees of freedom the teachers allowed in children’s explorations. The more children were developing their ability to interact and communicate with objects and peers, the most complex the science experiences were becoming as the teachers were highlighting the connections between everyday concepts and scientific concepts. Gradually, the science experiences were shifted from what is observed and described ‘here and now’ towards conceptualizing and designing imaginary spaces and using abstract scientific criteria to form the science concepts. The institutional practices the teachers used shaped the conditions for children’s development in science but at the same time, the institutional practices were shaped by children’s cultural age. This was an important finding given that most of the studies in the broader literature capture how science concepts are formed mainly between the age of 3 to 6 years old but not how science concept formation changes and how it needs to be differently supported across cultural age periods (see O’Connor et al., 2021).

The findings also illustrated children did not enter the activity settings with a personally formed and pre-determined motive. Their motives were developed during the activity setting and were shaped by the unique social situation created within the activity setting. This comes in line with Hedegaard’s (2002) conceptualization of motives as social and cultural formations. However, it is through the social interactions during the activity setting that the scientific motive came in line with the child’s motive to play. As Hedegaard and Chaiklin (2005) argued the child develops motives as they participate in institutional practices. This suggests children formed their personal pathways in science in relation to their play and to what was personally meaningful and important to them.

In addition, forms of collective science experiences appeared to emerge, establish, and develop further as children became oriented towards a science motive. A precursor situation of collectiveness was noted at the infants’ classroom based on infants’ engagement with the object (the drum) that was central for exploring the concept of sound. This was followed by an early form of a collective science experience in the toddlers’ classroom that was based on a cultural artefact (boxes) with a symbolic meaning of a conceptual system. Characteristics of a collective science experience became more visible in the early childhood classroom where children managed to share an abstract intellectual space independently from the physical presence of objects and the proximity to them. These findings suggest that a sense of understanding and engaging with science as a social practise begins at infancy and dynamically develops across the first four years of a child’s life. This adds to the literature on early childhood science education, where empirical studies have primarily focused on social interactions and collective practises within preschool classrooms, rather than catching the thread from the genesis of a sense of collectiveness during science experiences at infancy. Simultaneously, a sense of the cultural character of science emerges as children engage with objects and artefacts as part of the science experience. This aligns with previous studies in the field (e.g., Fridberg et al., 2018; Hansson et al., 2020; Vartiainen & Kumpulainen, 2020) where everyday objects, material tools, and cultural artefacts with a symbolic meaning appear to be critical in early childhood science learning. What was new though here is the different roles that the objects and the artefacts had in interrelation with the cultural age of the children. The social and cultural understanding of children about science changes in dialectical interrelation to the child’s cultural age. This is also reflected in the degree and the form teachers introduce and use to exploit objects and artefacts during science experiences.
Conclusions

The study sought to understand how infants, toddlers, and preschoolers become oriented to science as they participate in collective play through a CPW. We showcased cross-sectionally and longitudinally the nature and development of scientific concepts related to the educational reality of infants, toddlers, and preschoolers. By following different cultural age groups of children as well as the same cohort from infancy to toddlerhood, and by simultaneously creating the same CPW conditions, we determined that a motive for learning science concepts can begin in infancy in educational settings.

What appeared as key for the development of a motive orientation for the conceptual learning of infants was a sense of collectively sharing the same experience. A sense of togetherness with proximity within a shared imaginary CPW, meant that infants and the teachers could communicate in relation to the story and to the science concept of sound being introduced to amplify science learning. The CPW gave a common experience and a set of resources that acted as placeholders for the science experience within the play, and it also gave a routine in which the teachers could introduce a mature form of a science concept and the infants could explore through imitation and later through motivating others to collectively explore the materials. This outcome aligns with the finding of the empirical research in the field that positions infants and toddlers as capable and active learners in science (Byrne et al., 2016; Forman, 2010; Gopnik et al., 1999; Keil, 2011). Although it is not possible to determine exactly to what degree conceptual understandings were reached for infants, it is possible to see their motives towards these experiences through how they enter the activity setting, how they contribute to the activity, and how the activity engages their attention. This gives possible new directions for not only data collection in what is the very first period of science learning in educational settings, but it also introduces a framework for studying the conceptual development of infants.

The study also found qualitative differences in conceptual engagement in science between cultural age periods. Examining how the same CPW was created by the teachers for the exploration of sound, and then later in relation to an ecosystem for the toddlers, was directly in line with the toddlers’ capacity to go beyond objects tied to the narrative experience of science in the story, and to think more theoretically about their world. Whilst it is not possible from the language of toddlers to determine their conceptual understandings, it is possible to notice their actions, and how they enter the play, and solve problems. Accordingly, the same CPW created the conditions for the preschoolers to further develop their theoretical thinking of the world as well as deepen and expand their conceptual understandings. It is not just to study how infants, toddlers, or preschoolers enter the activity settings, what they do and how they shape the activity settings, but it is also to look at the kinds of scientific conceptual development that is afforded by the teachers. In studying children, we have to also study the conditions that teachers create in their educational programs. It is a dialectical relation.

We suggest that the outcomes of this study of scientific conceptual development for infants, toddlers, and preschoolers has shown the significance of beginning with narrative knowledge in which empirical knowledge of science is embedded, but that it should not stay at this level. We suggest toddlers should also begin to build theoretical models of thinking for gaining a system view of the world in which they live. This could be followed by preschoolers developing this theoretical knowledge in a more independent way. In line with other studies (Fridberg et al., 2019, 2020; Siry et al., 2012; Vartiainen &
Kumpulainen, 2020), the study also suggests the critical role of a scientific narrative for the development of scientific thinking. The scientific narrative begins and stays with scientific thinking and is the glue that helps infants, toddlers, and preschoolers to build a motive orientation to science in which empirical and theoretical knowledge can grow.

The findings of this study not only have implications for practice but is illustrative of how science is so fundamental for young children’s thinking about their world, as they begin in infancy being introduced to narrative thinking through stories and their own life experiences at home, to empirical thinking as they research, explore and stay curious about their world, and theoretical thinking as they bring their empirical knowledge into a system of relations and reach more abstract forms of thinking. Not only should we not underestimate infants’ capacity to engage in scientific thinking, but we need to recognise the different kinds of thinking that come together for deep conceptual development of the child in science, so we continue to create these conditions for scientifically engaging them in their world systematically over time.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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