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Scientific Playworlds: a Model of Teaching Science in Play-Based Settings

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Abstract Eminent scientists, like Einstein, worked with theoretical contradiction, thought experiments, mental models and visualisation—all characteristics of children's play. Supporting children's play is a strength of early childhood teachers. Promising research shows a link between imagination in science and imagination in play. A case study of 3 preschool teachers and 26 children (3.6–5.9 years; mean age of 4.6 years) over 6 weeks was undertaken, generating 59.6 h of digital observations and 788 photographs of play practices. The research sought to understand (1) how imaginative play promotes scientific learning and (2) examined how teachers engaged children in scientific play. Although play pedagogy is a strength of early childhood teachers, it was found that transforming imaginary situations into scientific narratives requires different pedagogical characteristics. The study found that the building of collective scientific narratives alongside of discourses of wondering were key determinants of science learning in play-based settings. Specifically, the pedagogical principles of using a cultural device that mirrors the science experiences, creating imaginary scientific situations, collectively building scientific problem situations, and imagining the relations between observable contexts and non-observable concepts, changed everyday practices into a scientific narrative and engagement. It is argued that these unique pedagogical characteristics promote scientific narratives in play-based settings. An approach, named as *Scientific Playworlds*, is presented as a possible model for teaching science in play-based settings.

Keywords Early childhood teachers · Cultural-historical · Science education · Playworlds · Play · Affective imagination

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Introduction

Despite the vast evidence showing the contribution of play to childhood learning and development, little is known about how scientific reasoning in guided imaginative play can be designed into play-based teaching programs so that preschool teachers intentionally engage young children in scientific thought in play-based settings. The study reported in this paper addresses this problem.

Many eminent scientists have revealed childhoods where thought experiments and visualisation during imaginative play feature (e.g. Rothenberg 1979). Einstein reported spending hours playing with his toy trains and, as an adult, advocated that "Play is the highest form of research". What they appear to have in common is an exceptional cognitive capacity to visualise, imagine, model and explore theoretical contradictions for certain features of the physical world (e.g. Kass 2003). For instance, *thought experiments* and *mental models* that give fundamentally different theoretical insights are evident in the scientific work of Michael Faraday when exploring electricity and magnetism. Albert Einstein's theory of relativity was partially derived through thought experiments. Steven Hawking used visualisation to consider big ideas in science, such as the origins of the university, and through this paved the way for new lines of scientific inquiry in science. Barbara McClintock imagined travelling down the microscope, examining the genetic structure whilst simultaneously imagining the living ecosystem of corn fields (Fox Keller 1983). In her scientific work, she was simultaneously imagining the relations between molecular and observable contexts, changing the course of genetics research. Many of these eminent scientists comfortably engaged in theoretical contradictions, and through this created the conditions for new scientific thought (e.g. Albert Einstein when reconciling Newton's laws with relativity mechanics).

Whilst it seems intuitive that exposure to science education in the formative years (i.e. birth-five) when cognitive function is being established, can help build cognitive capabilities for scientific thought, not just for those with a genius for science enquiry but for all young children (Cook et al. 2011), little attention has been directed to studying scientific reasoning in guided imaginative play. Guided imaginative play that explores the physical world offers an ideal opportunity to teach the concepts of science (theories or laws) (Bergen 2009). Yet, science education for the early childhood period, where imagination and creativity is commonplace in young children's play, has not yet been comprehensively investigated as an evidence-based model of teaching science for preschoolers. This is particularly surprising given the potential links between play and science inquiry. Could a play-based model of teaching science that supports the creative cognition of pre-schoolers encourage more teaching of science? Unfortunately, we cannot answer this question because very little is known about what might be an effective model of teaching science through imagination in play in play-based settings—especially for infants and toddlers, where a dearth of research exists (Sikder and Fleer 2014).

In this paper, the findings of a case study of 26 children and 3 teachers are reported. The focus of the research was on how teachers engaged children in scientific play and how imaginative play promotes scientific learning in play-based settings. This paper begins with a brief review of the relevant background literature, followed by the conceptual framework guiding the study, the study design and then the findings and discussion. The paper concludes by outlining a cultural-historical approach to teaching early childhood science, named as a *Scientific Playworld*.

Knowledge Forms and Imagination in Science for Under 5's

Reviews of the learning of preschool science suggest two types of interrelated knowledge domains—domain-specific science learning (e.g. what children know about a concept) and domain general knowledge, such as the cognitive skills needed to understand the domain specific knowledge (e.g. process skills or scientific thinking) (Trundle and Saçkes 2015). The former has traditionally been studied in relation to a range of science concepts, such as astronomy (Hannust and Kikas 2007), electricity (Fleer 1995), food (Cumming 2003), digestion (Martins Teizeira 2000), natural science (Venville 2004), force (Hadzigeorgiou 2002) and matter (Krnel et al. 2005). The latter research has focused more on determining children's abilities in how things function and work, as models for supporting everyday life (Cook et al. 2011; Gelman and Brenneman 2004; Howitt et al. 2011). What these latter studies point to is the general ability of preschool children to engage in scientific reasoning or thinking skills (e.g. Bulunuz 2013; Eshach and Fried 2005; Metz 2004). But these studies and reviews do not give insights into what might be a model of science teaching for play-based setting where scientific thought experiments and visualisations of science through play are used to support the learning of science concepts.

In contrast, there is some promising evidence of the relations between imagination in play and creative cognition in science that supports the link between visualisations of big ideas in science and play. The characteristics of curiosity (Blake and Howitt 2012) and wonder (Hadzigeorgiou 2001; Siry and Kremer 2011), alongside of children imagining scientific concepts during role-play (Fleer 2010), have been identified. What is known is that when scientific problems are introduced during children's play (Fleer 2011) where teachers role-play scientific concepts with children (Fleer 2014), more authentic science learning has resulted (Fleer and Pramling 2015). But these studies do not discuss the pedagogical practices linking imagination in science and imagination in play.

Although children's natural curiosity has been studied during science concept formation (e.g. rainbows to understand concept of light refraction; Siry and Kremer 2011), and playful approaches have been shown to help children satisfy their curiosity, we do not yet know enough about what forms of guided play enable exploration of authentic interests (Blake and Howitt 2012) and scientific imagining (Hadzigeorgiou 2016) of young children. The available studies point to the need for better understanding how to draw upon a pedagogy of play for supporting science teaching in early childhood settings.

Models of Teaching Science to Preschool Children

What is known about the existing teaching models of teaching science to preschool children is that the available models tend to concentrate on setting up resource rich learning environments (e.g. Zhang and Birdsall 2016) where discovery learning is promoted (Fleer 1995; Fleer 2009), but where many opportunities to teach science in play-based settings are lost (Tu 2006).

It appears that early childhood teachers' models of teaching science draw upon the methods and approaches transferred from primary and secondary science education where the foundational research is based on learning environments suitable for children older than 8 years (Fleer 2009). Teachers have difficulties with inquiry-based approaches (Fleer 2009, 2011b), because the children have different developmental capacities, do not readily ask scientific questions that can be used as the basis for the inquiry (Fleer and Pramling 2015) and teachers lack confidence in their knowledge of science concepts (Garbett 2003). More needs to be known about what kinds of existing and new pedagogical practices could support science learning in play-based settings.

Whilst there are a lot of models of play in the literature (e.g. Pellegrini 2011), conceptions about play across cultures (e.g. Göncü et al. 2007) and definitions for what is play and what is not (e.g. Lillard 2007), there is no model of play specifically developed to support science learning. The closest possibility is an approach known as Playworlds. This approach includes the teacher in children's play (most definitions of play do not) and it foregrounds a problem scenario (as a play inquiry) as part of building a play narrative (Hakkarainen et al. 2013). There is a lot of research interest in Playworlds in Sweden (Lindqvist 1995), Finland (Hakkarainen 2010) and the USA (Ferholt 2010). But this research has focused primarily on building play narratives over extended periods of time (e.g. Lindqvist 1995) rather than focused on scientific learning of young children. However, what appears to be unique about Playworlds is that it gives a pedagogical role to the adult (see Hakkarainen et al. 2013), which actively supports imagination, and which in turn has been shown to develop children's imaginative play (Lindqvist 1995). As such, the present study drew upon Playworlds to design and study a model of science teaching for play-based settings that featured teacher strengths in the pedagogy of play.

Conceptual Framework

The conceptual framework guiding this study is based on a cultural-historical theory for informing a strength based view of science pedagogy (Zeidler 2016), particularly Vygotsky's (1966) conception of play for framing the unique nature of early childhood education. Vygotsky theorised play as the creation of an imaginary situation, where children change the meaning of objects and actions, and give them a new sense. Vygotsky proposed that this can be seen when a child uses a stick to act as though riding a horse. The child has changed the meaning of the stick to be a horse, and changed their actions to be a horse rider. Vygotsky's premise is that in play, children imagine and create new meaning, supported by objects, actions or words. In this study, it was thought that this cultural-historical conception of play could be used to theorise how children change the meaning of actions and objects in their play to take on a scientific meaning.

Vygotsky's conception of play alone does not theoretically explain what might be the force for the development of scientific thinking, imagination and dealing with contradiction. Other concepts were needed for understanding the scientific play of children. The study used the concepts of *drama* and *dual positioning*.

Drama-Based Play and Active Exploration of Imagination in Science In a cultural-historical reading of role-play, play pedagogy is psychologically connected to Vygotsky's conception of drama. The genesis of cultural development as proposed by Vygotsky (1997) suggests that when children engage in drama, every function in the cultural development of a child appears in two planes—in social relations *between people* (interpsychological level) and also *within the child* (intrapsychological level). Vygotsky (1997) proposes that it is through drama that children develop and gain different perspectives and gain new insights. At the interpsychological level, children become consciously aware or explore that which they are role-playing. Importantly, it is through drama that the feeling of "we" rather than "I" is created, as a form of social consciousness (multiple perspectives). The child actor creates on the stage infinite sensations, feelings, or images that become a visualisation of the whole theatrical performance with the audience. Children's play as a form of drama, potentially enables a collective consciousness about everyday life events, such as pretending to ride a horse, that has the potential to be directed to thinking and imagining in science. But this requires a more refined understanding of the psychology and pedagogy of play for science learning in play-based settings.

Two-Positional Perspective Kravtsov and Kravtsova (2010) introduced the concept of a two-positional perspective in play, where the idea of audience is central for children's development. They stated that "play from the "dual (or two)-positional" perspective allows the child to better understand him/herself, as well as understanding the surrounding world" (p. 33). The child is inside the play acting out what s/he has experienced, observed or read/viewed in everyday life (e.g. nature, cooking at home, phenomenon on TV, a smart device games or in books), whilst also being able to step outside or above the play, directing how the play should take place (e.g. as we see when child changes the play).

Using the concept of a *two-positional perspective* supports the analysis of children's modelling in play and science through analysing when children visualise, model or imagine scientific concepts during play. In play, children use metacommunicative language (Bretherton 1984), such as "Pretend I am inside the drop of water or inside the compost bin", and use a sing-song cadence at the end of a sentence to signal that they are inside the imaginary situation to their play partner (…and the worms were wriggling around [inflexion on the word around]), signalling an invitation to imagine along with them, and use conjunction words to keep the storyline going (e.g. *and* or *then*). Analysing children's metacommunicative language from a two-positional perspective gives more confidence in research about when a child is in the imaginary situation and when they are not. Metacommunicative language also has the potential to signal in the analysis particular modelling and potential thought experiments being tested in their play (e.g. wriggling worms who are exploring how a worm moves without legs). Further, teacher use and modelling of metacommunicative language specific to preschool science, such as "I wonder if…", has the potential for better understanding how play-pedagogy could consciously and systematically over time support science learning in play-based settings. But a cultural-historical study of this kind has not yet been undertaken.

A summary of the concepts that informed the study design and analysis is shown in Table 1. In keeping with a cultural-historical informed study that features a system of concepts, the content of the table is provided to show which concepts were used in this particular study.

Together, these cultural-historical concepts provided the framework for the study. What is unique about this theoretical framing is that unlike constructivist-inspired research, a cultural-historical study does not look at the end point or cognitive result alone, but rather it also seeks to capture the process of the development of children's scientific thinking.

Study Design

The study was designed as a cultural-historical case study of one preschool site where the teachers, with support from the researchers, implemented a Playworlds approach to teaching science content to young children. The goal was to understand the pedagogical practices in the play-based setting that supported the scientific engagement of the children and teachers and the development of scientific thinking within imaginative play.

Table 1 An overview of the theoretical concepts guiding the study and analytical frame

Theoretical concept	Explanation of the concepts for this study
Cultural-historical conception of play (Vygotsky 1966)	Creates an imaginary situation (adult/child) and changes the meaning of an object and/or action
Interpsychological and intrapscyhological functionoing (Vygotsky 1997)	Play is jointly created *and later* independently enacted as the social becomes the child's personal understanding. Contradictions and dramatic events create the conditions for children's development
Play from the "dual (or two)-positional perspective" (Kravtsov and Kravtsova 2010)	Signals they are in the imaginary situation through words, actions or objects. Offers solutions to problem situations inside/outside of imaginary situation
Metacommunicative language (Bretherton 1984) in collective play (Fleer 2011)	Underscores actions or words; high inflexion at end of sentence; uses words such as "Pretend I was …", uses conjunctions to blend story lines such as "and" or "then they went…"
Cultural-historical conception of imagination in science (Vygotsky 2004)	Evidence of thought experiments; visualisation of big ideas; engaging in theoretical contradictions; imagining the relations between observable contexts and non-observable (e.g. solar system, molecular level). Child creates models in play to show ideas, such as when role-playing, using physical materials to make something, draws upon symbols and uses digital animation

Sample

The preschool is located in an inner city suburb of Melbourne, Australia. The children live in high-rise flats or in small historic homes in the region. A mix of low and middle socioeconomic families send their children to the preschool. The centre operates from 9 until 3 each day.

The children who attend the preschool and whose families consented for their child to participate in the research include 6 Vietnamese heritage families, 6 Indian heritage families, 5 European heritage families, 3 Chinese families, 2 Ethiopian families, 1 Greek family, 1 Timorese family, 1 South Sudanese family and 1 Libyan family. Many of the families are newly arrived in Australia. The 26 children who attend the preschool are aged between 3.6 and 5.9 years (mean age of 4.6 years).

There are three staff who work in the preschool site and who participated in the research. The lead teacher holds a university degree in early childhood education, and is of European heritage origin. Another teacher is completing a degree in early childhood education. She holds a Bachelor's degree in science and has a vocational qualification in early childhood. She speaks fluent Vietnamese and is of Vietnamese heritage origin. The third teacher has a vocational qualification in early childhood and she is of Chinese/Timorese heritage origin. Two of the three teachers have over 10 years of teaching experience in early childhood education.

Procedure

Professional Development

To achieve the aims of the study, the procedure was organised to include professional development.

1. All teachers participated in professional development in their centre on a *Playworlds* approach.
2. A booklet of teaching ideas and supporting material about Playworlds was given to the teachers.
3. The brainstorming of science teaching ideas suitable for Playworlds was supported by the research team.
4. Identification of both a play narrative or story (The Magic Wishing Chair by Enid Blyton) and related science concepts (microbes and microscopic organisms) was undertaken to support the teachers. This story focuses on preschool aged children going on adventures to other imaginative lands by sitting on a magic chair. The magic chair has wings and flies the children to new adventures on different days.
5. Ongoing professional support for the science concepts was provided to the teachers.
6. Teachers implemented the *Playworlds* approach over 4 weeks during one school term, but with a focus on developing science concepts.

Video Observations

Video observations were made over the 4 weeks of implementing the *Playworld*. Two and sometimes three cameras documented the play-practices of the children and teachers during the *Playworld* activity, the general play in the outdoor area, all group times and all of the scientific investigations that occurred either to support the *Playworld* or as a separate activity outside of the imaginary situation. A total of 69.6 h of video data were generated, and 788 photographs of play practices were documented. Nine visits to the preschool were made over 4 weeks.

Interviews

The professional development session, follow-up meetings and informal interviews in situ or held at the end of most weeks formed part of the data set. This part of the study design took place over 6 weeks. All sessions were video recorded and sessions not recorded were discussed through an interview on a subsequent day when the research team visited the site. Interviews were usually in relation to what was happening on the day of filming and what had previously taken place in the day or week when the research team had not been present. This allowed for instant capturing of teachers' perspective on what had happened in the course of implementing their program.

Analysis

In line with the theoretical approach of the study, the data analysis framework drew upon Hedegaard and Fleer (2008) cultural-historical methodology for studying young children. Three iterative analytical dimensions encompass the cultural-historical methodology used—everyday interpretations, situated interpretations and theoretical interpretations.

Everyday Interpretations

Step 1: Data were digitally logged in their raw form with annotations and summaries of their content (e.g. *RB008*).

Step 2: Data were tagged in relation to teachers' pedagogical practices when using a *Playworlds* approach for teaching science.

Step 3: Data were also tagged in relation to the moments in which children imagined, appeared to exhibit behaviours and make comments related to thought experiments, and when showing behaviours or words associated with visualisation.

Step 4: Data were also tagged for free play moments outside of the *Playworlds* teaching, and also play related investigations inside and outside of the *Playworlds*.

Situated Interpretations

Step 5: The *everyday interpretations* (steps 1–4) across the whole data set were cut into video clips (e.g. named as *Clip 3*). These everyday interpretations were put in a digital folder focused on differing descriptors of pedagogical practices linked with imagination in science behaviour and teachers' pedagogical practices. Central here was identifying science moments across the data set.

Step 6: Common trends or themes were identified and the folders further refined and named according to the situated practices, such as imagination in science, thought experiments, visualisation, science concepts and curiosity in science (e.g. coded as *131,113*).

Theoretical Interpretations

Step 7: In line with the goals of the study and the theoretical concepts informing the research (Table 1), links were made between digital folders of video clips (e.g. coded to *08S*). For example, the cultural-historical conception of play was used to identify if, when and how children changed the meaning of actions and objects in their play to be scientific. Folders were digitally brought together in relation to the play practices of children and pedagogical features of the *Playworld* approach used by the teachers, but always in relation to teaching, promoting or imagining of science concepts by children, by teachers and by children and teachers together (e.g. named as *Playworlds*).

Step 8: Representative examples of video or teacher or/and child(ren) dialogue for each of the outcomes of the theoretical interpretation were made and used to highlight some of the key pedagogical practices of the resultant *Scientific Playworld* (discussed in findings). **Steps 1–8** were iterative, because the emerging theoretical categories were used to re-analyse the full data set for frequency, type, duration and quality of pedagogical practices/imaginings. Pairing of science pedagogical practices and children's scientific imagining as evident through the play actions drove this final part of the theoretical analysis. This allowed for an understanding of how imaginative play promotes scientific learning (Research Question 1), as well as how teachers engaged children in scientific play (Research Question 2).

Findings and Discussion

The focus of the research was to understand how teachers engage children in scientific play in preschool settings. The study found a range of ways in which guided imaginative play can be designed into play-based teaching programs to intentionally engage young children in scientific thought. The major pedagogical practices for promoting imaginative scientific play were found to centre around building collective scientific imaginary situations where children and teacher could engage in shared and sustained scientific wondering.

Building Collective Scientific Imaginary Situations

Even though the literature collectively indicates that play is culturally learned (e.g. Lillard 2007), current pedagogical practices tend to treat play as universal and natural. As a result, very little research attention has been directed to how imaginative play as a learned practice, can be explicitly introduced to support abstract learning in science. However, in this study, it was found that a key practice in play observed was the building of collective scientific imaginary situations.

Three different ways of building collective scientific imaginary situations were evident in the data. First, the teachers drew upon their practice of reading stories to create a collective imaginary situation with the children at group time. The story of the *Wishing Chair* was used to build an imaginary situation. However, the selection of the story was not random. It was important for the teachers to introduce *a story which had a structure that allowed the children to collectively go on adventures*. The story of the *Wishing Chair* created the conditions for the children to imagine themselves, going on the chair and flying to faraway lands for exploration. In line with Hakkarainen (2010), the story selection invited the children to jointly create "imaginary situations based on tales, stories and children's fiction (ideal cultural forms) which serve as the basis of adult-child joint playworlds and child initiated pretend play" (p. 79).

Second, the pedagogical strategy used by the teachers featured some kind of psychological tool to support the children's collective imaginings of going on adventures stimulated through the story of the Wishing Chair. The teachers put a chair into the space where the children sat for group time. The chair acted as a placeholder for the imaginary situation being collectively created, and this object supported all of the children to imagine the journey together. The chair helped the children to imagine the journey. This is consistent with a *Playworlds* approach. As suggested by Hakkarainen (2010), "In all playworlds some kind of psychological tools was used in transitions from classroom to imaginary playworld" (p. 79). He gives the example of the stories in the Narnia series by C.S Lewis, in particular the story of *The lion, the witch and the wardrobe* to create a *playworld*. A cardboard box was fixed to a doorframe to act as the entry into the *Playworld* of Narnia. This cardboard box mounted to the doorframe marked the boundary between the *Playworld* and the classroom. He also gives the example of the fairytale of Rumpelstilskin. In this *Playworld*, a spell is placed on the palace, turning it upside down and making everyone walk backwards. The psychological tool used for the transition is the act of the children turning their jackets inside out, with the buttons on their backs, and walking backwards. This action by the children marks that they are in the palace—in the *Playworld*. But these children (over 6 years) were much older than the children in this study.

The wishing chair in the present study lent itself to psychologically supporting the children to transition from the preschool and into the *Playworld*. The wishing chair also physically acted as a "placeholder" for the imaginary situation being created. According to Vygotsky (2005), initially objects, then actions, and later words act as placeholders in the development of complex play. In line with Vygotsky's (1966, 2005) conception of play, the children and teachers in this study used placeholders to support the whole group to imagine together. But this practice alone did not guarantee that a scientific narrative could result or that children could imagine scientific explanations or concepts. The study found that the story of the Wishing Chair could support the building of collective scientific imaginary situation. However, it did not result in a scientific imaginary play situation being developed. But what was important was that the teachers needed to work with the familiarity of a regular story to create a *Playworld*, before they could work with building a *Scientific Playworld*. This outcome of the study was evident through their planning documentation and comments made in situ during interviews.

A third key dimension of building a collective scientific imaginary situation was the use of a range of cultural devices that more closely linked to the science that the teachers were supporting the children to learn. In this case study, the teachers were exploring the microbes in their environment through using a microscope and hand lenses to study the contents of the compost bin and also samples of pond water from the outdoor play area. Magnification was also a new concept that had to be explicitly introduced, if children were to engage with the concept of microbes. The children used hoops on the ground in the outdoor play area and magnifiers to identify a boundary and study closely the life evident within the enclosed space. For example,

> *Alex, and his teacher are in the outdoor area. They each have a magnifying glass. A hoop has marked a space on the ground. The teacher holds a large spoon which act as a digging device and also as a pointer. They have been exploring the area. Alex says, "Let me just look in the hole once more". The teacher repeats Alex's comment and invites further comment, "It is getting bigger. Is it?". Alex responds by saying, "The hole when I look in my magnifying glass… Don't you want to have a look?". The teacher says, "Sure. Can I look through mine or yours?". Alex responds, "You can look through mine. Do you see anything big?". The teacher looks closely and says, "Makes these (pause) um… rooty, planty sort of things down here look big.". Alex confirms this observation, and says, "I can see it all big". The teacher pauses and reflects, "Umm" and then says, "I can see it looking a bit bigger too"* (RB 23 24).

In addition to the magnifiers, the children also used iPads for magnification. The teachers wanted the children to learn about small and microscopic organisms. The digital devices available to the children supported their explorations of the environment because they could zoom into very small organisms to see them clearly, but also to document their finds as photographs or video clips to share with each other at another time. However, having these experiences with these devices did not necessarily result in the imagining of scientific concepts. The study found that the teachers needed to build a *scientific narrative* which would allow the children to role-play being microscopic, so that they could consciously think and embody what they were experiencing. For example, the use of a fabric tunnel acted as a cultural device to support the children to imagine going down the microscope they had been using in the centre. But also, the fabric was used to support the children to imagine being a worm or a caterpillar/butterfly (Fig. 1), as the following example (Wayne, Jackie and Chantelle) illustrates:

> *Wayne and Jackie are standing next to Harriette the teacher. Harriette is holding the tunnel so that the children can crawl through the tunnel. The children crawl through the tunnel, laughing and smiling, and then return to Harriette to have another turn. The children continue to go through the tunnel. Harriette comments on their movements. Chantelle walks past a few times, carrying a handbag at each pass. She eventually stops and says, "What is that Harriette?". Harriette pauses, and says, "It is aaaa…. It could be a worm skin, a worm sack". Chantelle responds by saying, "That was that!". The*

children giggle and squeal. Harriette notices that Chantelle has moved closer, and gestures to her to have a turn. Harriette says, "Chantelle is going to have a go". The children together with Harriette explore the fabric tunnel in a new way. Harriette invites the children to stand once they are inside the tunnel. She does this many times, but on each occasion the children continue to crawl through and out of the tunnel. Harriette then takes the fabric and goes inside, standing up, and exclaiming, "I am too big for the tunnel". The children laugh and ask if they can now stand inside the tunnel. Jackie says, as he goes into fabric tunnel, "Butterfly". Harriette affirms this by saying, "A butterfly yes". Wayne shows interest and Harriette says, "You could be the butterfly and go inside it like this (models going into the fabric tunnel). If you stand up in here". Harriette then supports the children to stand inside the fabric tunnel. Jackie flaps his wings and flies around the fabric tunnel. Harriette says, "There you go. Butterfly wings are going" (RB008 131113 08S; Clip 3).

The approach adopted was discussed by the teachers with the researcher during interviews:

Teacher: Part of that thinking and experience about what it is to be tiny, enjoyed by Wayne and Jackie who used the tube of fabric—crawling through. Howard also joined in. They often don't spend time together, so Howard was inspired to join in and that was fabulous. I am a bit of a spur of the moment person, as we did at the end of the morning with the mats and hats, and 'imagine if'. I was pleased that most of the children gave that a go.
Researcher: …the wriggling, they were able to role play
Teacher: To interpret that…
Researcher: …crawling through the microscope (Fleer 2017).

The teachers also introduced a plastic bubble (an inflated 3-m plastic bubble; as shown in Fig. 2 below) to the children. The children and the teachers went inside this bubble imagining they were inside a drop of pond water that they had previously studied:

Harriette: Imagine if this was like a drop of water
You're inside the drop of water.
What might you do?
Alicia: Good.

Fig. 1 Fabric tunnels to support imagining

Harriette: Oh you are going swimming under this Alicia.
Fiona: Swim. Good
Alicia: Hey we go in the waterrrrrrr…..
Harriette: Can you see outside the drop of water?
Fiona: Yep (Fleer 2017).

The teachers' introduction of a cultural device that closely mirrored what they were experiencing and which relied upon their imagination was an important part of the *Scientific Playworlds* approach being implemented. The cultural devices mirrored the scientific investigation, and the bubble and the fabric tunnel, physically acted as a placeholder for their imaginary situation. But unlike the chair, the children's narratives in the imaginary situations were more scientific. The children's experiences with magnification of organisms in their environment enriched how they could play in the collective scientific imaginary situations. Vygotsky (2004) has postulated that the "creative activity of imagination depends directly on the richness and variety of a person's previous experience because this experience provides the material from which the products of fantasy are constructed" (pp. 14–15). It is not possible to imagine being inside a drop of pond water, if a child has not had experiences of knowing what organisms might be found there, or have had access to tools to study a drop of pond water. Further, a child does not need to directly experience everything. Vygotsky (2004) suggested that "a person's experience is broadened, because he [sic] has to imagine what he has not seen, can conceptualize something from another persons' narration and description of what he himself has never directly experienced" (p. 17). The study found that the experiences when re-presented through role-play in the bubble or after going down a fabric microscope appeared to make conscious to the children through the dramatisation of their experiences, important scientific dimensions of their everyday world—but ones not easily seen by the naked eye. This is consistent with the manner in which Barbara McClintock investigated the jumping gene. She imagined herself going down the microscope, projecting herself inside the microscope joining the chromosomes. She said, "If you want to really understand about a tumor, you've got to *be* a tumor" (Fox Keller 1983, p. 202; original emphasis). Through imagination, she developed an "exceedingly strong feeling" for the oneness of things" (Fox Keller 1983, p. 201). That is, her approach "both promotes and is promoted by her access to the profound connectivity of all biological forms—of the cell, of the organism, of the ecosystem" (Fox Keller 1983, p. 201), and through this, she was able to change the course of genetics research.

Fig. 2 Setting up and exploring the bubble—being inside a drop of pond water

But these cultural devices of fabric microscope and the plastic bubble alone would not have supported the development of scientific thinking in this study. Much of science being explored is not directly observable. Many science concepts have to be imagined. Building collective scientific imaginary situations was found to support the children to develop their play, imagination and therefore their scientific understandings over time. But play is not only imaginative but also emotionally charged. Introducing scientific experiences, and using cultural devices to support the role-playing of scientific imaginings on their own, are not enough for engaging young learners in scientific thought. As such, it was found that emotionally charged situations appeared to help engage the children more in the collective scientific imaginary situations. This was the fourth important characteristic of building a collective imaginary scientific situation:

> *The children are in the outdoor are. Some of the children are holding hand lenses. The teacher faces two children Mitchell and Alex and says, "Mitchell you go and choose the log you want us to look under". Mitchell uses marching actions with his hand walks purposefully to a series of logs. The teacher and Alex follows. The teacher says, "Today might be a really good day for finding things, because..." and then in a high pitch and emotionally engaging playful voice she continues, "the ground has been made very wet with the rain". Alex says with energy, 'Because bugs LOVE rain". The children move around to a log that faces Mitchell, as the teacher asks, "Bugs love rain, do they?", Alex responds, "Yeah, 'cause I watched it on telly and I saw they did like rain". Mitchell says to Alex with enthusiasm, "…and they are SO funny". Alex then makes grunting noises, saying with enthusiastic and forceful tone, "Let's go here, and …". The teacher asks for helpers to push over the log, as another child, Renata joins the group. As they push the log over Alex says, "Aaarrrr... I am strong!!". The teacher immediately comments in an exaggerated tone "Oooo I can see a worm. Ooo I can see another bug. O O O O. What's down here?" and at the same time Alex says with great passion, "O, Arrr". The teacher points and continues with great emotionally charged expression, "...and a slug". Mitchell says with great excitement, "I see… I see... a worm, like a 'snap!'* (RB011 131115 08PS4: Clip 1).

In the *Playworlds* literature, dramatic collisions are featured because many of the tales and stories are emotionally charged. They create some form of tension, such as being shipwrecked and encountering Captain Hook on a voyage, or meeting the wolf three times in the fairytale of the three little pigs or identifying with Wilber by feeling frightened and worried for the spider in the story of Charlotte's Web. In this study, the children conceptualised their experiences and used tools to explore the concept of magnification. Magnification was not only a challenging concept but also appeared to represent a dramatic contradiction for the children. For example, the teachers introduced to the children a giant shoe and invited the children to imagine themselves wearing the giant shoe. This created an obvious contradiction between the size of the children's feet and the giant shoe. The children were experiencing, but also imagining this contradiction.

> *Harriette the teacher asks, "Imagine, you were Cinderella and your foot could fit inside this shoe". Harriette holds up the large shoe and all the children gaze intently at the shoe. "Whose shoe is that?" exclaims one of the children loudly, appearing to show amazement at how large the shoe is. Harriette asks, "Do you know the story about Cinderella?" and many of the children respond "I do". Harriette briefly summarises the*

story of Cinderella, drawing attention to the problem scenario of finding the person who would fit into the shoe found. Harriette then asks, "Do you think we have got someone here who might fit into this shoe?". "Me", "No me" call out many of the children. Harriette asks, "Would you like to try?"… Harriette then invites the children to take off their left shoe, and then in turn they each try on the shoe and then try to walk in the shoe. Harriette then asks, "Imagine if your feet could fit in there". Harriette comments or responds in relation to the children's responses to trying on the shoe: "Imagine how big you would be if you wore this shoe" … The children discuss where the shoe has come from, and Harriette reports that the shoe was from an American Basketball Association. She tells the children it is size 55 and then invites the children to look at their shoe size, noting many are size 3. Harriette then concludes, "So if you were big enough to fit into this shoe, I think you would be a giant" (RB008 131113 08S; Clip 3).

These moments of contradiction were observed in other scientific narratives developing over the 4 weeks observed. The drama associated with finding and observing spiders (see Fleer 2016) and imagining how it is possible to be inside a drop of water when you are so big or drawing oneself as part of a study of microbes (Fleer 2017) were dramatic for the children. The contradiction between being small in an adult world but being big in a microscopic world was felt and emotionally expressed when making discoveries under logs in the outdoor area. Although the contradictions are not always dramatic, they appeared and developed as part of the scientific narrative that was forming in the play-based setting in a range of different ways, such as log investigations; role-playing being inside a fabric tunnel as a worm; being in the plastic bubble pretending to be inside a drop of water; using the digital microscope to study hair, soil, water, skin, etc.; iPads to zoom and explore for creatures; and using hand lenses exploring the compost bin.

Scientific narrative development can also be found in the unstructured play of students in secondary school. For example, Andree and Lager-Nyqvist (2013) found that play can and does support scientific learning of difficult concepts. For instance, they note that play is initiated and used as part of their practices. For instance, they found

- Different tone is used to initiate an imaginary situation where each child acts in a new role (e.g. role of witch man), partially transcending the given task of predict, measure and record. Here, the children are resistant to the existing classroom practice of a step by step procedure.
- The division of labour creates the possibility for inventing a new approach for the use of the equipment, whereby meaning is made of the science experiment by being a doctor and an assistant—role-playing as they become familiar with the microscopes.
- Students invent new rules for performing the set science experiment, such as "invents rules of fermentation (the dough has to rise) and where the wheat flour becomes a pivot to the imaginary situation" (p. 1747).

Andree and Lager-Nyqvist (2013) suggest that a collective narrative forms in the science classroom. That is, "through play, the students in these classrooms interpreted their experiences, dramatised, gave life to and transformed what they knew into lived narratives" (p. 1747). They concluded that even though the students did not follow the prescribed scientific approach, with step by step procedures, rather they played in a range of ways, their actions were never off task and then they argued that the learning was more meaningful and deeper. But young children with less-developed skills in play need support with collectively building scientific narratives in their play. The present study found that for scientific play to emerge, the teachers had to specifically build the play narrative with the help of cultural tools, such as the microscope, the hoops, hand lenses and the plastic bubble. Scientific play narrative was a learned cultural practice that the teachers needed to pedagogically support. The teachers drew upon their pedagogical strengths of interacting with children in play-based settings, but in this study with its focus on science, the teachers used particular forms of discourse to build shared and sustained wondering in the *scientific imaginary situations* they created.

The key feature of the program that involved wondering can be seen in the expansive example that follows: Harriette the teacher wonders with the children, but she also asks the children to imagine the different attributes of the slug. The children observe and discuss the stretching of the slugs, but also wonder what it might be like if they oozed slime from their bodies.

> *The children are looking under logs with their teacher Harriette. The children turn over a log and many organisms, including slugs, became visible. Harriette says, "We are watching the slug. Let me have a look. They are disguised in the tanbark". The children take it in turns using the hand lens. Alex says, "Look he is really getting longer". Harriette responds, "Ummm…he might have come to a stop". Mitchell in an excited tone says, "I can see slime coming out of him". The teacher thoughtfully asks, "Oh is that his slime? Gosh, imagine if you had slime that came out of your feet, or out of your fingers, everywhere you went". The children laugh. Then Harriette* asks, *"Do you see the white, sort of fibre bits here. Oh, if I peel that back... What do they look like under the magnifying glass?". Mitchell responds, saying, "He is getting longer". Harriette notes this: "You are right, he is getting longer". Mitchell then says to Alex, "Alex you look under it" as he hands over the hand lens to Alex. "Wow he is REALLY stretching out", says Alex. Mitchell asks, "Can I have a look?". Alex hands back the magnifying glass to Mitchell. Mitchell moves closer to the slug and says, "Let's see what they look like?". The teacher inquires, "I am interested to know what this...". Mitchell interrupts and says with great excitement at his discovery, "That slug, it got LONGER". The teacher asks, "How did it get longer?" to which Mitchell responds by saying, "Because it is stretching. Arrrr". Harriette wonders, "Do you get longer when you stretch?". Mitchell moves his arms up and out away from his body, as Harriette says, "Wow. Looks like you are right". "Watch this" says Alex as he also stretches out. Wow" says Harriette. Alex says," I am SO long". Harriette then stretches also. Alex says, "Do you want to see how tall I am?".*

The continual references to imagining and wondering by the teachers supported the building of a scientific narrative. Hadzigeorgiou (2001) puts forward the view that *wonder* is an emotional quality that captures an important relationship between the child and their environment and that this can be pedagogically supported in preschools by teachers. Hadzigeorgiou (2001) argues that the building of a strong conceptual base through science learning "cannot take place without the establishment of a long-term relationship between the world of science and the child. This relationship can be established only if children are helped to develop certain attitudes towards science" (p. 64). Hadzigeorgiou (2001) comments that "Wonder, in fact, gives things their meaning and reveals their significance" (p. 65). In this study, wonder was *not* something that was naturally *within* the child as a scientific way of interacting with the environment, but rather *wonder was socially produced* by the teachers through how they continually spoke about the environment, events and introduced activities.

As has been suggested by Fensham (2015), wonder has two meanings. It can be the sheer wonder of something that is the awe experienced—this was evident when the children were looking under logs at all the organisms found there. But wonder can also be a phenomenon which starts someone questioning. In this study, the teachers also created this through how they inquired in situ about things that emerged or which were specifically introduced, such as the wondering about the giant shoe and whose foot it might fit.

Scientific Playworlds: a Model of Teaching Science in Play-Based Settings

In sum, the findings of this study suggest that a *Scientific Playworld* has the potential to pedagogically support teachers to take up an intentional and dramatic role in supporting imagination in science—something they are likely to be good at doing due to their work in play-based setting and specialist training. But in this study, for *playworlds* to develop scientific narratives, some key pedagogical characteristics were important. The teachers needed to build a *scientific narrative* which would allow children to role-play scientific ideas, such as being microscopic. The role-playing allowed the children to consciously think and embody what they were experiencing. A wondering discourse was needed for broadening or widening the scope of the imaginary situations. Further, the teachers' introduction of a cultural device needed to closely mirror what the children were scientifically experiencing, so that it drove or enriched children's imaginings. In these collective scientific imaginary situations, emotionally charged situations appeared to help focus attention and engagement on the science concepts being explored. These pedagogical principles for supporting a *Scientific Playworlds approach* are shown in Table 2 below in column 2 and captured as a model in Fig. 3 further.

As the goal of this study was to better understand how play-based settings, such as preschools, can support young children's scientific thinking, it was important to determine those pedagogical practices that were in tune with teachers' pedagogical strengths in promoting learning through play. Those pedagogical practices that emerged as key for the collective building of a scientific narrative and for promoting scientific learning in imaginative play are shown in column 2. They are in line with what is known about the pedagogical practices of Playworlds (shown in column 1). But they are also different enough to warrant the research attention given and summarised in column 3 and theoretically supported in column 4.

The findings of the study and the framework summarised in Table 2 are suggestive of the need to go beyond a simple statement that children learn through play, and consequently will learn science concepts through play. Further, Vygotsky's conception of play alone did not theoretically explain how the development of scientific thinking was promoted by the teachers. As such, the outcomes of this research show the need for a model of teaching science that is based on empirical evidence of how imaginative play promotes scientific learning. The framework of pedagogical practices that are shown in Table 2 are drawn from this study, and potentially act as a basis or possible foundation for a model of pedagogical practices that together create the conditions for children's scientific thinking in imaginative play contexts. Figure 3 shows the relations between the pedagogical practices that were found to iteratively support the teaching of scientific imagining, wondering and thinking in this study.

A model for the teaching of science in play-based settings is urgently needed by early childhood teachers. Scientific Playworlds which begins with the collective scientific imaginary situation, and which draws upon a cultural device that is related to the science being learned, and which invites children to go on scientific journeys, together create the dynamic imaginary scientific context. These findings are theorised and shown in the top half of the model in Fig. 3.

Table 2 The key pedagogical characteristics of *Scientific Playworlds*

Pedagogical practices unique to *playworlds*	Pedagogical principles to support *Scientific Playworlds*	Examples from the data set	Theoretical concept
A story with a structure that allows the children to collectively go on adventures		Children *imagine going on adventures* inspired by the *Wishing Chair* by Enid Blyton	Playworlds (Lindqvist 1995
Psychological tool to support the transition from the preschool and to the imaginary situation	Cultural device that closely mirrors what the children are scientifically experiencing	*Fabric tunnel* was used for simulating science experiences and a plastic bubble for imagining being inside a drop of pond water	Playworlds (Lindqvist 1995
Being inside the imaginary play, taking a role	Creates an imaginary scientific situation (adult/child)	The teacher or a child changes the meaning of an object, for e.g. when using the fabric tunnel for imagining being a worm, "*It could be a worm skin, a worm sack*".	Cultural-historical conception of play (Vygotsky 1966)
Being deliberately in frame, setting problems up inside the imaginary play; inviting children to imagine together	Collectively building scientific narratives scenarios or problem situations	Play is jointly created *and later* independently enacted as the social becomes the child's personal understanding. *Alex in an excited tone says, "I can see slime coming out of him". The teacher thoughtfully asks, "Oh is that his slime? Gosh, imagine if you had slime that came out of your feet, or out of your fingers, everywhere you went".* Contradictions and dramatic events create the conditions for children's development	Interpsychological and intrapscyhological functionoing (Vygotsky 1997)
	Consciously considers scientific concepts	Signals they are in the imaginary situation through words, actions or objects, "*Imagine how big you would be if you wore this shoe*". Offers solutions to the problem situation inside/outside of imaginary situation, such as, *tells the children it is size 55 and then invites the children to look at their shoe size, noting many are size 3. Harriette then concludes, "So if you were big enough to fit*	Play from the "dual (or two)-positional perspective" (Kravtsov and Kravtsova 2010)

Table 2 (continued)

Pedagogical practices unique to *playworlds*	Pedagogical principles to support *Scientific Playworlds*	Examples from the data set	Theoretical concept
		into this shoe, I think you would be a giant".	
	Imagining the relations between observable contexts and non-observable concepts	Child creates scientific models in play to show ideas, such as, when role-playing, using physical materials to make something, draws upon symbols, uses digital animation, etc. "*That slug, it got LONGER*". *The teacher asks,* "*How did it get longer?*" *to which Mitchell responds by saying,* "*Because it is stretching. Arrrr*". *Harriette wonders,* "*Do you get longer when you stretch?*". *Mitchell moves his arms up and out away from his body, as Harriette says,* "*Wow. Looks like you are right*". "*Watch this*" *says Alex as he also stretches out. Wow*" *says Harriette. Alex says,*" *I am SO long*".	Play from the "dual (or two)-positional perspective" (Kravtsov and Kravtsova 2010)
	Wondering: widening the scope of the imaginary situations WONDER: "I wonder what might happen if…?". IMAGINE: "Imagine if you were a…?"; DOING: "What would you do if…?" EVALUATE: "Do you think there really are…?"	Underscores actions or words through use of high inflexion at end of sentence or emotionally charged language, *You are inside the drop of water. What might you do?* *The teacher asks,* "*How did it get longer?*" *to which Mitchell responds by saying,* "*Because it is stretching. Arrrr*". *Harriette wonders,* "*Do you get longer when you stretch?*"	Metacommunicative language (Bretherton 1984) in collective play (Fleer 2011)
Dramatises concepts; creates dramatic moments and tension	Emotionally charged situations help focus scientific attention and engagement	Engaging in theoretical contradictions—e.g. magnification process—shrinking down into a drop of water; being big in a microscopic world and at the same time small in an adult world	Cultural-historical conception of imagination in science (Vygotsky 2004)

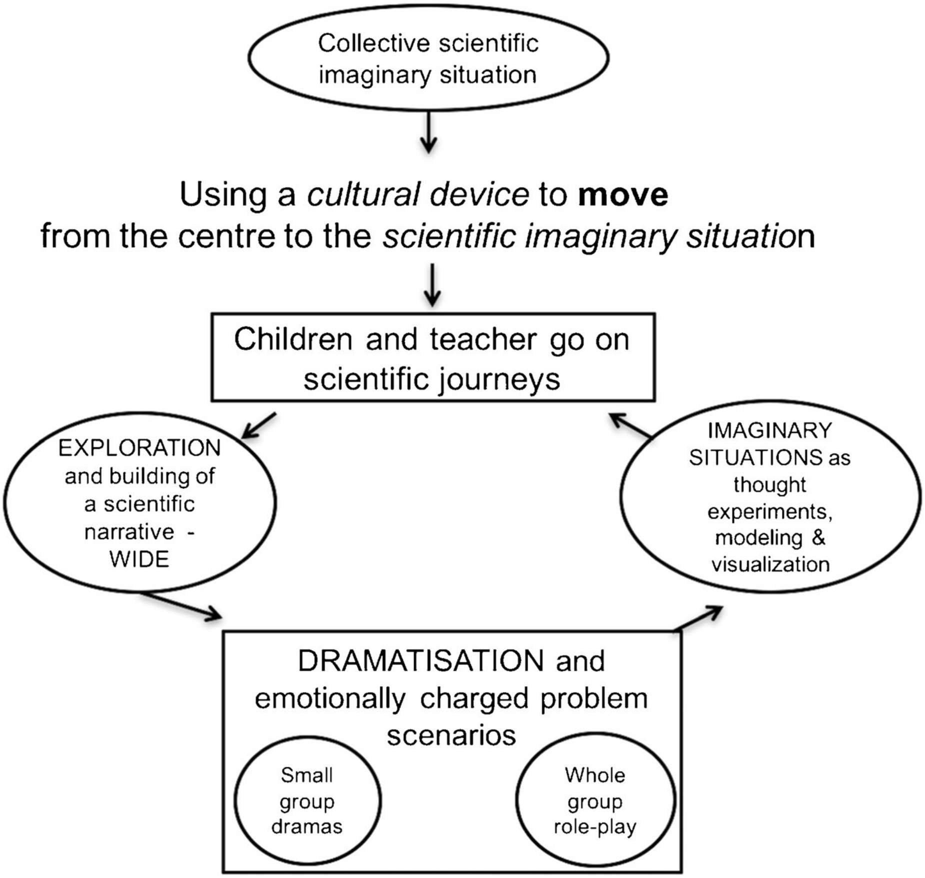

Fig. 3 Scientific Playworlds model for teaching science in play-based settings

The bottom half of the model theorises the iterative process of building the scientific narrative, where a form of drama or contradiction arises and where a scientific problem needs to be solved. This tension creates the driving force for ongoing and changing imaginary situations that this study found deepened the scientific imagining and conceptual understandings. It is theorised that it is in the imaginary scientific situations that the need for more science learning results—because of the need to solve the problem situation. In theorising the results of this study, imaginary play is the context, the motive and the narrative. But it is also the glue for holding together the science learning for the children. It is not an isolated activity, but it is ongoing activity over time that holds the children's attention and desire to keep the scientific journey going. Figure 3 brings together the findings of this study and theorises these into a model of teaching science for play-based settings.

Conclusion

This study sought to determine if and how imaginative play could promote scientific learning, as well as to identify the pedagogical strategies used by teachers to engage children in scientific play.

It was learned that the imaginary situations that were introduced using a *Playworlds* approach, combined with the scientific problems encountered, created the conditions for imagination in science. Children appeared to engage in thought experiments, when they imagined themselves being a slug trying to move along a surface. The children also used scientific narrative forms in the *Scientific Playworlds*, and engaged in mental modelling when, for example, on an adventure inside a drop of water. Finally, the dramatisation of their investigations in the compost bin or when looking at water samples from the pond in their outdoor play area created new developmental conditions for the children because they had to embody the idea of magnification and to think about a microscopic world that was not visible to the naked eye. The study found that the building of a scientific narrative, with a discourse of wondering signalled a pedagogical characteristic that turned the *Playworld* approach into a *Scientific Playworld*. Collective imagining and wondering were key, and this appeared to turn everyday events into scientific events for the children. This scientific wondering and imagining appeared to be a key characteristic of teaching science which resulted from the play-based setting and the teachers' expertise in play pedagogy. The *Scientific Playworld* approach gave a scientific structure to the teachers' pedagogical practices, and also, it supported a sustained and deepening focus on concept development over time through imagination, playfulness and wondering.

The benefit of the *Scientific Playworlds* for early childhood teachers is that it potentially gives an approach for systematically teaching science concepts in play-based settings. An approach to teaching science which utilises imagination in play is something early childhood teachers are familiar with. A pedagogical model (Scientific Playworlds) and scientific discourse (wondering and imagining) appeared to develop in the play-based setting a *scientific narrative* and *imagination in science* approach. *Scientific Playworlds* as an approach has the benefit of helping early childhood teachers to teach science because it is strength based, thus potentially supporting rather than blaming them for their lack of confidence and competence to teach science effectively (Andersson and Gullberg 2014). The results of this study may afford more teaching of science in the early years because the pedagogical practices come from researching play-based settings (rather than drawing on models developed in non-play-based settings). However, further research is needed to determine if a *Scientific Playworlds* approach would have wider appeal and use across a broader group of early childhood teachers and contexts.

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