



Working paper number 40 -

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

This is an original manuscript/preprint of an article published (online) by Elsevier in *Learning, Culture, and Social Interaction* on 17th August 2023, available online:

<https://www.sciencedirect.com/science/article/pii/S2210656123000697?via%3Dihub>

[Article DOI: <https://doi.org/10.1016/j.lcsi.2023.100753>].

We encourage you to use this preprint for educational purposes. It is intended to further scholarship for policy and practice, not for commercial gain. To cite this work, please refer to the published journal article:

Fleer, M. (2023). The role of imagination in science education in the early years under the conditions of a Conceptual PlayWorld. *Learning, Culture and Social Interaction*, 42, 100753.

<https://doi.org/https://doi.org/10.1016/j.lcsi.2023.100753>

The role of imagination in science learning in early years classrooms under the conditions of a *Scientific PlayWorld*

Marilyn Fleer
Conceptual PlayLab
School of Educational Psychology and Counselling
Monash University

Abstract

Scientists imagine when thinking scientifically, often conceptualised as thought experiments (Albert Einstein), reconciling both the study of the universe and the molecular world (Stephen Hawking) or when engaging with complex ideas, such as in genetics when imagining going down a microscope to study genes (Barbara McClintock). These imaginings are important in science. But how do they develop in the early years of school? This paper asks the question, “What is the role of imagination in science concept formation from children aged 4 to 6 years?”. Building on earlier work, the cultural-historical study reported in this paper involved 18 children aged 5.6-7.4 years (mean 6.4 years) and 4 teachers in an educational experiment of a Scientific Conceptual PlayWorld over 11 weeks. A total of 34.2 hours of digital video data, 10.4 hours of digital interviews, and 247 digital images were recorded. Using Vygotskian concepts for analysis, the results show that imagination as a psychological function was brought to bear on the scientific problem, and during children’s participation in a scientific Conceptual PlayWorld, their imagination was amplified, and scientific thinking became located within a personally meaningful framework explained through the concepts of affective imagining, embodied imagining, collective imagining and creative imagining.

Keywords: imagination, science, elementary, play

Introduction

There is growing interest in understanding how children form and develop scientific concepts over time (Fragkiadaki, et al., 2021). Developing scientific thinking is not just a short-term goal. Children change their thinking over time through their active participation in different parts of an educational system. There are major changes in the institutional practices in an educational system for children (Hedegaard, and Munk, 2019), such as when they move from an early childhood setting into a school environment (Davydov and Kudriavtsev, 1998). The former practices are more oriented to children’s play (Vygotsky, 1997), and the latter more focused on supporting the formation of abstract thinking and reasoning (Davydov and Markova, 1991). This transition is both pedagogical and psychological.

What is known about the psychological development of the child from birth to eight years, is that early in infancy through to the end of preschool they are developing their psychological function of imagination (Vygotsky, 1998). Imagination is conceptualised in this paper as a higher psychological function, taking its place with other functions, such as memory. Contrary to popular belief, the development of imagination does not disappear, but rather develops throughout childhood (Perone and Goncu, 2014; Vygotsky, 2004), even though it is not always made visible in schools (Andree and Lager-Nyqvist, 2013).

The developmental expectations for imagination and later more school based conceptual learning are mirrored by the institutional practices of the respective settings. The notable institutional change from play to learning as the central psychological formation (Vygotsky, 1998) brings with it the opportunity for studying how imagination as a psychological function works in relation to the development of abstract thought. The rationale is based on a cultural-historical conception of crisis (Vygotsky, 1994), where greater insights become possible in research when studying moments of major change (see Hedegaard, and Munk, 2019).

To better understand the development of imagination, the study reported in this paper looked closely at the institutional transition point of the first years of school, so that a more nuanced understanding of imagination in science concept formation could be achieved. It was in this psychological context of institutional change, that we were interested to study “What is the role of imagination in science concept formation from children aged 4 to 6 years?”.

To address the question of the research, this paper begins with a broad overview of what is known about studies into science education and imagination, followed by an in-depth theoretical discussion of the cultural age period under study, and the cultural-historical concepts which framed the research. The findings are reported as exemplars of imaginary moments in the science activity within a Scientific PlayWorld. The paper concludes by discussing how the findings add to scholarship generally in science education, and more specifically in relation to creating motivating conditions for children’s development of imagination and abstract thinking in science. The paper argues that there is a dialectical relation between the development of children’s imagination in play and their conceptual thinking in science.

Overview of imagination in science in the early years

Whilst there is a growing amount of research undertaken in relation to children’s thinking in science generally (O’Connor et al., 2021), less is known about imagination as a psychological function and its role in children’s conceptual development in science (Smith and Fusaro, 2021). There are three themes in the research that are oriented to, or relevant for, the role of imagination in science, and they are briefly discussed in this section.

First, there are studies that focus specifically on models of teaching that are oriented to pedagogical practice that support imaginative moments for creating motivating conditions for science inquiries or wonderings. For instance, Brostrom (2015) investigated 12 preschools in Denmark (6-year old’s) and identified science learning possibilities as starting points for wondering in science. Agency and democratic rights of children were supported through teachers building on children’s own curiosities, as well as by teachers being attentive to everyday situations that supported sustained and shared conversations about possible science learnings, such as, when children ask questions during free choice time or group sessions. For instance, “How come sometimes the moon is visible, though nobody is asleep?”. Similarly, Ismail et al., (2022) showed how free play supports physics-related learning moments in a kindergarten in Switzerland (4–8-year old’s). In their *je-desto* project they set up sensory experiences for children through creating a cinematic production for children to explore light. Their study found that teachers had a “crucial role in creating suitable play environment, providing feedback in play and facilitating sustained shared thinking after play” (p. 1). Both Ismail et al., (2022) and Brostrom (2015) take as their beginning point children’s play, their natural curiosity, and discovery learning as the basis for science teaching. Where they differ, can be seen in how teachers do or do not create the science possibilities. For instance,

teachers respond to children's spontaneous curiosities (Brostrom, 2015) or they set up experiences for children's "self-discovered scientific laws in play environments" (Ismail et al., 2022, p.8). Ismail et al., (2022) stated, "the physical laws, ... should be experienced by the children independently through play. In other words, it should not be the teacher who familiarizes the children with these physical laws; instead, the play environment itself should led them to these insights" (p. 8).

Siry (2013) has also questioned the role of adults when organising tightly framed pedagogy, suggesting that little room is given over to playful investigations. In her study of floating and sinking, where children explored buoyancy, Kindergarten children in Belgium revealed that they could conduct investigations on their own, and that adults should listen to and learn from what children are doing and saying, to better support and develop scientific inquiry. This work builds on Siry and Max (2013) who investigated children aged 4 to 6 years, in open-ended explorations of water using different sized containers and coloured dye. Children imagined soup making, and on another day smaller aquariums with different coloured crayons and materials, such as wood, brought out scientific questions of how do the colours get into the water, ways of explaining their observations, such as 'colours are melting', through to designing and controlling variables to test out ideas by using small containers and different crayon types. Mentioned explicitly in their research was children's wondering, such as, the blue is more soaked or the thin one melts, structured investigations, we need a thick one, with speculations, they have different manners for melting, to asking more questions, such as can they be different crayon materials, how can we find out? They concluded, "The investigations that the children ended up participating in were quite complex, and they emerged from their own wonderings as they first spent a long time engaging in play-based exploration of water in a large aquarium" (p. 897).

In summary, these studies of *spontaneous play with opportunities for science learning* suggest that children are seen as the authors of their own scientific learning through their natural curiosity, imagining and play. The models of teaching foreground children as the drivers of their own learning, and teachers as responding to children's wonderings, or setting up science learning environments for discovery science.

Second, there are many studies that begin science learning for children in play-based settings through explicitly setting up imaginative play scenarios through children's books (Brunner and Abd-El-Khalick, 2020), poetry (Vartiainen and Kumpulainen, 2020) and drama, such as a forensic science scene (Howitt et al., 2011) or a scientific playworld (Fleer, 2019).

Children's picture books and stories have emerged in the literature as a powerful way of creating imaginary situations where science learning is embedded (Adbo and Carulla, 2020; Fleer, 2019; Hansson et al., 2020; Howitt et al., 2011). Unlike Brostrom (2015) and Ismail et al., (2022), the teaching models bring children into the imaginary worlds of the stories (Adbo and Carulla, 2020; Brunner and Abd-El-Khalick, 2020; Fleer, Hansson et al., 2020; Howitt et al., 2011), design imaginary science laboratories (Vartiainen and Kumpulainen, 2020), and position children as *Little Scientists* (see MacDonald, et al., 2020).

In these teaching models, imagination is what keeps the children engaged with the scientific problem under investigation (Vartiainen and Kumpulainen, 2020). But there are important pedagogical differences in the models and different foci in terms of the science to be learned. For instance, scientific process skills that scientists use to make discoveries are a key outcome for some (e.g., Vartiainen and Kumpulainen, 2020), whilst for others it is engaging

children in an inquiry approach within the drama of the story (Adbo and Carulla, 2020; Fleer, 2019) or the problem in the imaginary situation (Howitt et al., 2011). These models of teaching science bring imaginary play and science learning together. To understand how this happens, the details of some of these studies are presented.

In Australia, creating imaginary *Scientific PlayWorlds* begins with the dramatic story, where problems arise that need scientific solutions for the play to continue. Children jump into the story of the Magic Wishing Chair by Enid Blyton and become the characters in the play, researching what is needed to help solve the problems they encountered on a microscopic scale when journeying into their preschool environment (Fleer, 2019). Children aged between 3 and 6 years solved the problem of how to see small things in the imaginary play of going inside a drop of water, going underground as worms, etc, and in so doing developed both their imagination and concepts associated with the big idea of magnification. As with Brostrom (2015), the focus of a *Scientific PlayWorld* is the children's play. But rather than leaving the learning of science to serendipity in relation to what might come up in children's play, a *Scientific PlayWorld* model asks the teachers to plan an authentic problem to be solved as part of the imaginary situation and the story narrative. This is in keeping with Howitt's et al., (2011) study in Australia, who used a rhyming story of "We're going on a bear hunt" to investigate through forensic science: Who left the [bear] footprints? Basic principles of *forensic science* were studied by four-year-olds in a play-based setting using guided scientific inquiry skills of exploration, questioning, prediction and explanation. Howitt et al., (2011) has said that the "heart of inquiry-based learning is the student trying to make sense of the phenomena under study" (p. 46). Like Fleer (2019), drama, imagination, and the narrative of the story framed the scientific learning of the children. In these teaching models, for the play to continue, the scientific problems have to be solved.

Building on the foundations of affective imagining described in Fleer and Pramling (2015) and Fleer's work on *Conceptual Play* in science (Fleer, 2009a;b; 2010; 2019), Adbo and Carulla (2020) innovatively begin with a story where a character receives a magnifying glass and snow flake as a birthday present to initiate learning about magnification (big and small) and chemistry by studying materials and their properties (all things are made of small particles). Results show the importance of adults in introducing into the scientific activities and play the scientific content (with their words and concepts) for establishing common ground. Their research in Sweden showed that these very young children could imagine the concept of dissolving. Adbo and Carulla (2020) said that the children "showed understandings of, and were able to identify the theoretical underpinnings of the phenomena at hand" (p. 10). In line with those studies that support the role of the adult in children's scientific wonderings (Brostrom, 2015), Adbo and Carulla (2020) suggested that teachers have a very important role in introducing words and concepts to name science activities of 3-year-old children, stating that, "due to the state of their language development, [the results] further strengthens the argument of teacher-guided efforts over discovery learning" (p. 10). This contrasts with that of Siry and Max (2013) and Siry (2013) who background the teacher in favour of a more co-constructed interaction between the teacher and the children in Belgium. However, the differences in cultural age periods (former 3-year-olds and the latter 4–8-year-olds) and the more formal pedagogical systems in Belgium explain the context of these differences in the social situation of studies and their implications. Also different to those studies that focused on children's books for creating drama and imagination, Adbo and Carulla (2020) found that with the 3-year-old children, *affective imagining* had to be conceptualised with a precondition of *affective action*. Adbo and Carulla (2020) said the children were "clearly emotionally engaged in the activity, and the eagerness to see the

results could be compared to the definition of wonder” (p.11). Further, they found in their analysis, that the “category of *in and out of imagination* did show a natural flow of connections between everyday and science concepts, suggesting that the children were indeed well in the process of creating theoretical knowledge” (p. 11).

Similar to Howitt’s et al., (2011) forensic science model, Vartiainen and Kumpulainen (2020) introduced a model of teaching science in Finland that brought children into an imaginary laboratory ‘as if’ they were scientists. Rather than a book, *Poetry Science* acted as the catalyst for *Scientific Play* (Vartiainen and Kumpulainen, 2020). Vartiainen and Kumpulainen (2020) describe *Poetry Science* as “a pedagogical method to engage young children in science inquiry through imagination and play” where children and teachers co-produce knowledge and science practices (p. 429). Different to Brostrom (2015) and Ismail et al., (2022), they did not begin the focus of their research by studying science possibilities in play, but rather they studied the manifestations of play during inquiry-based science activities – the reverse. They were interested to know how scientific play mediates children’s engagement in science inquiry. Like Brostrom (2015) they recognised the importance of children’s prior knowledge and curiosity, stating, “The poems of the method are designed to trigger children’s imagination, curiosity and previous experiences with the scientific phenomena at hand” (p. 429). A puppet called Elliphant was used with the poems to transition children into the imaginary situation of a scientific laboratory, where the children acted as if they were scientists using baking soda and vinegar to inflate a balloon. Lab coats and safety goggles signalled they had entered the imaginary situation of the lab where they engaged in the scientific process skills of asking questions, wondering, observing, measuring, hypothesizing, testing, communicating results and extending their experiments. Their results showed that in this imaginary situation, the children engaged in scientific talk and problem solving, and were able to apply new meanings to the science objects and processes.

There are other models of teaching that use books for discussing science. For instance, in *book talks* in Sweden, children and teachers engaged in discussions about the nature of science (Hansson et al., 2020), where children between 1 and 5 years bring forward personal constructions of the scientific process and the characteristics of science. But also, children discuss the limits and the human elements of science. *Book talks* by its very nature demands a great deal of imagining. The nature of science has also been studied by older students using *read-aloud* techniques (Brunner and Abd-El-Khalick, 2020).

In summary, whilst books and drama bring forward an imaginary situation, there is one key difference in the teaching models. The content of the *imaginary scientific situation* is based on ‘being a scientist’ learning scientific process or inquiry skills mirroring a form of the real world (Vartiainen and Kumpulainen (2020) or a simulated world of forensic science (Howitt et al., 2011) or the narrative of a children’s book (Adbo and Carulla, 2020; Fleeer, 2019) in which children meet problems that need scientific solutions. The former is framed as imagining being scientists engaged in scientific inquiry, whilst in the latter, imaginary play and a play problem becomes the focus. These studies show two different ways into imagination in science and imagination in play. But also, the study by Adbo and Carulla (2020) draws attention to the different cultural age periods of the children and the context in which the imaginary scientific play is being encouraged, suggesting that the *affective action* of 3-year-olds is a precursor to *affective imagining* of 6-year-olds in the learning of difficult scientific concepts.

Third, there are studies undertaken in naturalistic settings which have brought forward the important role of *intersubjectivity and question asking*. Whilst there are clear connections with the research on children's inquiries as part of imaginative play, the studies that look at children's questions in science foreground the importance of personally relevant content that is to be imagined. For example, *ScienceStart!* is a program designed to systematically bring structured hands-on science activities into kindergartens in the US, through whole group instruction followed by a selection of free choice hands-on science activities (French, 2004; Peterson and French, 2008). The pedagogy cycle begins with an introductory session (reading a book, *Little Blue, Little Yellow*), the exploration of materials (colour mixing), and the generation of questions to explore or investigate. Peterson and French (2008) investigated the impact of their program using the example of a colour mixing activity (ending in tie-dyeing tee shirts as culminating activity) in which children showed evidence of inquiry skills, explanatory language, and on topic-responses under the conditions of explanatory support by the teachers. The program with its focus on children's questions is reminiscent of longstanding research in New Zealand, known as an interactive approach to teaching science or generative learning model (Osborne and Wittrock, 1985). Much of the research at that time suggested it was difficult for children in early childhood to pose investigable questions. More recently, Ocasio (2021) in her analysis of the content in the standards and related research for 2.5-5yr old children across US states, identified more abstract concepts (science facts) than science inquiry skills to be learned. She suggested that abstracted concepts appeared to feature heavily in the US (Ocasio, 2021) with less focus on *doing science* and *building inquiry skills* in a context where imagination has been shown in previous studies to be important (Howitt, et al., 2011).

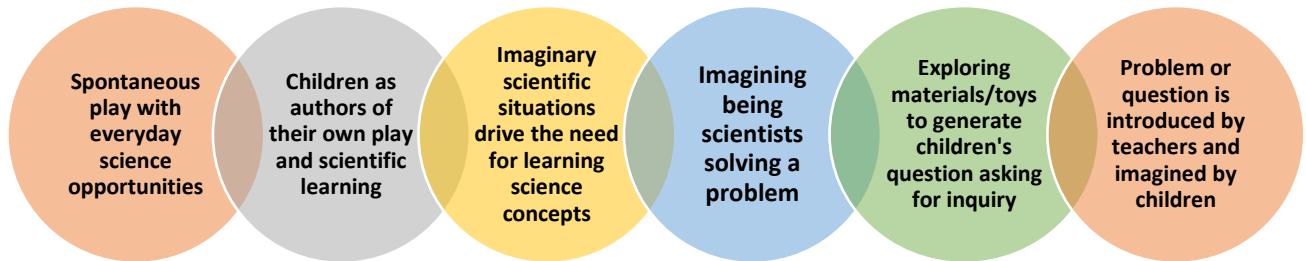
Interestingly, question asking was also the focus for bringing in science content into conversation between teachers and 3-year-old children in a study by Fridberg et al., (2019) in Sweden. The object of the learning (science concept) and the child's perspective were examined through researching intersubjectivity between children and teacher. The context was a water purification demonstration (how to make dirty water clean) with the goal of developing understandings of filtration processes for designing a wastewater treatment plant. Under these conditions, the results show that children and teachers talk past each other (divergent foci). However, when the teacher and children aged four and five years, co-designed a wastewater treatment plant, and the children were encouraged to try different filter materials, with the question: 'How does it work?', then *sufficient intersubjectivity* for science learning was reported. In a follow up study using the same data set, Fridberg et al., (2020) determined that *intermediary objects of learning* could be promoted through 1) everyday phenomenon of known words (clean to hold meaning for concept of purification), 2) development of a theoretical model (wastewater treatment plant) and 3) science concepts (filtration) through analogies and abstractions (verbal metaphors and demonstration of making water dirty and filtering it – toothpaste and water). The latter study raises concerns about disruptions to intersubjectivity between teachers and children in the context of nouns – purify – and suggests that everyday phenomena of verbs – to clean – can act as *intermediary objects of learning*. Important for the focus of this paper on imagination, is the finding that the "process of filtering dirty water is of course not visible to the children. The 'dirt' in the water is constituted by small particles -ones not visible to the human eye. Hence, the children cannot 'see' [but have to imagine] the filtering and experience the active part of a filter" (p. 593). These findings bring in a new kind of question about the role of imagination in relation to the specific cultural age period of the children and what might be a reasonable conceptual achievement/engagement in science for 3-year-olds and 4-year-olds.

Related to intersubjectivity, are those studies that focus on scientific questions. There are models of teaching which begin with children's explorations of toys to support the asking of scientific questions in a context of imagination, science and play. As a basis for scientific learning in Turkey, the *Primrose* (Balanced Learning) curriculum starts with an *explore phase* in an early learning cycle (play, explore, discuss, and assess), where children are asked to talk about how they have used or play with toys (in the example, magnetic toys) (Saçkes et al., 2020). The explore phase is designed to connect with children's prior experiences of magnets. The Explore phase is a set of purposefully planned investigations, with a question such as, "What happens when you put two magnets near each other?" (p. 307). This is a teacher guided activity. During the Discuss phase the teacher introduces scientific terms and asks questions to direct thinking. The Assess phase of the cycle focuses on the teacher listening to the children during periods of play in the activity centre to determine if they use scientific language as previously introduced. The result show that the program intervention effect was substantial and positive, with a higher rate of change in science interest for girls. This is in keeping with research by Bulunuz (2013) in Turkey who found playful learning was more effective than direct instruction. In contrast, Blake and Howitt (2012) observed three ways of informally teaching science in play-based settings, and determined that one-off science activity without ongoing follow-up resulted in little scientific learning (lost opportunities), whilst ongoing teaching-child interactions during free play supported children's wondering and higher order problem solving (satisfying curiosity), and increased emergent scientific learning possibilities for observation, classification, problem solving, creativity and critical choice (guided play).

In summary, the studies reviewed here focus on beginning with science concepts in the first instance (rather than play or inquiry skills), and in so doing are more oriented to setting up explorations in which children are encouraged to ask scientific questions. Under these conditions, intersubjectivity between children and teachers towards the object of the learning (science concept) was found to be difficult when no *intermediary object of learning* was considered. This is suggestive of the need for children to imagine a problem from the exploratory period, and to have competence in asking scientific questions in relation to what teachers are introducing. The introduction of materials or toys to explore, or a problem such as creating a wastewater model, brings forward the idea of what is the phenomenon that may be personally meaningful to children. It has been shown in previous research that the phenomenon, such as rainbows (Siry and Kremer, 2011) or shadows (Herakleioti and Pantidos, 2016), is more personally meaningful to children, than beginning the learning of science through introducing abstract concepts, such as light. The phenomenon of a rainbow is experienced in everyday life, whilst the concept of the refraction of light needs to be imagined and culturally explained or conceptually understood.

An overall summary of what can be learned from the corpus of research reviewed is that the models that explore the relations between imagination and abstract thinking in science can be conceptualised along a continuum, as is shown in Figure 1. This figure gives a broad synthesis of the models of teaching generally, rather than seeking to capture all models presented in the literature. The continuum reflects a development in imagination in children's play (left side), where science learning is more incidental or spontaneous, through to a focus on more abstract scientific thinking with concepts and processes (centre right), to direct instruction (right side) where children's imagining of the concepts is not featured explicitly in the pedagogy.

Figure 1: ‘Imagination’ and ‘abstraction’ continuum in teaching models



The continuum is illustrative of not just the diversity of models of teaching that feature the cultural age period of 3 to 6 years, but the figure captures the pedagogical nature of the institutional practices for play (left) through to more formal learning (right). In so doing, the figure shows how imagination as a psychological function is explicitly represented in play through to how it becomes increasingly covert or less visible in school practices/explanations of the pedagogy of science education.

When taken together, imagination as a psychological function has received some attention in the science education literature. However, what is featured mostly in the teaching models is a conceptualising of imagination at the everyday level. Most scholars have not explicitly discussed imagination as a higher psychological function. Rather imagination is presented as:

- 1) imagination in practice (e.g., Hadzigeorgiou, 2016),
- 2) imagination as a by-product of science learning (e.g., Adbo and Carulla (2020), and
- 3) imagination as pedagogical characteristic to enable teaching (e.g., Howitt et al., 2011).

What is missing from these important works, is a conceptualisation of imagination as a psychological function and how it develops dialectically in relation to abstract scientific thinking (Vygotsky, 1997). It is in this reading of imagination (see next section), that we can gain a more nuanced understanding of the role of imagination in science concept formation across cultural age periods.

A cultural-historical conception of imagination and imaginary play

The focus of the study reported in this paper, brings forward the need for a more nuanced theoretical understanding of children’s imagination and conceptual development from infancy to the end of primary school. As a backdrop, we needed to locate the child across different cultural age periods when studying the child in an instructional context of 4 to 6 years. Rather than biologically framed conception of a child where the passport age of the child is featured (Vygotsky, 1998), a cultural-historical view considers the child and their participation dialectically in the social and material settings in which they inhabit. It is not

just the biology of the child and how s/he imagines, but rather it is how a child enters into, participates, and changes the practices of the activity setting, that are captured in a cultural-historical conception of child development (Hedegaard and Munk, 2019). It is the beliefs and practices of teachers who create the conditions within the activity settings for the child, and who give possibilities for their development, that forms a cultural-historical study of imagination and science concept formation. This conceptualisation of studying child development is captured in the term cultural age periods.

When the preceding review of the literature and a theoretical overview of development are taken together, it becomes possible to conceptualise imagination as a psychological function that is in the process of developing. Table 1 brings the theory of imagination as a psychological function into close alignment with the cultural age periods of children's development from birth to the end of primary school. Column 1 represents the cultural age period. Columns 2 and 3 show developmental characteristics in relation to imagination and abstract thinking associated with the cultural-age periods of children.

Table 1: The development of imagination from infancy to Year 6

Cultural age period	Imagination	Theoretical premise
Infants and toddlers	<ul style="list-style-type: none"> • Props can act as placeholders for meaning (Vygotsky, 1966) • Props act as pivots for new action • Props as symbols that support the development of imagination (Fragkiadaki, et al., 2021) • In infancy an imaginary situation is developing collectively (Fleer, et al., 2020) 	<p>Play is the source of children's development of imagination as they directly experience social and material interaction (Vygotsky, 1966)</p> <p>Maturing of play seen from using objects, to using objects as tools to represent ideas/things in the action of play.</p>
Preschoolers	<ul style="list-style-type: none"> • Imaginary situations free the child from situational constraints and allow him or her to learn to act by thinking (Vygotsky, 1966) • In play, it is no longer the object or situation that generates meaning, but rather meanings that allow the generation of situations and the transformation of reality (Clerc-Georgy & Martin, 2022: p. 3). 	<p>Play creates the zone of proximal development for abstract thought (Vygotsky, 2005)</p> <p>Maturing of play seen through a focus on the objects, to the idea of the object, to the word to represent the object, to the rules of found in social settings/society as they are taken into play (Vygotsky, 2005).</p>
School age	A dialectical movement between getting closer to reality (exploring the roles and rules of community) and moving away from reality (imagining new play scripts) (Vygotsky, 2004).	The development of memory and its progressively dominate role in the first stages of schooling allows the child to bring into existence what is not present in the "here and now."

		(Clerc-Georgy & Martin, 2022 p. 7). Maturing of play is seen through thought detached from perception.
--	--	---

Table 1 illustrates from a cultural-historical perspective what changes over time, and it is this conceptualisation of imagination that supported the study design and analysis of data.

Study design

The Intervention

A Conceptual PlayWorld is a pedagogical model developed to support teachers to design teaching programs where concepts act in service of the children's play. Based on 10 years of research (Fleer 2011; 2019; 2018; 2019), the intervention foregrounds imagination in STEM concept formation. The model of teaching begins with a children's book (Characteristic 1), that becomes the basis for an imaginary space (Characteristic 2), that children and teachers enter (Characteristic 3), and meet play problems that need to be solved using STEM concepts (Characteristic 4). Teachers and children jump into the story in character (Characteristic 5) and live the problems and design the solutions in play. The Scientific Conceptual PlayWorld that was the focus of the study reported in this paper was *The Secret Garden* by Frances Hodgson Burnett. The imaginary situation of the book became space travel and the NASA space station, with the science concept being the relations between the Sun, moon, and the earth. Children solved the problem of Rescuing Cousin Robin from the far side of the moon and later, rescuing Colin who was on the near side of the moon.

Sample

A total of 18 children aged 5.6-7.4 years (mean 6.4 years) participated in the research. The children were of Australian/Anglo/NZ; Euro-Australian; Euro/NZ/Australian and Asian-Australian backgrounds. Seven children were girls and 11 were boys.

Procedure

The Scientific Conceptual PlayWorld was planned over an 11 week period with implementation of the program taking place over 8 weeks. The research involved 19 visits to the school to make digital observations using 2 cameras, and a final stimulated recall with 9 children in groups of 2-3.

Data generated

A total of 34.2 hours of digital video data was gathered, of which 10.4 hours was interviews and planning of the teachers. There were 96 emails and digitally recorded planning documents, 182 drawings and photographs of prototypes, and 43 photographs of children working. A further 23 mind maps were digitally recorded.

Analysis:

The data were examined in relation to the cultural-historical conception of imagination (Column 3), where everyday practices were studied in relation to behavioural and pictorial evidence of the characteristics described in Table 1 Column 2. For example, when children role-played the rotation of the moon as it orbited the earth in play, this was an example of maturing of play as seen through thought detached from perception. Drawings of flight plans for the rocket was considered as evidence of no longer focusing on the physical object to

generate meaning, but rather imagined meanings generated solutions and transformed reality in children's imaginary play.

Findings

As might be expected in a teaching model that has as its core imaginary situations of jumping into a story and meeting scientific problems, there were many moments of children using their imagination to support their science learning. Imagination appeared in children's scientific learning in five ways, and these give insights into how imagination as a psychological function resourced children's abstract scientific thinking.

IMAGINARY MOMENTS:

First, and most obviously, when the children were in the imaginary situation of *The Secret Garden* they were imagining reliving the story. They also imagined being in the NASA space station, launching their rocket using their flight plans, and they imagined being on training camp preparing for space travel (*Characteristics 1 and 2*). Examples of some of these *imaginary moments* are shown in Figure 2. Top left children are in the Secret Garden. Mid top and bottom, the children are in the training camp. Bottom left they are in their rocket. Right side children are in the NASA Mission Control watching their rocket launch on the large electronic board that they had collectively coded a flight path for. Children changed the meaning of the objects in their visual field (Table 1 Column 3) to be science based. This is in keeping with what Adbu and Curralla (2020) also found. What we determined was that the Scientific PlayWorld of the Secret Garden created many moments of imagining. The imaginary play appeared to be resourcing children's experiences of space travel, and this in turn positioned the scientific problem that later emerged in the role-play, as being personally meaningful to the children.

Figure 2: An overview of some imaginary moments in the Scientific PlayWorld of the Secret Garden



AFFECTIVE IMAGINING:

Second, the children were imagining the problem situation affectively. That is, the children imagined Cousin Robin stuck on the far side of the moon needing help. Cousin Robin needed to be rescued, and this drove their imagining of possible solutions – flight plans that allowed for the navigating to the far and near sides of the moon, as they were imagining themselves saving both Cousin Robin and Colin (affectively imagining) (*Characteristic 4*). Figure 3 is an example of imagining the earth, moon and Sun and imagining their relations in the context of the problem of wanting to rescue Cousin Robin.

Figure 3: Imagining the flight path for rescuing Cousin Robin.



The imaginary situations were affectively experienced by both the teachers and the children, as Cassandra explains after the children designed their rockets, planned their flight paths, and imagined their rescue mission in practice whilst on NASA space station:

Amazing, it was amazing, so engaged, so excited, I've never heard so much yelling about being on a rocket in my life. I should imagine that rockets are noisy, but I think ours might have been the noisiest. It was really, the planning to engage children with particular roles, really worked. When we came back at the end during the rocket design process and worked just with the children who collected data, they actually transcended into that, they moved into that imaginative space. They said, "When we were" and "When I was having my space food" or "When I was weightless, and I went for a space walk outside and I did a backflip". They were able to recount from the imaginative space, which was amazing. That to me was the most wonderful part (PS013 T5).

The affective nature of the imaginary situation supported the children's recount and further exploration of science. The children imagined the science that they could not directly observe. Vygotsky (2004) has theorised this, stating that "Every emotion has specific images corresponding with it." (p. 17). It was *affective imagination* that laid a foundation from which children could help solve problems collectively – saving Cousin Robin. Ruth identifies how children's building of an emotional connection and empathy with the characters in the story,

was an important dimension of laying a foundation for the imaginary situations of the Scientific PlayWorld.

In terms of the story, that's what we were lacking [in previous science learning], and it just adds another layer of depth I think in terms of the collective, so when I gave the example of the child who's Colin in the wheelchair, she was attached to that character, even when I went back into the classroom later on to return an iPad she pretended to follow because her legs were weak, so that's part of her now. I feel like that's easier to hold on to than acting out a science concept, so that was really important (PS011 T8).

The teachers noted that the children's motivation for learning scientific concepts increased over time because they were invested in solving the problem in the imaginary situation. They worked collectively to achieve this goal. As Cassandra explained, the problem situation was motivated by wanting to help rescue Cousin Robin.

Yeah, so setting up the problem and being thrust into a position where oh gosh we've got a problem and we've got to try and find a resolution for that. And the resolution is through the amassing of this knowledge, that's just working beautifully, and the kids are seeing that purpose. A lot of the time when we're working on things together the purpose is clear and it may be a joint endeavour, but it doesn't have the same sense of, **maybe it's urgency**, that provides that motivation. So, for us that's amazing (PS013 T5).

Because the imaginary situation of the story was affectively felt by the children and there was a sense of urgency in solving the problem, children became affectively oriented to the science. The story narrative with its obvious science problem, became the lived experience and embodied play of the children. It was in this context that the science concepts became embedded.

Affective imagining appeared across the data at the everyday level as:

- Wanting to help the characters in the story (emotionally invested)
- Planning the rescue (emotional pull)
- Needing to prepare for space travel (anticipation)
- Needing to know how to navigate (code) the space rocket to the far side of the moon (wanting to help by using science concepts to successfully launch)

But at the scientific level of imagination as a psychological function, Vygotsky (2004) has argued that there is an association between imagination and emotions. In this study it was the story that gave the conditions to bring out *affective imagination*. This in turn created the psychological conditions for the dual development of "...the intellectual and the emotional... Feelings as well as thoughts drives human creativity" (p. 18). The *affective imagining* of the children allowed the teachers to sensitively take forward the science in the narrative of the story, which developed over time and enriched both the imaginary play and the science learning possibilities for the children.

IMAGINARY SITUATIONS CREATE MOTIVATING CONDITIONS FOR SCHEMATIC REPRESENTATIONS OF SCIENCE LEARNING

Third, the study also found that the imaginary situation with its problem motivated the children to draw plans of their rescue, thereby putting into symbolic form their imagining of the problem and the solution. This is in line with van Oers (2012), who has noted that “We have evidence to conclude that children can produce much more sophisticated schematic representations of [imagined scientific concepts] quantities and their relationships as long as it is meaningful for the children (and functional in the context of their play)” (p. 118). The study found that the imaginary situation with the problem to solve, created the need for symbolic representation of the imagined solution. As children gained more scientific understandings about the relations between the Sun, earth and moon, their capacity to represent their imagining became more sophisticated, and this in turn helped them plan how to solve the play problem better. For example, [Figure 4](#) illustrates how children were conceptualizing the relations between the earth, moon, and Sun as part of planning their space travel and rescue mission of Cousin Robin.

Figure 4: Imagining the relations between the earth, moon and Sun when planning the rescue of Cousin Robin



Imagining problems and solution is also shown in [Figure 5](#). Children incorporated into their designs, plans, and prototypes the problem and the solution. For example, in [Figure 5](#) an example of how children were discussing the percentage of power left, and the percentage of oxygen available for Cousin Robin, and this amplified the urgency of the rescue.

ii
~~Plot~~
 Max
 Rocket Solution
 15% 15 out of 100 Left
 Max
 Max
 Robin
 Moon
 Bird a Spaceship
 Current Robin is not
 clean in the universe
 115th
 we should give her
 water to drink
 4 to eat
 3 Rice

SPACE PLAN: MISSION - Save YOUNG

Diagram

VENUS

STARS

nose cone

Solar Panels

ROCKET

Dark Side of the Moon

if you arrive at night you could turn on the lasers

Escape Pod door closed

Astronaut

NASA SPACE Station

NASA

16

actions (Figure 2), but as they refer to their flight plans when preparing their rescue and observing their rocket launch (NASA mission control Figure 2, rights image). Vygotsky (2004) argued that under these conditions, imagination becomes reality. In this imagined reality that is created through role play and drawings, children think and act under the conditions of solving a problem using their growing conceptual understandings of the relations between the earth, moon, and Sun.

AMPLIFICATION OF IMAGINATION

Fourth, the study found that the children's imagination was being amplified through the introduction of a new science problem posed by the teachers as part of the Scientific PlayWorld narrative – Cousin Robin was on the far side of the moon, but Colin had now landed on the near side (Figure 7). The drama surrounding the new problem was planned by the teachers, as Ruth explains:

So that came out of 2 goals, one goal was to have suspense and drama and another goal was to connect Cousin Robin to the story so we thought we'd have Cousin Robin with Cousin Colin. And we thought we were going to, last night we just planned the letter but then this morning when Patrick was writing it, we thought it'd be fun to actually have it in the letterbox and that was a bit of an excursion to all go out and get it. So we had a pretend phone call from the person at reception who announced that we had a letter, we didn't know who it was going to be from, that was pretty exciting, so then we all ran out there, found it, and then the children, we have some readers in the group so they were able to read the envelope and then that was the beginning to write the next part of the adventure. Because we knew that Colin was missing, so we went to look for clues.

Figure 7: Amplification of scientific rescue - finding a letter from Colin

Dear Children:

This is your sincere friend Colin, from the book that you are reading. Now that I have found a new lease of life, I can't go back inside and I must do something meaningful with my life. You have worked so hard trying to help Cousin Robin. I felt that I was of no use when I was sick. When I saw your designs I had a light bulb moment and thought 'I MUST DO SOMETHING TO HELP!'

I hope you don't mind but I have borrowed some of your ideas. I know I didn't ask and I do apologise. When I heard Cousin Robin's satellite message I could not sleep another night knowing that Cousin Robin is on the moon on her own knowing that she has limited supplies. Now that I am well and growing, I've gone ahead of you to rescue her.

Please don't try and stop me. This is my destiny!

Sincerely,

The introduction of a new problem through the letter (Figure 7) and associated portfolio of Colin's documents for space travel meant that the children needed to fine tune their rocket flight path to land on the far side and the near side of the moon.


SHARED INTELLECTUAL ZONE

Fifth, the imaginary situation became a shared zone of imagining by teachers and children. It was through the further amplification of the problem by the teachers that the children and the teachers engaged in the conceptual problem in a new way. The study found that the teachers began imagining and embodying the science through role-play. As Cassandra and Patrick recall:

That wonderful morning when we were talking about rotation. And how the moon moves with the earth, satellites around the earth, so you always see the same face, and the kids came in, as we were, the adults trying to model it, we are sort of walking around each other, so you see, ““When you face this way” (points hands to an imagined earth)...laughs... so we really were really active parts of the [Patrick: I’m spinning around Olivia], Yeah.

Their embodying of the concept of the relations between the moon and earth are summarized in Table 2.

Table 2: Teachers role-playing the relations between the moon and earth

Cassandra as moon and Rebecca as the earth:	Data
Cassandra: I am spinning around. I have looked at this wall.	

And this wall.



And this wall.



I am always facing the earth.



The teachers grapple with the complex science, as they show each other through role play the rotation of the moon as it satellites around the earth (which is also rotating), to better understand why the same side of the moon is facing the Earth.

Significantly, the teachers do this in the morning as the children are arriving for school. Their role-play is keenly observed by the children, who contribute to the conceptual struggle with the science, as is shown through the children observing and then participating, to solve the problem of how the moon is slowly rotating, as they satellite the earth.

One of the children watching, says, “I thought the moon went like this” as he rotates himself quickly in one spot. Rebecca notices and acknowledges this idea, “Yeah, well that’s what we thought Chase. Chase say it again?”. Patrick responds to Chase, “Yeah, you thought the moon was spinning a lot?”. Rebecca also copies Chase’s action saying, “Yeah, like this, around the earth” to which Olivia says, “But it’s [earth and moon] going at the same speed”. Chase exclaims, “Ahhhhhhhh” and Rebecca says to everyone, “But what we just learnt Chase, is that it’s going like this?”. Chase draws this together by saying “But imagine”. Patrick says, “So it is spinning Chase. But it’s spinning as it goes round”. Rebecca asks Chase, “Do you want to come and be the moon with me?” as they hold hands and experience the perspective of being the moon satelliting around the earth. Rebecca says “It goes like this” as they step around Olivia who is now acting as the earth.

Figure 8: Chase and Rebecca (right side) co-experience being the moon orbiting and rotating to show the same side of their bodies to the Earth



Erin observes and add to this, “And imagine that this was... [the moon]. Rebecca and Chase continue to step around, rotating slowing and acting ‘as if’ they are the moon orbiting the earth. As they go orbit, Rebecca asks Chase “What can you see?” as the other children observe closely their actions.

Figure 9: Chase and Rebecca continue to co-experience the orbit around the Earth as children observe



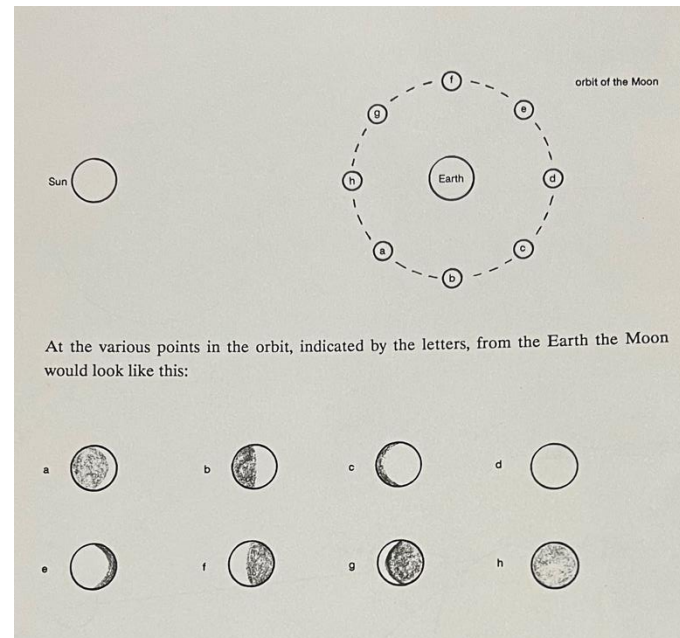
Other children co-experience the role-play with the teachers at this moment, but further role-playing of this scenario are featured many times more in the program. This reflects a realization of the power of imagining something that is not directly observable, a concept that needs to be experienced through different perspective for understanding the science - both of which can only occur in the imaginary situation. Vygotsky (2004) argued that "...what an enormous role imitation plays in children's play. A child's play very often is just an echo of when he [sic] saw and heard adults do; nevertheless, these elements of his previous experience are never merely reproduced in play in exactly the same way they occurred in reality" (Vygotsky, 2004: p. 11). Children observing the teachers role-playing the science, and then co-experiencing the science together with the teachers, supports the children to co-experience the concepts, and this paves the way for productive imagining and realizing of the concepts at a later stage.

The teachers discuss the significance of experiencing the science themselves, as is caught in the interchange immediately after role-playing the relations between the moon and the earth: Cassandra asks, "But does it help you doing it?". Rebecca responds, saying "Yeah, I think the children need to practice being [the moon]. Patrick acknowledges the challenge, "It's still difficult going around it [earth] though because you hit your shoulder". Rebecca draws attention to the need to be both, "The Earth and the moon. You need to be the moon (pointing to Olivia).

The teachers had amplified the science, and in so doing generated more child experiences inside and outside in the imaginary situation to explore the relations between the moon and earth through role-play. The teachers did not bring in the role of Sun when considering the phases of the moon. The complexity of conceptualizing the relations between the moon and the earth where perspective taking was needed, was sufficient cognitive load for the children. The complexity of representing such difficult science has been recognized previously, for instance "It is very difficult to show on one diagram the Moon's orbit, the illuminated part of

the Moon and the view we get of the Moon from Earth [see Figure 10]” (Leeds National Curriculum Support Project, 1992: No number). I would suggest it is even harder to imagine the moon’s orbit and rotation in relation to the Earth’s rotation on its axis.

Figure 10: Diagrammatic representation of the orbit of the moon



In summary, the complexity of the science appeared to create a shared intellectual zone between the children and the teachers as part of their role-play where:

- New problem in the play amplifies children’s imagining
- Children observe teachers’ role-play
- Children and teachers co-experience the conceptual problem
- A shared intellectual space emerges

Discussion

The study reported in this paper sought to contribute to understanding the role of imagination in science concept formation for children aged 4 to 6 years. There appeared to be five characteristics of imagining under the conditions of a Scientific PlayWorld. They were:

- Imaginary moments
- Affective imagining
- Imaginary situations create motivating conditions for science learning
- Amplification of imagination
- Shared intellectual zone

Vygotsky argued that “Every act of imagination starts with this [lived everyday] accumulation of experience... the richer the experience, the richer the act of imagination” (p.15). But as was shown in this study, different expressions of imagining became evident in a context of a non-tangible and not directly observable scientific concept of the relations between the earth, moon, and Sun. Science brings out these different dimensions of imagining for children and teachers that has not been explicitly reported in the literature (Table 1) or Vygotsky’s (2004) conceptualization of imagination and creativity.

The complexity of the science brought with it not only pedagogical challenges for the teachers, but also psychological demands on the children. This gave the possibility to study imagination as a psychological function in the context of children experiencing and thinking in relation to science concepts. Theoretically, a more nuanced understanding of the psychological function of imagination was made visible in the practices of the children, and this gave new insights into how imagination and abstract thinking are in relations with each other. This was seen in the pedagogical practices of a Scientific PlayWorld where embodiment of concepts was being role-play. This was also seen when the teachers and Chase tried to work out why the same face of the moon was always visible on earth. A form of *embodied imagining* was noted in this study. Vygotsky (2004) has argued that “imagination’s drive to be embodied, this is the real basis and motive force of creation” (p. 41).

Children’s solving a social problem with science that is not directly observable gave new conditions for studying children’s imagination in the social situation of development of 5-to-7-year-olds. First, it was noted that children’s imagination could be amplified collectively. For instance, the additional problem of needing to rescue Colin (near side of the moon) in a context of rescuing Cousin Robin (far side of the moon) gave more conceptual complexity, because a deeper relational understanding of rotation and orbiting of the moon and earth was needed for plotting the rocket course. The amplification of collective imagination in relation to the problem was akin to collective abstraction of the science problem under study. *Collective imagining* through teacher amplification of the problem inside of the imaginary situation of the Scientific PlayWorld, has not been discussed previously in relation to Vygotsky’s conception of the psychological function of imagination.

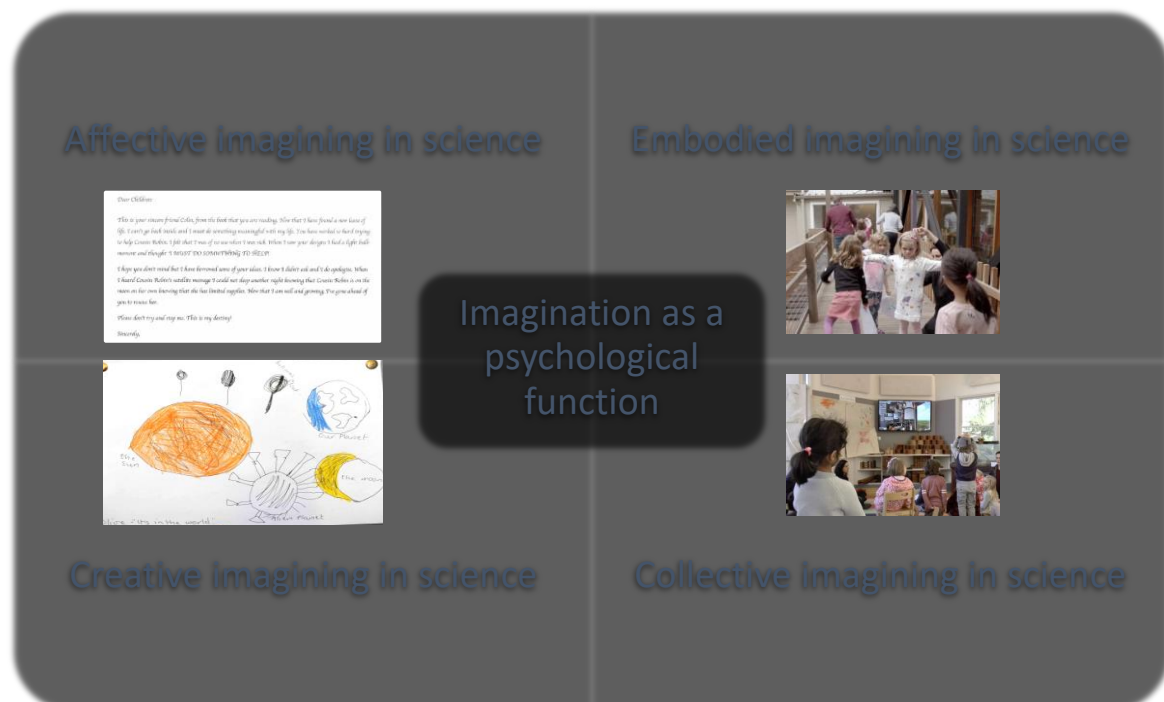
Second, the study found that drawing and role-playing the problem and the possible solutions, appeared to crystalize imagination into reality as a form of *creative imagining*. Vygotsky (2004) has theorized that imagination becomes crystalized and exists in the child’s life and community (creation). As was shown through the figures of children’s schematic representations, imagination became reality for the children. They documented their growing conceptions and solutions to the motivated conditions of wanting to help the characters in the story. Over the period of the research, children represented their imagination through their drawings, explanations using arrows in the drawings, and through role-playing the problem and solutions. Imagination as a psychological function was supported by the motivation of wanting to help the characters through learning science, and the joint struggle with the concept was because the science was not directly observable, not tangible, and had to be imagined. This is in keeping with those studies that identified the importance of children authoring their own learning (Siry, 2013; Siry and Max, 2013) in contexts that mattered to them (Bromstrom, 2015). But different to these studies, the conditions for authoring were not those that arose spontaneous, but rather were driven by the imaginary narrative and drama generated through the story and the Scientific PlayWorld of the Secret Garden.

Third, *affective imagining* was shown in this study when children re-lived through the story the problem and were role-playing the solutions that needed to urgently be solved because Cousin Robin was running out of oxygen. Affective imagining as a concept is captured in what Vygotsky (2004) called emotional imagination, where every act has with it an emotional image or tone that is felt by the child. The study found that children were gaining rich experiences through being in the Scientific PlayWorld of the Secret Garden, embarking on space travel to rescue the main characters in the story, and these were emotionally felt. The

emotional image drove a shared intellectual zone in the imaginary situation for teachers and children as they explored very complex science concepts. Different to Adbo and Carulla (2020) who suggested affective action as a precondition for affective imagining for 3-year-old children, the older children in this study were emotionally charged to solve the dual problem when both Cousin Robin and Colin were respectively on the far and near sides of the moon.

Taken together, it can be argued that imagination as a psychological function is more nuanced for the cultural age period of 4 to 6 years, through the concepts of affective imagining, embodied imagining, collective imagining, and creative imagining. These characteristics are represented relationally in Figure 11 and help explain how imagination as a psychological function was resourcing children's developing conceptions of a difficult science concept that is not directly observable.

Figure 11: The essence of imagination as a psychological function in the context of science learning of a concept not directly observable



Conclusion

What was learned from this study of imagination in science concept formation for young children was that imagination as a psychological function resourced children's learning of science concepts. This is different to what can be found in the literature. What is shown is that imagination is mentioned mostly in studies for the prior to school setting (Brostrom, 2015; Ismail et al., 2022; Siry 2013; Siry and Maxm 2013). In these studies children imagining in science is explicit (Adbo and Carulla, 2020; Fleer, 2019; Howitt et al., 2011; Vartiainen and Kumpulainen, 2020). But mostly they are related to practice (Hadzigeorgiou, 2016), as a by-product of science learning (Adbo and Carulla, 2020) and as a pedagogical characteristic to enable teaching of science (Howitt et al., 2011) rather than as a

psychological function that is resourcing play and scientific learning. The findings of this study add to what is known for children in the school setting who are learning science.

During the school years, imagination appears to be more covert and has received less attention in the science pedagogy (see Figure 1). Yet this study has shown how imagination was needed for older children to engage conceptually with very complex science concepts. This suggests that imagination as a pedagogical practice is needed for school science, but also imagination as a psychological function continues to support the learning of science by the school child. The study contributes to a deeper understanding of imagination as a psychological function, and the need to bring into the models of teaching in the first years of school, the dual development of imagination and concept formation in science.

References

- Adbo, K., and Carulla, C.V. (2019). Designing play-based learning activities in the preschool environment. *Chemistry Education Research & Practice*, 20(3), 542–553, doi:10.1039/c8rp00306h.
- Adbo, A. and Carulla, C.V., (2020). Learning About Science in Preschool: Play-Based Activities to Support Children’s Understanding of Chemistry Concepts, *International Journal of Early Childhood*, 52:17–35, doi.org/10.1007/s13158-020-00259-3.
- Andree, M., and Lager-Nyqvist, L. (2013). Spontaneous play and imagination in everyday science classroom practice, *Research in science education*, 43, 1735-1750, doi: 1007/s11165-012-9333-y.
- Blake, E., & Howitt, C. (2012). Science in early learning centres: satisfying curiosity, guided play or lost opportunities? In K. C. D. Tan and M. Kim (Eds.), *Issues and challenges in science education research: Moving forward* (pp. 281–299). Dordrecht: Springer.
- Bulunuz, M. (2013). Teaching science through play in kindergarten: does integrated play and science instruction build understanding? *European Early Childhood Education Research Journal*, 21(2), 226–249 doi: 10.1081350293X,2013,789195.
- Brostrom, S. (2015). Science in early childhood, *Journal of Education and Human Development*, 4, 21(1), 107-124, doi: 10.15640/jehd.v4n2_1a12.
- Brunner, J.L. and Abd-El-Khalick, F. (2020). Improving nature of science instruction in elementary classes with modified science trade books and educative curriculum materials, *Journal of Research in Science Teaching*, 57, 154-183. Doi: 10.1002/tea.21588.
- Davydov, V.V., and Kudriavtsev, A.K. (1998). A concept of educational activity for schoolchildren, *Soviet Psychology*, XXI (2), 50-76.
- Davydov, V.V., and Markova, V.T. (1991). Developmental education, *Russian Education & Society*, 40(7), doi: 10.2753/RES1060-939400737.
- Fleer, M. (2009a). Understanding the dialectical relations between everyday concepts and scientific concepts within play-based programs. *Research in Science Education*, 39(1),

281-306.

Fleer, M. (2009b). Supporting conceptual consciousness or learning in ‘a roundabout way’ in play-based contexts. *International Journal of Science Education*, 31(8), 1069-1090.

Fleer, M. (2010). *Early learning and development: Cultural-historical concepts in play*. Cambridge, New York: Cambridge University Press.

Fleer, M. (2019). Scientific playworlds: A model of teaching science in play-based settings. *Research in Science Education*, 49(5), 1257-1278 DOI: 10.1007/s11165-017-9653-z.

Fleer, M. and Pramling, N. (2015). *A cultural-historical study of children learning science*. Amsterdam: Springer.

French, L. (2004). Science at the centre of a coherent, integrated early childhood curriculum, *Early Childhood Research Quarterly*, 19, 138-149, doi:10.1016/j.ecresq.2004.01.004.

Fridberg, M., Jonsson, A., Redfors, A., and Thulin, S. (2019). Teaching chemistry and physics in preschool: A matter of establishing intersubjectivity. *International Journal of Science Education*, 41(17), 2542–2556, doi: 10.1080/09500693.2019.1689585

Fridberg, M., Jonsson, A., Redfors, A., and Thulin, S. (2020). The role of intermediary objects of learning in early years chemistry and physics. *Early Childhood Education Journal*, 48(5), 585–595. Doi:10.1007/s10643-020-101016-w

Fragkiadaki, G., Fleer, M., & Rai, P. (2021). The social and cultural genesis of collective imagination during infancy. *Learning, Culture and Social Interaction*, 29, 100518

Hansson, L., Leden, L., and Thulin, S. (2020). Book talks as an approach to nature of science teaching in early childhood education. *International Journal of Science Education*, 42(12), 2095–2111, doi: 10.1080//09500693.2020.1812011.

Hedegaard, M., and Munk, K. (2019). Play and life competences as core in transition from kindergarten to school: Tensions between values in early childhood education, In M. Hedegaard and M. Fleer (eds.). *Children’s transitions in everyday life and institutions*, (21-46), Bloomsbury Academic: London.

Herakleioti, E., & Pantidos, P. (2016). The contribution of the human body in young children’s explanations about shadow formation. *Research in Science Education*, 46(1), 21–42. <https://doi.org/10.1007/s11165-014-9458-2>.

Howitt, C., Lewis, S., and Upson, E. (2011). ‘It’s a mystery’. A case study of implementing forensic science in preschool as scientific inquiry. *Australasian Journal of Early Childhood*, 36(3), 45–55.

- Ismail, N.G-A, Pahl, A., and Tschiesner, R. (2022). Play-based physics learning in kindergarten, *Education Sciences*, 12, 300, doi:10.3390/3educsci2050300
- MacDonald, A., Huser, C., Sikder, S., and Danaia, L., (2020). Effective early childhood STEM education: findings from the *Little Scientists* evaluation, *Early Childhood Education Journal*, 48, 353-363, doi: 10.1007/s10643-019-01004-9
- Ocasio, A.R., (2021). *The abstraction problem: An analysis of early science learning standards in research*, unpublished Master of Arts in Psychology thesis, University of Cincinnati. Ohio, US.
- O'Connor, G., Fragkiadaki, G., Fleeer, M., & Rai, P. (2021). Early childhood science education from 0 to 6: A literature review. *Education Sciences*, 11(4), 178. <https://doi.org/10.3390/educsci11040178>
- Osborne, R., and Wittorck, M. (1985). The generative learning model and its implications for science education, *Studies in Science Education*, 12, 59-87.
- Peterson, S.M., and French, L. (2008). Supporting young children's explanations through inquiry science in preschool, *Early Childhood Research Quarterly*, 23, 395-408, doi:10.1016/j.ecresq.2008.01.003.
- Perone, A. and Goncu, A. (2014). Life-span pretend play in two communities, *Mind, Culture, and Activity*, 21, 200-220, doi: 10.1080/10749039.2014.922584.
- Sağkes, Trundle, K.C., and Shaheen, M. (2020). The effect of balanced learning curriculum on young children's learning of science, *Early Childhood Education Journal*, 48, 305-312, doi:10.1007/s10643-019-00985-x.
- Siry, C. (2013). Exploring the complexities of children's inquiries in science: Knowledge production through participatory practices. *Research in Science Education*, 43(6), 2407–2430. 10.1007/s11165-013-9364-z
- Siry, C. A., & Kremer, I. (2011). Children explain the rainbow: using young children's ideas to guide science curricula. *International Journal of Science Education and Technology*, 20(5), 643–655, doi: 10.1007/s10956-011-9320-5.
- Siry, C., & Max, C. (2013). The collective construction of a science unit: Framing curricula as emergent from kindergarteners' wonderings. *Science Education*, 97(6), 878–902. <https://doi.org/10.1002/sce. 21076>
- Smith, M.C. and Fusaro, M. (2021). Imagination and Fantasy: Correlates of Preschoolers' Science Relevant Inquisitiveness, Imagination, Cognition and Personality: Consciousness in Theory, *Research, and Clinical Practice*, 40(4) 393–417, 10.1177/0276236620963928
- Vartiainen, J., & Kumpulainen, K. (2020). Playing with science: Manifestation of scientific play in early science inquiry. *European Early Childhood Education Research Journal*, 28(4), 490–503.

Vygotsky, L. S. (1966). Play and its role in the mental development of the child. *Soviet Psychology*, 3, 6–18.

Vygotsky, L. S. (1987). The development of scientific concepts in childhood. In R. W. Rieber & A. S. Carton (Eds.), *The collected works of L. S. Vygotsky* (Vol. 1, pp. 167–241). Dordrecht: Springer.

Vygotsky, L. S. (1994). The problem of the environment. In J. Valsiner and R. vander Veer (Eds.), *The Vygotsky reader* (pp. 347–348). Blackwell.

Vygotsky, L. S. (1998). The collected works of L.S. Vygotsky. In T. M. J. Hall, and R. W. Rieber (Vol. Eds.), *Child psychology. Vol 5* New York: Kluwer Academic and Plenum Publishers (Ed. English translation).

Vygotsky, L. S. (2004). Imagination and creativity in childhood. *Journal of Russian & East European Psychology*, 42(1), 7–97.

Vygotsky, L.S. (2005). Appendix. From the notes of L.S. Vygotsky for lectures on the psychology of preschool children, *Journal of Russian and East European Psychology*, 43 (2), 90-97.

Marilyn Fleer holds the Foundation Chair of Early Childhood Education and Development at Monash University, Australia. She was awarded the 2018 Kathleen Fitzpatrick Laureate Fellowship by the Australian Research Council and was a former President of the International Society of Cultural-historical Activity Research (ISCAR). Additionally, she holds the positions of an honorary Research Fellow in the Department of Education, University of Oxford, and a second professor position in the KINDKNOW Centre, Western Norway University of Applied Sciences.

Acknowledgements

With thanks to all the research participants, the members of the Conceptual PlayLab research team, Drs Rebecca Lewis, Sue March, Taj Johora and Oriana Ramunno, Monash University, and the Australian Research Council [FL180100161; DP 140101131] for Laureate Fellowship funding.