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The role of imagination in science education in the early years under the conditions of a *Conceptual PlayWorld*

Marilyn Fleer

Conceptual PlayLab, School of Educational Psychology and Counselling, Monash University, Australia

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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 does imagination matter in science education? What is the role of imagination in science education in the early years of school? To answer this question, we undertook a cultural-historical study of 18 children (5.6–7.4yers mean 6.4) and 4 teachers who participated in an educational experiment of a Conceptual PlayWorld over 11 weeks. A total of 34.2 h of digital video data were recorded. The results show how imagination was brought to bear on the scientific problem of the relations between the earth, moon, and Sun. The complex science being imagined by children and teachers brought forward imaginary moments and situations as embodied actions, socially engineered affective imagining, common play problems for motivated conditions for science learning, and the need for creating tangible pivots. These conditions developed different expression of imagination: affective imagining, embodied imagining, amplified imagining, and collective imagining. We argue that complexity in science under the conditions of a Conceptual PlayWorld develops different forms of imagining, thereby contributing to a more nuanced understanding of imagination in science education.

1. Introduction

Over the past twenty years there has been a growing interest in understanding how to support young children's learning in science (O'Connor et al., 2021). Many different models of teaching have been developed with a range of outcomes reported (Blake & Howitt, 2012; Mulyeni et al., 2019; Peterson & French, 2008; Saçkes et al., 2020). One area that has received less attention in research and practice, is the role of imagination in the learning of science by young children (Caiman & Jakobson, 2022; Corni & Fuchs, 2020). 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 imagination (Vygotsky, 1998). Contrary to popular belief, the development of imagination does not disappear, but rather develops throughout childhood (Perone & Goncu, 2014; Vygotsky, 2004), even though it is not always made visible in schools (Andree & Lager-Nyqvist, 2013). Therefore, understanding how different teaching models in science draw on imagination to support the learning of science would appear to be an important but less visible dimension of science education.

To address the question of the research, this paper begins with a broad overview of what is known about those models of science education where imagination is featured in some way as part of the pedagogical practice. This is followed by the cultural-historical

E-mail address: marilyn.fleer@monash.edu.

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concepts which framed the research and drove the analysis. Next the study design and results of the research are reported through typical and interrelated examples of pedagogical practice and the expression of imagination by children. 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 in a context of complex science. The paper argues that there is a need for recognising in science education a more nuanced understanding of imagination when exploring complex science that is not directly observable.

We acknowledge that imagination remains a contested term. According to Steier and Kersting (2019), "There are parallel tensions within the domains of imagining and of embodied meaning making" (p. 152). They suggest 3 conceptions of imagination: 1) as a mental image within the individual mind; 2) as an activity within a social and physical context; and 3) as an embodied action (particular gestures) to show material reflection or simulation of a person's cognitive structure. In this paper imagination is conceptualised as a higher psychological function, taking its place with other functions, such as memory, perception, will and emotions. But importantly, in our cultural-historical conception of imagination as a psychological function we foreground that imagination must be understood as taking shape within the pedagogical practices or models of teaching in science education.

2. 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 and its role in science education (Smith & Fusaro, 2021). Important cultural-historically oriented research has discussed the place of imagination within a broad range of disciplines (e.g., Gfeller & Tania Zittoun, 2021; Zittoun & Cerchia, 2013). In this paper imagination is limited to science education research. There are three themes in the science education research related to models of teaching that are oriented to, or relevant for, the role of imagination in science education, 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, Broström (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. According to Ismail et al. (2022), *je-desto* project was first named by Nathalie Glauser-Abou Ismail in Germany to integrate science learning into kindergarten free play time where "The pivotal points are the physical laws, [are] experienced by the children independently through play. … the teacher … familiarizes the children with these physical laws; [and] the play environment … [which then] lead them to these insights" (p. 8). 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 Broström (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 (Broström, 2015) or they set up experiences for children's "self-discovered scientific laws in play environments" (Ismail et al., 2022, 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. 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 introduce science learning for children in play-based settings, for instance, through explicitly setting up imaginative play scenarios using children's books (Brunner & Abd-El-Khalick, 2020), poetry (Vartiainen & Kumpulainen, 2020), or art (Caiman and Jakobson (2022). There are also studies that focus on drama through 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 & Carulla, 2020; Fleer, 2019; Hansson et al., 2020; Howitt et al., 2011). Unlike Broström (2015) and Ismail et al. (2022), the teaching models bring children into the imaginary worlds of the stories (Adbo & Carulla, 2020; Brunner & Abd-El-Khalick, 2020; Hansson et al., 2020; Howitt et al., 2011), design imaginary science laboratories (Vartiainen & Kumpulainen, 2020), support science-art activities for imagined solutions (Caiman & Jakobson, 2022) 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 & 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 & Kumpulainen, 2020), whilst for others it is engaging children in an inquiry approach within the drama of the story (Adbo & Carulla, 2020; Fleer, 2019) or the problem in the imaginary situation (Howitt et al., 2011) or imagining solutions and creating these in art (Caiman & Jakobson, 2022). 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. For example, chidren 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 Broström (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 et al.'s (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, 2009b, 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 (Broström, 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 & 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 Broström (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 Broström (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 & Abd-El-Khalick, 2020).

In summary, whilst books, art 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 & Kumpulainen, 2020) or a simulated world of forensic science (Howitt et al., 2011) or the narrative of a children's book (Adbo & Carulla, 2020; Fleer, 2019) in which children meet problems that need scientific solutions or through visualisations in art where implicit scientific knowledge is explored (Caiman & Jakobson, 2022). 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 & French, 2008). The pedagogy cycle begins with an introductory session (reading a book, Little Blue, Little Yellow), the exploration of materials (colour missing), 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 ti-dying 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 & Wittorck, 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 2.5–5 yr 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 filtrating 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 of different aged children.

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 & Kremer, 2011) or shadows (Herakleioti & 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.

Overall, what can be learned from the corpus of research reviewed is that the models that explore imagination in science education can be conceptualised along a continuum, as is shown in Fig. 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. But rather, the children are expected to imagine the concepts as part of solving the science activity/ problem.

The continuum is illustrative of not just the diversity of models of teaching science that feature imagination, 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 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.

3. A cultural-historical conception of imagination and imaginary play

A more nuanced theoretical understanding of children's imagination and imaginary play from infancy to the end of primary school is needed to better understand the continuum in Fig. 1. Locating the child across such a broad cultural age period is an important backdrop when studying the role of imagination in science education because there are different instructional contexts where imaginary play and pedagogy are realised. 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 perspective on development (Hedegaard & Munk, 2019).

Imagination (Vygotsky, 1998) is said to develop when children are engaged in imaginary play. In imaginary play, children are in play relations with each other. As children's play develops, Vygotsky (1966) theorised that the child shows evidence of changing the perceptual field of what is in front them by imagining the objects and actions to be something else. For example, a series of different sized balls is no longer objects to throw and catch, but rather act as placeholders for imagining the relations between the earth, moon, and Sun. The objects act as pivots to support new imagined spacetime thinking and imaginary play as the balls and a net are used to imagine sophisticated physics concepts, such as relativity. Children in their play move closer to reality as they come to understand the rules and roles associated with how the world or universe works in 4-Dimensions. Vygotsky (1966) suggested that children of school age will spend longer talking about the rules of the imaginary play or imagining of spacetime, than playing. As the play itself develops further, the implicit rules of play are brought forward, as opposed to during the preschool years, where the imaginary situation with its implicit rules dominated children's activity. Vygotsky's (1966) premise was that through imaginary play a child's psychological function of imagination develops.

4. Conceptual and perceptual challenges when imagining the relations between the earth, moon and Sun

In the study reported in this paper, the science content being explored by children is the relationships between the earth, moon and Sun. To understand the nature of imaginary play and science learning for this area of science, a further review of the research is needed. In the contemporary research of Hilppö et al. (2016) on the dynamics of science classrooms and Steier and Kersting's (2019) meta-imagining and embodied concepts of spacetime with secondary students, both focused on imagination in relation to the learning of

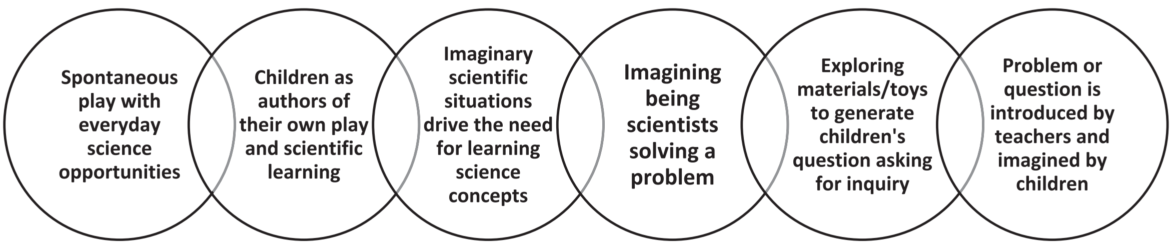


Fig. 1. Explicit imagining and implicit imagining continuum in science education teaching models.

concepts associated with the earth, moon, and Sun — but with varying degrees of cognitive load and imagining as relevant for the cultural age period of the children in their respective studies.

Steier and Kersting (2019) argued that people live in a 4-dimensional universe of spacetime, but the psychological function of perception is encultured within a conceptual system of 3-dimenions that have been historically shown as 2-dimensional representations. Einstein's theory of relativity challenged the idea of gravity being a force. He theorised gravity as a manifestation of the relations between space, time, and gravity, where the geometry of the universe was set as a dynamic 4-dimensional fabric that he named as spacetime. Steier and Kersting (2019) suggest that "Students need to perform a considerable imaginative effort to overcome their experiential understandings of gravity, space, and time" (p. 151). This brings to the fore both the child's psychological development of imagination and the pedagogical model that draws on imagination or imaginary play. They state, "The apparent naturalness of the Newtonian description of gravity is closely related to another perceptual challenge that students encounter in the domain of general relativity. The relativistic notion of curved spacetime might contradict students' experiential understandings of the force of gravity" (p. 151). Whilst Steier and Kersting's (2019) research of spacetime was with secondary students, the conceptual arguments posed are relevant to the developmental trajectory associated with the pedagogical practices of using imaginary play and the development of imagination during the process of exploring complex science.

Like Steier and Kersting (2019), Hilppö et al. (2016) have also argued that imagination is a constitutive element of science learning. They have extended the studies of Zittoun and Gillespie (2016) and Zittoun and Cerchia (2013), by presenting a theoretical example to illustrate loops of imagination that include temporality, plausibility, and generalisation, to featuring the spatial in a context of wondering about "Where does a stone come from?" to explore the formation of the earth in context of the universe. Specifically, they argue for expansive dynamics of imagination where meaning-making is a relation between proximal and distal time and space, that they believe helpful for a study of both the microscopic world to planetary spaces and timescales. Importantly, they theorise the need for pedagogically refining dynamics of imagination to take account of "how a classroom community develops a progressively more refined understanding of science topics under discussion" (p. 22) so that an acceptable explanation becomes possible. This is suggestive of a collective form of imagining as is foregrounded in the models of teaching science by Howitt et al. (2011), Fleer (2019) and Vartiainen and Kumpulainen (2020) or a sense of belonging in a science learning classroom (Caiman & Jakobson, 2022).

Imagination has also been associated with representation and perception. Representations as imagined solutions in science teaching, and models have emerged through the research of Caiman and Jakobson (2022), Prain and Tytler (2012) and Tytler et al. (2019). Drawing flowers to depict the structure of the plant, through to exploring feathers and representing these in broader context of science learning (Caiman & Jakobson, 2022) are illustrative of the role of imagining and observing in support of science education. In an empirical related example of three-and-four-year-old European heritage children, evidence was found of the importance of imagination and pedagogy when children's imaginary conceptual system was oriented to a front view perspective to re-conceptualising a plan-view orientation over time (Fleer, 1992). The children co-participated in the storytelling of 3 little pigs by looking down on a block building of the pigs' homes (in plan-view), then drawing plans from a plan-view orientation. However, when working in pairs using their plans to build their structures, difficulties arose when each child oriented their plan with a different north-south orientation to guild their collective build. Adding to this finding, Steier and Kersting (2019) also noted perceptual challenges across cultures, citing examples of different navigational systems between Micronesian and Western navigators, "and how their choice of representation limits their understanding of the situation" (p. 151). There are also examples of well-known historically documented perceptual changes of the Earth appearing flat when looking to the horizon. Heliocentric view of the Earth is another perceptual example because the reference points of people conceptualise the Earth as being in the centre of the universe. Similarly, the Mercator perspective taken by cartographers in early map making culturally skewed continent size and location when putting into 2-dimensional format 3-dimentional curvature and distorting corresponding area of each country (as well as the north-south orientation). Representations as documented imaginings appear to have an important place within the pedagogical models of science education. But, when considering the theoretical foundations relevant to the focus of this paper, most models of science teaching for older children implicitly theorised the role of imagination in science learning and did not bring forward some of the perceptual and conceptual challenges identified by Steier and Kersting (2019) and others.

Taken together, foundational theorisation of imagination from a cultural-historical perspective has developed through contemporary research in a context of the need for imagining complexity in science learning — as was evident in the research of Steier and Kersting (2019) metaimagining and embodied concepts of spacetime. But it was also evident in Hilppö et al. (2016) theorisation of young children. These important works bring forward imagination as fundamental in science education and the need to include imagination in the pedagogical models. However, for the younger children imaginary play with imagined solutions dominated the practices (e.g., Hadzigeorgiou, 2016), or imagination acted as a by-product of science learning (e.g., Adbo & Carulla, 2020; Caiman & Jakobson, 2022), or as pedagogical practices to enable teaching (e.g., Howitt et al., 2011; Vartiainen & Kumpulainen, 2020). In alignment with Steier and Kersting (2019), who argued for the need to reconcile the perceptual function associated with imagination and the pedagogical practices of teachers, the study reported in this paper sought to understand over time the dynamic processes of imagination when exploring complexity in science with young children.

5. Study design

To better understand imagination in science education, 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 education could be achieved. It was in this psychological context of institutional change from preschool to school (Hedegaard & Munk, 2019), that we were interested to study "What is the role of imagination in science education in early years of school?"

5.1. 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 over 10 years of research (Fleer 2005–2018),[1] 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. In this story of an orphaned child, Mary lives in luxury in a manor house but is lonely. In her quests, she meets other characters, including Colin who relies on a wheelchair to move around. When she follows a Red Robin, she discovers an abandoned garden that she explores. In the story friendships emerge as the characters go on adventures and help each other. In the Conceptual PlayWorld designed by the teachers, the imaginary situation of the abandoned secret garden is turned into space travel and the NASA space station, where understanding the relations between the Sun, moon, and the earth were needed to solve play problems that arise. Specifically, a social problem was introduced to the children whilst in the imaginary situations of space travel and visiting the NASA space station - Rescuing Cousin Robin from the far side of the moon and later, rescuing Colin who was on the near side of the moon.

5.2. 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.

5.3. 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.

5.4. Data generated

A total of 34.2 h of digital video data was gathered, of which 10.4 h 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.

5.5. Analysis

When the literature on imagination as reported earlier, is brought together with Vygotsky's cultural-historical theorisation of imagination and imaginary play, a powerful theoretical framework for the study of imagination in science education emerges. In order to understand the role of imagination in science education, the data were systematically examined following Hedegaard's (2008) model of a common sense interpretation, a situated practice interpretation and a theoretical interpretation. The raw data set was logged, summaries made, and linked with field notes and materials generated (photographs, drawings, etc.).

At a common sense level, the raw digital data were viewed and digitally copied and cut into segments, where evidence of children imagining in a range of ways was identified. For example, when children role-played the rotation of the moon as it orbited the earth in play, this was captured as one segment, and when children talked about the problem they were seeking to solve, different suggestions were separated in relation to the imagined solutions as a series of short video segments.

Next, the data segments were then interpreted from a situated practice level, which involved organising these data into digital folders associated with patterns of the different dimensions of imagining that were being expressed by both children and teachers — through words, actions, drawings, 'as if' play. For example, all examples of role playing the rotation of the moon as it orbited the earth in play were placed into one folder. Added to these different folders were links to the drawings, photographs, screenshots and relevant work samples and planning documents.

A theoretical interpretation involved examining the data in relation to the cultural-historical conception of imagination, where everyday practices were studied in relation to behavioural and pictorial evidence of how children were imagining in relation to the scientific problem they were seeking to solve during the Conceptual PlayWorld. For example, drawings of flight plans for the rocket was considered as evidence of no longer focusing on the physical object to generate meaning (moving from the prop to the idea of the prop), and where imagined meanings generated solutions and transformed reality in children's imaginary play (imagining new play scripts and imagined scientific solutions) as shown in Table 1 below (Columns 2 and 4).

Table 1 brings the theory of imagination as a psychological function into close alignment with the cultural age periods of children's

[1] Australian Research Council grants DP5, DP11, DP13, DP14, DP18, LP18, and FL18.

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. Because of the age range of the participating children, imaginary play was deemed to be the leading activity, and therefore conceptualising imagination in play for understanding science learning was deemed theoretically relevant for the analysis. Column 3 shows examples of pedagogical practices as cultural conditions for bringing content into the developing imaginary play of children relevant to cultural age period.

6. Findings

The study sought to better understand the role of imagination in science education by designing an intervention study to research how children imagined when exploring complexity in science and how teachers created imaginary play situations in a Conceptual PlayWorld associated with the relations between the earth, moon, and Sun. As might be expected in a teaching model that has as its core imaginary situations of jumping into a story and meeting scientific problems, we found the children were constantly using imagination to support scientific explorations. Imagination appeared in children's scientific explorations in four ways, and these give insights into our interpretation of the pedagogical practices found to support children's imagining in science education. We illustrate below typical examples from the data set that were selected because of their clarity of explanation and the complexity of the science.

6.1. Imaginary moments and imaginary situations (embodied imagining)

First, and most obviously, when the children were in the imaginary situation of *The Secret Garden* they were imagining reliving the story. They 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*). Typical examples of these *imaginary situations* are shown in Fig. 2. We found the imaginary situations brought forward a series of imaginary moments. Imaginary moments are when children are acting 'as if' in role or 'as if' using a concept to solve a problem, or acting 'as if' experiencing something associated with the narrative of the story, or when imagining each of these and representing their imaginings through drawing and creating. Imaginary moments appear at different points in time. Imaginary moments are in keeping with Vygotsky's (1966) conception of imaginary play, where the narrative of the story is co-experienced between play partners, objects take on new meaning, and rules and roles are explored, as the psychological function of imagination as reported by Vygotsky (1998) develops.

An imaginary moment is different to an imaginary situation. The latter is more reflective of the physical activity setting that is planned by the teachers. For example, in Fig. 2, top left are the children in the Secret Garden. This is a space designated by the teachers for imagining the story plot and the science problem and solution. Mid top and bottom, the children are in the training camp. Children prepare for space travel. 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. In the designated imaginary situations of these different activity settings, the children experienced imaginary moments where they changed the meaning of the objects in their visual field (Table 1 Column 3) to be science based. This is in keeping with what Adbo and Carulla (2020) also found. The Conceptual PlayWorld of the Secret Garden with the various activity settings designed by the teachers as part of the pedagogical model, created

Table 1
Theoretical analysis of imagination in play-based contexts.

Cultural age period	Imagination	Theoretical premise	Pedagogical practice examples
Infants and toddlers	• 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 (Fragkiadaki et al., 2021).	Play is the **source** of children's development of imagination as they directly experience social and material interaction (Vygotsky, 1966) Maturing of play seen from using objects, to using objects as tools to represent ideas/things in the action of play.	Teachers provide pictures, objects and show YouTube videos.
Preschoolers	• 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).	Play creates the zone of proximal development for abstract thought (Vygotsky, 2005) 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).	Techers invite the children to become the characters and role-play solutions.
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 and imagined scientific solutions) (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.	Teachers ask children to draw the problem and their solutions. These plans are used in the children's play when in the Conceptual PlayWorld.

Fig. 2. An overview of some imaginary moments in the Conceptual PlayWorld of the Secret Garden.

many moments of imagining for the children and the teachers. The imaginary play appeared to be resourcing children's experiences of space travel.

6.2. Socially engineered affective imagining (affective imagining)

Second, the children were imagining the problem situation affectively through the socially engineered problem introduced by the teachers. 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*). Fig. 3 is a typical example of imagining the earth, moon and Sun and imagining their relations in the context of the problem of wanting to rescue Cousin Robin. Arrows indicate the flight path (solution) in the context of the spheres which together represent the problem they imagined and were seeking to solve.

Fig. 3. Imagining the flight path for rescuing Cousin Robin.

The imaginary situations were affectively experienced by both the teachers and the children, as teacher 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 teacher recognised the children's imagining through their reflective comments, such as, when they said, "I am eating space food" or when "I am weightless". The collective nature of the imagining foregrounds the group rather than an individual in the process of socially engineered affective imagining. The problem and the solution are lived in the imaginary play, as the dual nature of worrying about Cousin Robin and feeling excited to be solving the problem. They were in constant tension. The affective nature of the imaginary situation supported the children's recount and further exploration of complex science. Steier and Kersting (2019) also found the children imagined the science that they could not directly observe. It was *affective imagination* that laid a foundation from which children could help solve problems collectively — saving Cousin Robin. Vygotsky (2004) has theorised this, stating that "Every emotion has specific images corresponding with it." (p. 17). Teacher 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 Conceptual 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 [helping Cousin Robin], so when I gave the example of the child who's Colin in the wheelchair [character in the story], 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 (Teacher Ruth: PS011 T8).

Solving a problem and acting 'as if' Colin in a wheelchair, is illustrative of how the children were living the story and affectively imagining. The teachers noted that the children's motivation for learning scientific concepts increased over time because they were

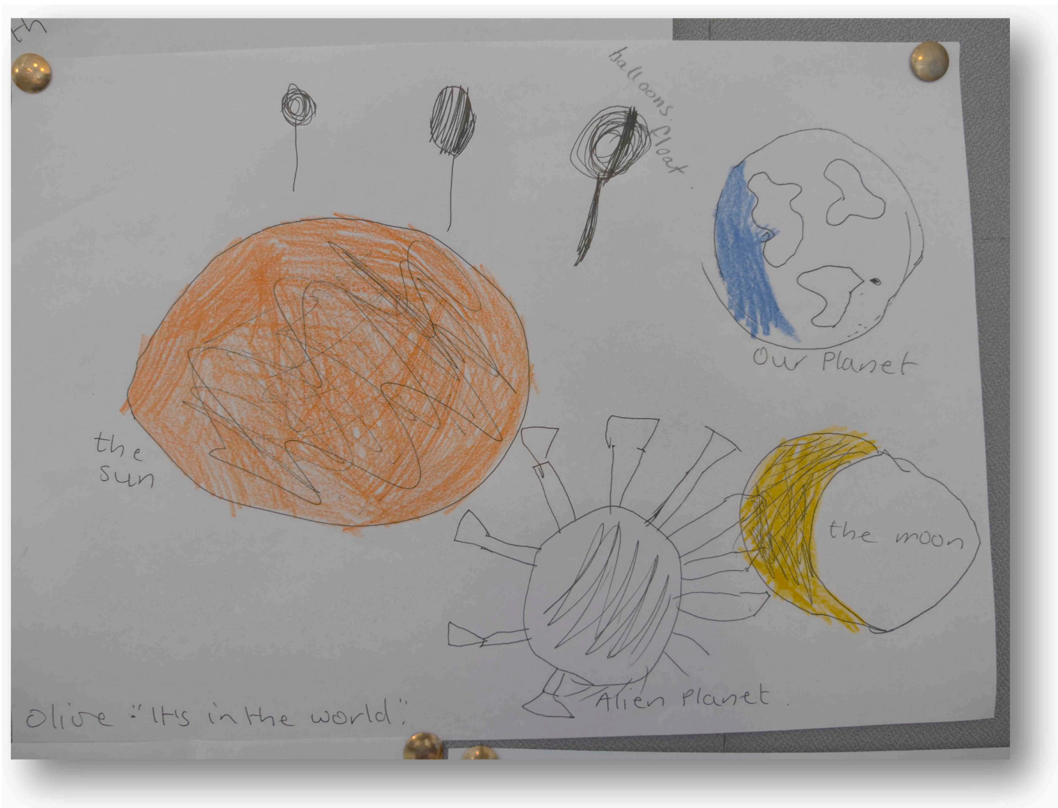
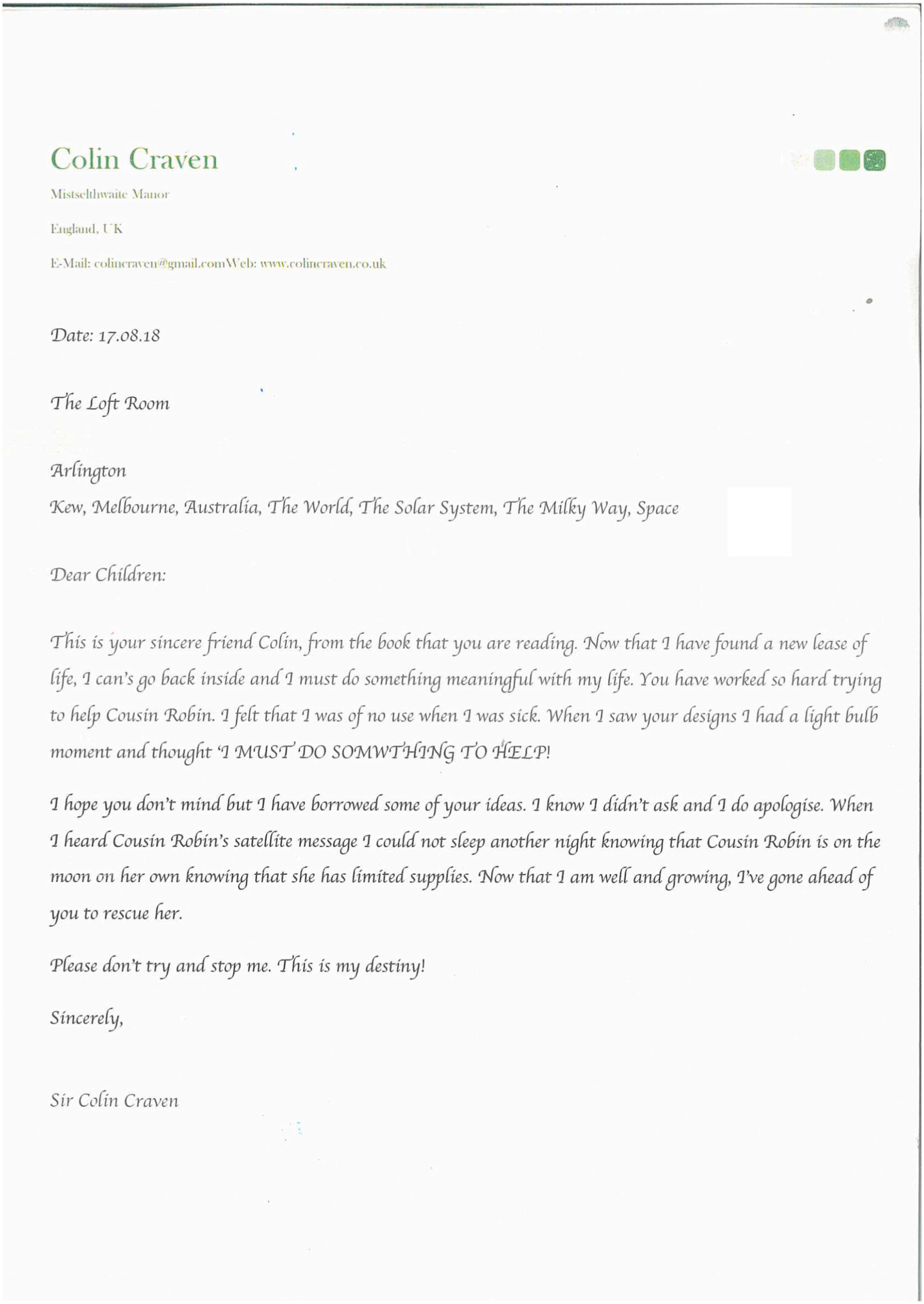


Fig. 4. Imagining the relations between the earth, moon and Sun when planning the rescue of Cousin Robin.



Colin Craven

Mistselthwaite Manor

England, UK

E-Mail: colincraven@gmail.comWeb: www.colincraven.co.uk

Date: 17.08.18

The Loft Room

Arlington

Kew, Melbourne, Australia, The World, The Solar System, The Milky Way, Space

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's 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 SOMWTHING 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,

Sir Colin Craven

(caption on next page)

Fig. 5. Amplification of scientific rescue — finding a letter from Colin.

invested in solving the problem in the imaginary situation. As Teacher 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 (Teacher Cassandra: PS013 T5).

The story narrative with its obvious science problem, became the affectively lived experience and embodied play of the children. It was in this context that the science learning became embedded in the imaginary situation as socially engineered affective imagining. *Socially engineered affective imagining* appeared across the data 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)

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 *socially engineered 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.

Fig. 6. Chase and Teacher Ruth (right side) co-experience being the moon orbiting and rotating to show the same side of their bodies to the Earth.

6.3. Complexity of the science creates need for tangible pivots (collective imagining)

Third, the study also found that the collective imaginary situation with a complex science problem motivated the children to draw plans of their rescue, thereby putting into symbolic form their imagining of the problem and the solution. For example, imagining is documented in the children's drawings as a problem scenario, as the relation between the moon, earth and Sun as they perceive it (Fig. 4) and as possible flight plans (Fig. 3). Caiman and Jakobson (2022) also noted in their art-science pedagogy that imagining science concepts when drawing emerges through visualisations and different representational modes. Tytler et al. (2019) has also shown how visual sign-making during science lessons gives the possibility for conceptual clarification, but also gives opportunities for students to engage with model-based reasoning. In our study, we found that the imaginary situation with a complex science 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 (Figs. 3 and 4). Caiman and Lundegård (2018) have shown how drawing has "the potential to increase young children's creations of new and imaginative science-related ideas and problems" (cited in Caiman & Jakobson, 2022, p. 836). However, different to the Conceptual PlayWorld model of teaching, in their research the additional scientific problems that emerged were not planned by the teachers. Rather they noted that in the dialogue associated with drawing, the children imagined a purpose that extended the problem situation into new directions.

We suggest that imagining begins to exist through the children's drawings, but also through their embodied actions (Fig. 2) as they refer to their flight plans when preparing their rescue and observing their rocket launch (NASA mission control Fig. 2, rights image). Vygotsky (2004) argued that under these conditions, imagination becomes reality. In this imagined reality, children create tangible artifacts for solving the scientific problem.

6.4. A common problem creates motivated conditions for science learning (amplified imagining)

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 Conceptual PlayWorld narrative — Cousin Robin was on the far side of the moon, but Colin had now landed on the near side (Figs. 4 and 5). The drama surrounding the new problem was planned by the teachers, as Ruth explains:

Fig. 7. Chase and Teacher Ruth continue to co-experience the orbit around the Earth as children observe.

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

Teacher Cassandra as moon and Teacher Ruth as the earth	Data example
Cassandra: I am spinning around. I have looked at this wall.	
And this wall.	
And this wall.	
I am always facing the earth.	

> 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.

The introduction of a new problem through the letter (Fig. 5) 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. The problems set up by the teachers amplified the need for science knowledge. But our study also found that the teachers had to imagine the complex science to support the science learning of the children. For example, it was through the further amplification of the problem by the teachers that the children and the teachers had to imagine the problem and solution differently. Initially the teachers needed to imagine the relations between the earth and the moon, and they did this through acting 'as if' the moon and earth rotating at the same time as the moon was circling the Earth. But later when considering the Sun, further scientific complexity emerged for the teachers. The conceptual struggle is shown in Table 2.

6.4.1. *Teachers imagining the problem*

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.

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.

6.4.2. *Children imagining the problem*

We also found that the children participated in the conceptual problem when observing the teachers' conceptual struggle as they role-played the science. For example, the problem of how the moon is slowly rotating, at the same time as it orbits the earth, was brought forward for the children as follows:

> Chase is watching the teachers and says, "I thought the moon went like this" as he rotates himself quickly in one spot. Teacher Ruth notices and acknowledges this idea, "Yeah, well that's what we thought Chase. Chase say it again?". Teacher Patrick responds to Chase, "Yeah, you thought the moon was spinning a lot?". Teacher Ruth also copies Chase's action saying, "Yeah, like this, around the earth" to which Teacher Olivia says, "But it's [earth and moon] going at the same speed". Chase exclaims, "Ahhhhhhhh" and Teacher Ruth says to everyone, "But what we just learnt Chase, is that it's going like this?" as Ruth rotates slowly whilst stepping sideways in orbit around the earth. Chase draws this together by saying "But imagine [inaudible]". Teacher Patrick says, "So it is spinning Chase. But it's spinning as it goes round". Teacher Ruth 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 (Figs. 6 and 7: Ruth is right with Chase to her right). Teacher Ruth says "It goes like this" as they step around Teacher Olivia who is now acting as the earth.

Another child Erin observes and add to the embodiment of the science concept, "And imagine that this was... [the moon]. Teacher Ruth and Chase continue to step, rotating slowing and acting 'as if' they are the moon orbiting the earth. As they orbit, Teacher Ruth asks Chase "What can you see?" as the other children observe closely their actions.

Other children co-experience the role-play with the teachers at this moment, and also at different times when the children and teachers reflect on what they had been doing when in the Conceptual PlayWorld of the Secret Garden. For example.

> The children are all seated in a circle and discussing what they have been learning, when Alden (child) asks the group, "When the moon turns, won't the building turn and still be on the dark side of the moon?". Teacher Cassandra seeks clarification by asking Alden, "So you are thinking, she [Cousin Robin] has to be staying on the dark side of the moon [gesturing sphere with hands], that part won't get light. Is that what you mean?". Alden responds, "Yeah. So it will just change round [gesturing rotation with hands]". One of the other teachers Patrick supports Alden's curiosity by bringing into the conversation some of the terms the children have been exploring when planning their space travel by saying: We have got to find out how does the moon move? Does it rotate, orbit? These are questions we have to ask because we don't know.". Teacher Ruth crystalises the problem Alden is curious about by affirming "These are great questions. I feel like that's the essence of our investigation at the moment".

Later the teachers supported the children many times to act 'as if' the moon and earth rotating at the same time as the moon was circling the Earth both outside in the Secret Garden and in large open areas, such as the school hall (see Table 3). In Table 3 is an overview of the children's collective embodiment of the scientific problem they are discussing. The actions are also reflective of what the teachers previously role-played and discussed (Table 2).

The typical examples shown in this section reflect a realisation of the place of imagining something that is not directly observable, a concept that needs to be experienced through different perspectives in order to understand the complex 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 (Table 2), supports the children to co-experience the complex science (Table 3), and this paves the way for productive imagining and realising of the concepts at a later stage.

Imagination appears to be resourcing the teachers and the children to explore complex science. The embodied actions of acting 'as if' key celestial bodies in the Earth's solar system do foreground the importance of the amplification of imagination when teaching complex science in 3 key ways.

First, 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?". Ruth responds, saying "Yeah, I think the childre n need to practice being [the moon]. Patrick acknowledges the challenge, "It's still difficult going around it [earth] though because you hit your shoulder". Ruth draws attention to the need to be both, "The Earth and the moon. You need to be the moon (pointing to Olivia).

Second, the teachers 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 initially bring in the role of Sun when considering the phases of the moon. The complexity of conceptualising the relations between the moon and the earth where perspective taking was needed, was sufficient cognitive load for the children. In the first instance, the complexity of representing such difficult science has been recognised previously, for example "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 Fig. 8]" (Leeds National Curriculum Support Project, 1992:

Table 3
Children role-playing (with teacher support) the relations between the moon and earth.

Children and teachers in the imaginary situation of the relations between the earth, moon and Sun	Data example
The children form teams to become the moon, earth, and Sun. A teacher is in role for each team.	
The moon team rotate and orbit the earth. The earth team rotate and the earth team with the moon team orbit the Sun.	
Some of the children look back to the Sun. The embodied experience of orbiting and rotating is collectively explored.	

No number). The results of this study would suggest it is even harder to imagine the moon's orbit and rotation in relation to the Earth's rotation on its axis.

Third, the common problem was imagined between the children and teachers because the teachers also struggled with imagining the relations between the earth, moon, and Sun. To imagine such scientific complexity was realised by teachers through physical embodiment as one teacher acting 'as if' she is the earth orbiting the Sun and rotating on its axis, whilst another teacher is acting 'as if' the moon rotating and orbiting the earth holding a child's hand. This helped explain why the same face of the moon is visible from earth. Later Teacher Olivia also took photos on her smart phone as she role-played orbiting the Earth 'as if' she was the moon. It was a shared conceptual struggle amongst the teachers. But it was also a struggle made visible to the children, as they initially observed, participated, and later experienced many times collectively solving the problem of designing flight plans to rescue Cousin Robin and Colin who were on different sides of the moon.

7. Discussion

The study reported in this paper sought to contribute to understanding the role of imagination in science education. We found four ways of imagining under four conditions found in the Conceptual PlayWorld of the Secret Garden where the children were exploring the relations between the earth, moon and Sun. They are shown in synthesis in Fig. 9.

When these findings into imagination in science for the first year of school are considered together, the results can be represented as a dialectical relation between children's imagining and imagination as a pedagogical practice for supporting the learning of complex science (Fig. 9). This is a more nuanced model of imagination in science to that shown in Fig. 1. The inner circle of Fig. 9 shows the

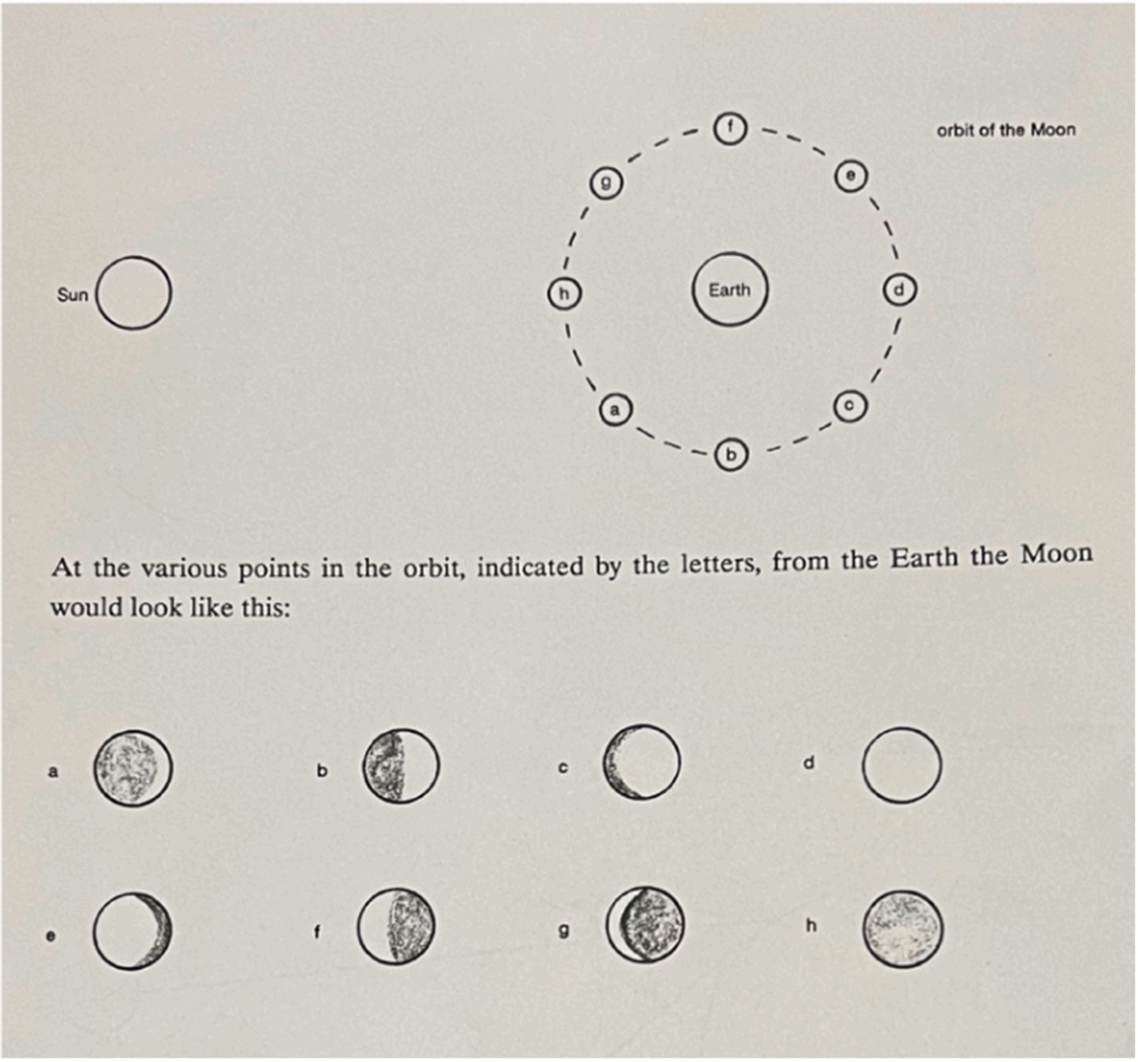


Fig. 8. Diagrammatic representation of the orbit of the moon.

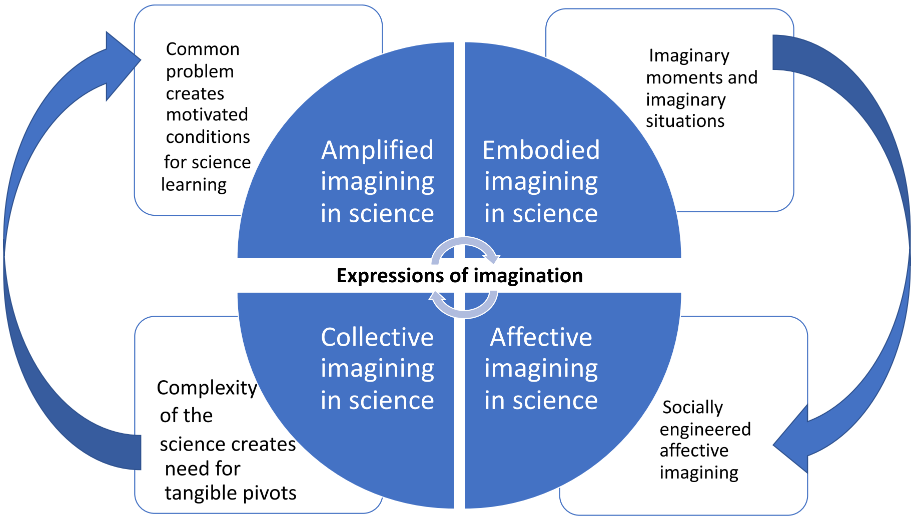


Fig. 9. A synthesis of children's expressions of imagination and imagination as a pedagogical practice in science education.

different forms of imagining by the children under the conditions of the pedagogical practices captured in the outer petals. A synthesis of the four dimensions of the dialectical relationship is discussed in this section.

First, a form of *embodied imagining* was found within the *imaginary moments and imaginary situations of the Conceptual PlayWorld*. The complexity of the science brought with it not only pedagogical challenges for the teachers, but also put psychological demands on the children because of the need to imagine something not directly observable. Steier and Kersting (2019) have written about this in relation to secondary students and showed how they needed to navigate different conceptual frameworks of the intuitive and embodied Newtonian physics and imagining spacetime in Einstein's theory of relativity. This type of challenge gave the possibility to study imagination in the context of children experiencing and thinking in relation to complex science. Our study made visible the embodied role-playing of the children, and this gave new insights into how embodied imagination and complex science are in relations with each other. This was seen when the teachers and Chase tried to work out why the same face of the moon was always visible from earth. Vygotsky (2004) has argued that "imagination's drive to be embodied, this is the real basis and motive force of creation" (p. 41). Gfeller and Zittoun (2021) have also written on the embodied dimension of imaginary process and noted degrees of embodiment, such as imagining through bodies and imagining in minds, where anticipations of the future are also expressed. A form of *embodied imagining* in the many moments of imagining emerged in our study and this adds to what is known about the teaching of science.

Second, *affective imagining* appeared when children re-lived the story narrative with the social problem — Cousin Robin was running out of oxygen. *Socially engineered 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. This study found that children were gaining rich experiences through being in the Conceptual PlayWorld of the Secret Garden, embarking on space travel to rescue the main characters in the story, and these were emotionally expressed. The emotional image appeared as a shared endeavour in the imaginary situation as teachers and children explored complex science together. This is different to Adbo and Carulla (2020) who suggested affective action is a precondition for socially engineered affective imagining for 3-year-old children.

Third, the complexity of the science generated the need for tangible products that could be used to further support the play problem. 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) needed the drawing of imagined solutions for understanding the rotation and orbiting of the moon and earth when plotting the rocket course (Figs. 2-4). The study found that drawing and role-playing the problem and the possible solutions, are in line with Vygotsky's (2004) conception of crystalising imagination into reality. We suggest this shows how complex science *creates the need for tangible products that act as pivots and placeholders for imagining the science problem in the play*. Caiman and Jakobson (2022) found that "art in science education has the potential to increase young students' creations of new and imaginative science-related ideas and problems" (p. 836). Our findings also reflect how Vygotsky (2004) theorised that when imagination becomes crystalised it exists in the child's life and community (as a creation of an artefact/process).

Fourth, we identified that a common play problem that was not directly observable *amplified the imaginary situation* for teachers and children to solve. The need for imagining the scientific solution appeared to create highly motivating conditions for learning. The motivating condition was akin to collective abstraction of the science problem under study. Imagination was supported by the joint struggle that was not tangible, but had to be imagined, and this is in keeping with those studies that identified the importance of children authoring their own learning (Siry, 2013; Siry & Max, 2013) in contexts that mattered to them (Broström, 2015). But different to those studies, the conditions for authoring were not those that arose spontaneously, but rather were driven by the imaginary narrative and drama generated through the story and the Conceptual PlayWorld of the Secret Garden. *Imagining* of a common play problem was motivating and this has not been discussed previously in the literature in relation to Vygotsky's conception of imagination in science education (Fig. 1). Closest is Hilppö et al. (2016) who noted interactive dynamics of imagination in a science classroom.

When taken together these four ways of imagining in science in the context of the pedagogical practices as shown in Fig. 9, captures a relational dynamic between expression of imagination and pedagogical practices, that we believe should be featured more in science education. Considering imagination as a psychological function, rather than only conceptualising imagination as a practice (Hadzigeorgiou, 2016), or as a by-product of science learning (Adbo & Carulla, 2020) or as a pedagogical practice to enable teaching of science (Howitt et al., 2011), misses the possibilities for the development of imagination through imaginary play (Vygotsky, 1966) in the context of complex science.

8. Conclusion

In our study children's imagining in science and teachers' pedagogical practices were researched under the conditions of complex science in a Conceptual PlayWorld. We did not seek to represent individual learning in science, but rather were interested to understand generally how imagination in complex science is expressed and under what pedagogical conditions could teachers support the development of imagination. However, our study question was limited to what is the role of imagination in science education in the early years of school. We suggest that the expressions of imagination identified support and extend the theoretical writing of Vygotsky (2004) on the dialectical relation between imagination and creativity. We argue that 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. This is in keeping with Steier and Kersting (2019) who said, "Treating imagination as an organizational feature of activity… allows us to attend to the ways that abstract, invisible, nonpresent are made to be present" (p. 147). The more nuanced expression of imagination found in our study was possible through the science education lens, and this is in keeping with Vygotsky's (2004) poignant but not elaborated suggestion that the science disciplines, and not just the Arts, require imagination. Science brings out these different expressions of imagining for children and teachers and this has not been explicitly elaborated in Vygotsky's writing.

Our study brings forward the idea that during the early school years, imagination appears to be overt and brought into the teaching models, but in higher years of schooling, imagination becomes more covert and its place in science education appears to have received less attention (see Fig. 1). Like Steier and Kersting (2019), this study has shown how imagination as part of the science education pedagogy was needed for supporting children to engage conceptually and explore very complex science concepts. We found that imagination as a pedagogical practice was variously captured in the study as children and teachers explored complex science. The pedagogical practices that supported collective imaginary situations and created motivating conditions for science learning, appeared to be amplifying children's imagination affectively, collectively, creatively through drawing, and embodied in actions. But under different study conditions, other pedagogical practices and ways of imagining may well emerge. The results of our research should be viewed with this limitation in mind. However, the findings of our study add to what is known about the pedagogical place of imagination in science education and the expressions of imagining possible by young children who are exploring complex science.

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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.