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The place of theoretical thinking in professional development: Bringing science concepts into play practice

Abstract

Decades of research into early childhood teacher confidence and competence in science abound. Mostly what is reported is that teachers do not have the background discipline knowledge of science concepts and thereby lack confidence to teach in this area. The net effect is a worryingly limited amount of science being taught in the early childhood period. This paper proposes a different approach to conceptualising teacher confidence and competence in science through a theoretically informed study that gives new directions into how to solve the pressing problem of increasing the amount of science taught in play-based settings. Teacher participation in a face-to-face and on-line PD program over 10 weeks was digitally documented and analysed. Using the concepts from cultural-historical theory, the results show four types of crises emerged in the PD program. Through a model known as a Conceptual PlayWorld, new conditions for practice change were created to amplify concepts in play-based settings. The major conclusion was that it is not teacher knowledge of concepts that is preventing science teaching, but rather it is how to pedagogically bring concepts into play practice to motivate and sustain children's engagement in science.

Keywords: early childhood; Professional Development; teacher competence; teacher confidence

1. Introduction

The longstanding research (Andersson & Gullberg, 2014), as well as contemporary studies (Barenthien et al., 2020a), points out that early childhood teachers (Garbett, 2003) have traditionally shied away from the teaching of science concepts. Most studies identify that early childhood teachers have limited knowledge of discipline concepts in science (Saçkes, 2014), in technologies (Tagawa, 2018), in mathematics (Oppermann et al., 2016), and recently in engineering (Lippard et al., 2017). Collectively referred to as STEM, the major conclusion is that a lack of discipline knowledge leads to a lack of teacher confidence and competence in teaching science. What is missing from these studies, is a broader contextual understanding of the teaching models of science available to guide early childhood teachers. This is because most models of early childhood science teaching appear to be built on research from school-based settings that are different to preschools (Barenthien et al., 2020a). Moreover, most were designed (Blake & Howitt, 2012) by modifying established teaching models originally developed for school settings (e.g., Metz, 2004) or were designed in relation to practices that are common across both settings, such as drawing (Tytler et al., 2020) and sometimes writing (Gillespie & Rouse, 2019).

It can be asked why it is so important to have models of teaching science built on research undertaken in play-based settings? **First**, in conceptualising this problem, we have to understand the unique nature of the early childhood contexts, because it is very different to formal school settings. Organisationally, early childhood teachers are charged with designing play-based programs where young children spend most of their time engaged in play, and only come together in whole groups for very short periods. This has been acknowledged by some researchers, where "learning takes place in social, mainly play-based situations and is formed on the basis of children's daily experiences and interests" (Barenthien et al., 2020a, p. 338). This is different to setting up a science inquiry with a whole class and asking children to work in small groups and/or independently on a science challenge.

Second, we need to also understand the unique developmental period of the preschool child. Young children's leading activity is to play (Vygotsky, 1966), and it is through play that teaching programs for learning are usually organised by teachers (Siry & Kremer, 2011). In most Western contexts, preschool children expect on entering play-based settings that they will play. This is a different orientation to school age children who expect on entering school that they will be motivated towards learning, such as learning to read, and where teachers design programs specifically in relation to discipline concepts (Authors 3, 2018).

Third, there is a long tradition in early childhood education for bringing into play programs pre-concepts associated with the Arts and also literacy (Barenthien et al., 2020a). But less so for science. For instance, with the exception of the US (Lippard et al., 2017), there has simply been no imperative to intentionally and comprehensively teach science concepts to preschool children in many countries. As noted by Barenthien et al., (2020a)， "a focus on fostering academic skills is a relatively new concept in early childhood education in Germany and in preschool teachers' training" (p. 347). When societies expect the institution of preschools to introduce science concepts, this sets up a pedagogical problem for teachers as well as a psychological challenge for children whose leading activity is to play.

Fourth, teacher motivation in intentionally teaching science also matters. In the literature on early childhood teachers' professional development (PD) it has been noted that teachers' motivation for practice change (Nuttall et al., 2015) is oriented towards designing and implementing effective play-based programs (Hadley et al., 2015). Therefore, improving early childhood teacher knowledge of science through professional development of science must begin with a focus on play pedagogies and the play-based settings in which they teach.

The purpose of this paper is to present the findings of a study into how early childhood teachers create practice change in relation to the unique characteristics of their profession so that they can pedagogically amplify science concepts in play-based settings. To achieve this, the paper begins by discussing what is known about how the early childhood teachers engage in the professional learning of science, followed by a discussion of a cultural-historical study design and the findings. The paper concludes by discussing a new conceptualisation of the problem of early childhood teacher confidence and competence in science.

2. Re-conceptualising what is known about teacher confidence and competence in science

What is known about early childhood teacher practice in science has come from studies into teacher knowledge of science concepts (Barenthien et al., 2020a), teacher beliefs about STEM (Simoncini & Lasen, 2018), teacher confidence in teaching science (Fraser et al., 2019), teacher pedagogical content knowledge (Kambouri, 2016), pre-service teachers' knowledge of STEM (Barenthien et al., 2020b), and studies into the amount of science teaching in play-based settings (Olgan, 2015; Saçkes, 2014). Additionally, early studies have also examined planned and actual teaching of science in early childhood classrooms, and make the claim that, "early childhood teachers' "teaching" in science is in serious need of development" (Kallery & Psilos, 2002, p. 49). All these studies suggest that early childhood teachers lack confidence and competence in teaching science in play-based settings, and they conclude that the problem could be fixed by building up their discipline concept knowledge through professional development (Tuttle et al., 2016), better pre-service training (Barenthien et al., 2020b), and doing more high school science courses (Kambouri, 2016). Given these conclusions, and the corresponding need for system change, it is surprising that no major shift has been observed in over two decades of research into this problem. Perhaps another way of looking at teacher knowledge of science is necessary and a new way of conceptualising the problem is needed.

Notwithstanding these important findings on teacher confidence and competence in science, could these same studies point to other areas not necessarily deemed significant at the time, but which could give new directions for early childhood science education? What might be the assumptions made about early childhood teachers and the contexts in which they work? What might be missing? Asking different questions, may give new insights. If we examine the literature from the perspective of how researchers position teachers and their practices, what might we learn? With this focus in mind, we were able to determine seven areas within the literature that went beyond a simple causal relationship between teacher knowledge of science and limited teaching of science in early childhood education.

First, when considering the research of Kambouri (2016) in the context of Traianou's (2006) critique about constructivism, we can notice the importance of researcher theoretical paradigm for guiding what to pay attention to in the practices of early childhood teachers. For instance, Kambouri (2016) in adopting a constructivist view of teacher knowledge identifies a strong link between early childhood preservice teachers perceived knowledge of science and confidence to teach, suggesting deficit practices in science (Zeidler, 2016), because "teachers usually do not identify the children's preconceptions perhaps because… they might not have the necessary skills…" (p. 8). This typical correlational research dominates the literature and when we step back from this and view it more broadly, a new assumption becomes visible. To explain this, we draw on Traianou (2006) who argued that for over 20 years a constructivist paradigm has increasingly fuelled an interest in researching individual teacher knowledge of science, mirroring the longstanding research in children's alternative views and thinking in relation to science concepts. This gives a theoretical context to the research paradigm adopted and helps to explain why so many studies over such a long period of time have only examined early childhood teaching of science in relation teacher knowledge of science concepts (Barenthien et al., 2020b) or how they think and/or feel about their science teaching (Fraser et al., 2019). With this theoretical lens in mind, it is not surprising that the study designs have focused on the individual and their thinking, rather than looking more broadly at the relationship between the teachers and the context of play-based settings. *This gives a different explanation to the why the problem of teacher confidence and competence has been the research focus, and perhaps why nothing has changed in practice because the problem is seen as being in the teacher.*

Second, studies have differentiated science knowledges of teachers, primarily in studies of science-specific content knowledge. It is argued that, knowing more discipline content knowledge than what is to be taught is important (Barenthien et al., 2020a; Garbett, 2003), identifying content that is located in the everyday and familiar activities of preschools, where suitability for "implementation in play-based activities" is viewed as key (Barenthien et al., 2020a, p. 339), and finally science-specific Pedagogical Content Knowledge (PCK) is also identified as being needed and sits within a broader group of studies into PCK (Nilsson & Elm, 2017; Tuttle et al., 2016). This is in line with the arguments by Kambouri (2016) and Barenthien et al., (2020a) who have suggested that teacher knowledge of children's ideas in science is also needed. In developing a pencil and paper instrument specifically to study early childhood teacher science-specific content knowledge， Barenthien et al.,'s (2020a) recent research identified deficit knowledge base, stating that the results continue to provide evidence of a lack of teacher knowledge. However, when they drilled down into their data, their results show variability between preschool teachers' knowledge of science-specific knowledge, which they argue is due to differences in opportunities for learning science during their professional training. Important to know, is that the early childhood teachers who participated in the study had vocational, rather than university degrees in early childhood education. Yet teacher qualifications and a recognition of diverse profile of staff who are in early childhood centres, has not been explicitly considered in most studies in early childhood science education. *Therefore, recognising early childhood teachers as a composite of diversely qualified staff, from certificate to degree qualified should be considered in research into teacher confidence and competence in science.*

Third, early childhood teacher motivation for science appears to be important, yet research results on early childhood teacher motivation are inconsistent (Barenthien et al., 2020b). For instance, in a study by Park et al., (2017), who examined 830 early years teachers' responses to a survey on teaching STEM, they found that there was a heterogeneity of responses by the early childhood teachers, with approximately one-third ranking quite high in readiness to teach science, stating that, this "signals that it would be misleading to generalize the claim made in some previous studies that early childhood teachers tend to neglect teaching STEM" (p. 11). In their open-ended survey, they also found that with increased years of experience came increased positive responses in early childhood teachers' beliefs surrounding their readiness for teaching STEM, and an awareness of the importance of early childhood science education. However, they also noted that 30% said that science was not appropriate to teach to young children. In contrast, Barenthien et al., (2020b) who surveyed 301 preschool teachers on their motivation for teaching science, found a positive relationship between teachers' PD experience and science related activities in preschools. They identified that a positive relationship is mediated through professional exchanges between preschools teachers in the context of discussing science content. Given the diversity that was reported by Park et al., (2017) and the positive links made by Barenthien et al., (2020b), this opens up the question of assumptions underpinning the claims made in previous studies on early childhood teacher knowledge. Relevance of the content of the PD has also been identified by Nuttall (2013) and Nuttall et al., (2015) who note that the important role of teacher motives, stating that the object of the PD must be "understood in relation to children's play-based learning" (Nuttall et al., 2015, p. 222) and not only in the specifics of the content to be learned during the PD. *Therefore, consideration of teacher motives and years of teaching experience are needed when interpreting studies of teacher confidence and competence in science content knowledge.*

Fourth, there is also growing evidence around the impact of PD generally for increasing the amount of science taught to children in early childhood settings. What is known is that there is a significant positive relationship between in-service PD courses and teachers' self-efficacy beliefs, enthusiasm and science-specific content knowledge (Barenthien et al., 2020b). This has also been found for initial teacher education. For instance, Piasta et al., (2015) identified that when 65 teachers participated in PD of maths and science content and activities, they increased the science learning opportunities of their children, but it led to only a limited impact on outcomes for children's learning in science. The PD was designed on the principles of relevance, building specific content knowledge, pedagogical practices, active participation and collaboration, hands-on practices and self-reflection and over 14 hr of PD for practice change. In another study of PD in science for early years teachers, Park et al., (2017) examined among a number of areas, teachers' readiness for teaching. In undertaking two open-ended surveys of 830 early years teachers they identified that only 12.7% were teaching science in kindergarten. Their results suggest that *more PD is needed in relation to why science is important, alongside of knowledge of science discipline concepts and knowledge of how to teach science*.

Fifth, there were studies that looked directly at teacher beliefs about the need for teaching science concepts to young children. Simoncini and Lasen (2018) in surveying 117 early childhood teachers who had a broad range of qualifications (postgraduate to vocational certificate level), and identified that science was thought to be important by them, but ranked it behind social and emotional development. Specifically, they noted that science was thought to be important for children's future, and they found that teachers made explicit reference to 'play-based' and/or 'hands-on' learning experiences in their definitions of science and formal science learning. Unlike previous studies which suggest that early childhood teachers cannot identify science concepts in relation to the play activities of preschools, Simoncini and Lasen (2018) showed through their open-ended survey that early childhood teachers were experts in doing this. *Knowing why there is such variability in beliefs about the relevance of teaching* *science to young children could give different insights into the limited amount of teaching of science in early childhood settings.*

Sixth, related to the question of relevance of science for early childhood teachers is what kinds of models of practice that are available to support teachers with their confidence and competence in science teaching in play-based settings. There were some studies that discussed different models of teaching science (Authors 1, 2009; Authors 2, 2015; Tu, 2006), and who in doing so, were able to raise questions about the dominant arguments about early childhood teacher confidence as core to the teaching of science. For instance, Campbell et al., (2018) looked at the possibilities for an integrated approach to STEM teaching in play-based settings through observations, interviews, and surveys and concluded that the preschools were full of rich science opportunities. They identified in practice the existing pedagogical models for teaching science as inquiry-based, science concept development, appropriate language development in science, and child-instigated approaches. In another observation and survey study by Campbell and Spelderwinde (2018) of bush kindergartens, they found that teachers' practices and beliefs in science showed mixed pedagogical approaches, suggesting that, "With greater understanding of science comes the ability to 'see' more science in a vast range of children's experiences and this may provide teachers with strategies to promote science understanding in children's play" (p. 44). This contrasts with Simoncini and Lasen (2018). Other studies have also focused on the opportunities for science learning in relation to the models of practice observed, such as, guided play and specific lessons designed in support of science learning (Blake & Howitt, 2012). Like Campbell and Spelderwinde (2018), Blake and Howitt (2012) identified missed opportunities through the teaching strategies adopted. Important to the focus of this study was the result which showed that simple one-off science activities were not effective for sustained science learning. They suggested that, "Intelligent, thoughtful pedagogy that creates a positive attitude towards science will incorporate meaningful investigations that meet both policy demands and the child's interest whereas over regulated demands and practical constraints will impede learning for young children" (p. 298). Whilst these studies have examined the existing models of science teaching in preschool settings, where a broad spectrum of support for science learning for preschool children is evident (Eshach & Fried, 2005), only a few studies could be found that explicitly looked at a model developed from research in play-based settings. Howitt et al., (2011) in their research investigated an inquiry model based on forensic science where a preservice teacher implemented a unit of science where children went on a forensic bear hunt to solve the problem of who left the footprints. They identified that scientific inquiry skills of preschool children could be developed through an inquiry model centered on forensic science. In another study of a model of teaching science in play-based settings know as a Scientific Playworld (Author 1, 2019), the foundational research underpinning this model used digitally observations of practices of teachers and children over six weeks and identified a series of pedagogical characteristics where scientific narratives were promoted in play, such as: the story builds collective narrative; psychological tool to support transition into imagining science; being inside imaginary situations taking a role such as being a microscopic organism; teachers setting up problems inside imaginary play; imagining observable and non-observable concepts; wondering; and emotionally charged situations to focus scientific attention of pre-schoolers. But no other study could be found that went beyond guided scientific inquiry (Campbell & Spelderwinde, 2018) or inquiry learning being implemented in preschools (Siry & Kremer, 2011). Consequently, more needs to be known about what might be effective models of science teaching for early childhood teachers, where data and findings have come from research in early childhood play-based settings. *Having models based on research based in play-based settings, may reveal different outcomes when studying teacher confidence and competence in the teaching of science in preschools.*

Finally, and most significant for the focus of this paper is that very few papers were identified which discussed the play-based setting of early childhood teachers as part of their design, results or findings. Closest is the research of Oppermann et al., (2016) who examined the influence of preschool teachers' content knowledge and beliefs surrounding their mathematical ability on what they called a sensitivity to mathematics in children's play. In drawing primarily on constructivist principles of PCK from research in secondary contexts, the central arguments being made for early childhood included the need for conceptual understanding of mathematics (through survey) in order to teach and the ability to be able to recognise mathematical content in play-based settings (through 4 written play scenarios). Their research focused on mathematical content knowledge of 221 preschool teachers and determined that teachers who had higher levels of mathematical knowledge could also identify mathematics in the play scenarios. However, when explaining the results, the researchers looked more closely at the different groups of teachers in relation to their beliefs and found more variance, identifying that "teachers' self-efficacy beliefs seem to serve as a filter through which maths knowledge and experiences are interpreted" (Oppermann et al., 2016, p. 181). This also contrasts with science research of Simoncini and Lasen (2018). Although the play practices were included through giving examples of play scenarios, the variability in reading the mathematics opportunities in play appeared to have more to do with confidence than competence in science knowledge.

Another study that took account of the play-based setting of early childhood teachers was that of Brenneman et al., (2019), who argued that preschool educators need PD to support the integrating STEM into their programs. Through an iterative design process with 6-8 teachers, a professional design community was formed with the research team and a district coach. Workshops focused on maths and science knowledge and teachers' beliefs about teaching concepts in preschools, and activities were **designed in relation to familiar learning activities**, such as "block building and making play dough, to illustrate that teachers were already doing science and maths in their classrooms and that these could be effectively enhanced to support more domains of development and learning and to do so in a way that was appropriate and accessible for young children" (p. 20). They found that the professional learning communities support the individualising of workshop content, small group lesson planning, drawing on everyday materials, and reflection of practice through videoing lessons activities. Like Oppermann et al., (2016) a sensitivity to the teaching context of early childhood teachers was included in the study design.

A third study that took account of the play-based setting of early childhood teachers was that of Andersson and Gulberg (2014) who undertook an action research study of 5 preschool and primary teachers as they planned and taught a unit of science on floating and sinking. The results showed that the teacher who was more oriented to 'teaching a concept' in the floating and sinking activity generated misconceptions, whilst the teacher who oriented the children to investigating if floating and sinking contributes to a feeling of participation, supported child agency in using an experimental approach. Andersson and Gulberg (2014) argued that, "there are competences other than subject matter knowledge that are also important when preschool teachers engage children in scientific activities" (p. 275). Importantly, they identified the need for the early childhood teacher to remain in the context, to have a situated presence, and to challenge further investigation by children. In contrast to Oppermann et al., (2016), they challenged the idea of teacher feelings of inadequacy and poor self-confidence in science.

It was also noted in the study by Simoncini and Lasen (2018) when analysing open-ended survey questions to what is STEM, that responses included cooking for science, high technologies, such as iPads were linked with technology (but no design), block play and box construction were connected with engineering, and specific concepts, such as one-to-one correspondence were mentioned for mathematics. Contrary to Campbell et al., (2018) and

Campbell and Spelderwinde (2018), their results support the view that early childhood professionals have understandings of science practice in the context of play-based settings, where play and hands-on experience in learning science matter. *Therefore, these studies collectively show the importance of bringing into the research design of early childhood teacher knowledge of science the context of the play-based setting.*

Although the studies into the unique nature of early childhood practices show a diversity of approaches to science (Blake & Howitt, 2012), the findings do collectively suggest that researching teacher knowledge of science concepts alone is not enough. Further, previous arguments that teacher knowledge is the cause of limited teaching in science, as has been the main tradition in the literature, does not give directions for practice change in early childhood science education. Simply giving more PD or designing better programs, have also not resulted in systemic practice change. We need to go beyond the early childhood teacher as the problem, and beyond the binaries of teacher competence and confidence, and instead conceptualise the problem dialectically. Therefore, we drew upon cultural-historical theory to design a microgenetic study of early childhood teachers professionally engaged in the problem of how to amplify science concepts in play-based settings. Our research question underpinning the study sought to understand: How do early childhood teachers engage in professional practice change to amplify science concepts in their play-based settings during a professional development program oriented to teachers' competence and confidence in science?

3. Theoretical foundations of the study

In order to conceptualise the problem of early childhood teacher confidence and competence in a new way, we drew upon two central concepts from cultural-historical theory for our study. They were the dialectical concept of the ideal and real form of development and the concept of crisis. These concepts and how they were used in this study are briefly introduced in this section.

3.1 The dialectical concept of the ideal and real form of development

In Vygotsky's writings, the environment is theorized not as a context but as the source of the development of the personality. Vygotsky (1994) explicates this process by introducing the idea of dialectical interrelation between the real and the ideal forms of development. The real forms of development are conceptualized as the primary forms that reflect the current and actual level of an individual's development at the beginning of a developmental process. The ideal forms are conceptualized as the mature and the higher forms of development that are introduced/presented in the collective/social environment and which are expected to be achieved at the end of a developmental process. The presence of the ideal forms from the very beginning of the process of development in the individual's environment is critical. During the process of dialectical interactions and negotiations between ideal and real forms, teachers acquire the mature forms of practice as part of their own personal ways of thinking and acting in their environment. Acquiring these ideal forms is not mechanical reproduction of practice but a realization of the complex social and cultural ways of acting in their unique context. In the context of educational experiment in a Conceptual PlayWorld (for further details refer Authors 1,2,3, 2020) the PD context created the ideal form of practice.

To achieve this dialectical relation between the ideal and real form of teacher development, the PD made available to early childhood teachers the 5 characteristics of a Conceptual PlayWorld (Author 1, 2020) which were featured through examples of videos, through a planning proforma, and through an app. We show specifically in Table 1 the characteristics of the model (Column 1) alongside of the intentional teaching of science (Column 2) that had been informed by previous research that resulted in the model of practice discussed previously as a Scientific Playworld (Author 1, 2019).

Table 1

Conceptual PlayWorlds for the intentional teaching of science

Characteristics of a Conceptual PlayWorld model	**Intentional teaching of science in imaginary play**
Selecting a children's book for the Conceptual PlayWorld	An engaging story to motivate science learning of children
Creating an imaginary Conceptual PlayWorld space	Creating an imaginary situation. Imagining the science concepts. Engaging in thought experiments.
Teachers and children entering and exiting the Conceptual PlayWorld together	Jumping into the story.
Problems arise in the Conceptual PlayWorld that need to be solved	Problems arise that need scientific concepts. Researching solutions.
Teachers take different roles in the Conceptual PlayWorld to actively support children's play development—subject positioning	Being characters from the story. Role-playing. Introducing new characters, such as, a scientist.

In summary, the dialectical concept of ideal and real form of professional development foregrounds in research that which is expected to be developed, needs to be in the environment from the very beginning. The ideal or mature form of professional practice was presented in the workshop through the videos on the app/large screen, and these acted as the basis of the supported actions in the activity settings of the professional development program which were 1) whole group input 2) workshopping in small groups using the proforma and content on the app, 3) sharing at the initial workshop, and 4) later sharing via zoom after implementation of the new practices of a Conceptual PlayWorld in science. Research that is oriented to identifying the ideal form in relation to the real form of the teachers' conceptions and practices can give insights into the pathways and moments in the PD that can give insights into teacher knowledge and competence of science concepts and confidence in the teaching of science. However, this concept was not enough to understand practice change. Therefore, we drew upon the cultural-historical concept of crisis.

3.2 Concept of crisis

We know from cultural-historical theory that crisis as a concept is suggestive of some kind of developmental condition emerging. Whilst this concept was conceptualised for children's development across age periods, rather than for teachers (Vygotsky, 2019), we were curious to know if crisis within the professional practice of teachers would propel forward their planning and implementation of a Scientific PlayWorld.

The concept of crisis had been theorized and introduced by Vygotsky in a twofold way. Firstly, as a philosophical concept to describe, critique and amplify the state of psychology as a discipline at the beginnings of the 20th century (Vygotsky, 1997). Secondly, as a psychological concept to capture and interpret social situations, inter-psychological mechanisms and processes that can lead to psychological development (Vygotsky, 1998). The present study focuses on the second theorization.

From this theoretical and methodological standpoint, the concept of crisis can be explained as a dramatic situation that the person lives through. This dramatic situation can be generated by contradictions that exist in a person's environment. Contradictions cause inner as well as external tensions and conflicts that are critical for transforming and changing a person's experience, motives and values by putting new demands on the person. In line with this Vygotskian perspective, experiencing a crisis is not conceptualized as an obstacle or a disorientation in the process of development. On the contrary, crisis is understood as a dynamic turning point that creates developmental conditions and becomes the source of a person's development. As Vygotsky (1998) argued, the development of the personality is not a case of stability and balance but a contradictory process and a crisis that includes transitions, destabilizations, qualitative changes and neoformations.

In this study we use the concept of crisis in order to understand the societal need for more science teaching in early childhood settings, the institutional demands on teachers to create new pedagogical practices for science education, and the personal motives and values of the early childhood teachers towards play and science. We look specifically at how these societal, institutional and personal motives can generate a crisis in early childhood teachers' environment and how this crisis can create the developmental conditions for the transformation of early childhood teachers' professional practice that leads towards their professional development.

4. Study design

4.1 Research question

How do early childhood teachers engage in professional practice change to amplify science concepts in their play-based settings during a professional development program oriented to teachers' competence and confidence in science?

4.2 Participants

In this study 28 early childhood teachers participated in professional development. The participants live in Australia and are Australian citizens. From the cohort of teachers, one identified as Aboriginal Australian. The teachers teaching profile included: 14 in preschool (3-5 year), 2 in preschool (4-5 years), 8 in school settings and one in outside care. From the 28 teachers, 4 did not specify the age groups they worked with. All teachers had between 5 and 10 years of experience, and all were degree qualified.

4.3 Professional Development Program Design

The PD program was made up of four periods. Period 1: Whole group presentation on a Conceptual PlayWorld model of intentional teaching of science. Period 2: Teacher planning in small groups using a proforma, an app with video examples of Conceptual PlayWorld model of intentional teaching of science, and content from the presentation. Small groups received facilitated support. Period 3: Teachers implemented a Conceptual PlayWorld model of intentional teaching of science. Period 4: Teachers shared via zoom their Conceptual PlayWorld. The session was facilitated around a set of interview questions.

Before Period 1, teachers were asked to bring their favourite children's book. As a group they chose, The Magic Hat by Mem Fox. This rhyming storybook is focused on a Magic Hat which moves from the head of a Wizard and onto a series of animal characters before being re-united with the Wizard.

4.4 Data collection

Three forms of data collection featured. Digital video recordings were the major data source, with two cameras used to capture whole group and small group interactions, planning documentation and later, participants were digitally recorded through a zoom platform as they participated in a focus group interview.

4.4.1Digital video recording

The digital recordings of Period 1 and 2 was 326 minutes and in Period 3 it was 272 minutes of zoom data. The total digital video data were 598 minutes over four period. For Period 2 one camera was used to record each of the groups presenting their planned Conceptual PlayWorld of the Magic Hat. A camera was positioned to be located next to each group on a tripod and this allowed the audio and the visual recordings of the group discussions. During Period 4 of data collection the procedure was changed due to the COVID-19 pandemic, and this meant that in Period 4 data collection had to be done through zoom. Teacher sharing of their Conceptual Playworld practices was recorded. The teachers were spread across a broad range of sites. Nine sites participated in Period 4.

4.4.2Planning documentation

Teacher plans were made using a proforma with content similar to Table 1. Teachers shared during zoom their plans. An estimated 28 plans, with teacher notes and Conceptual PlayWorld proformas were generated.

4.4.3 Focus group interview questions

During Period 4 of the data collection teachers participated in an interview using a set of structured questions. Teachers were asked to talk about their chosen story and the Conceptual PlayWorld they had undertaken between Period 3 and Period 4. Questions included, What were the challenges? What worked well? Did the Conceptual PlayWorld spill over into other curriculum areas? What advice would you give others about designing and implementing a Conceptual PlayWorld? As part of the interview, some of the teachers shared their plans, the resources made/gathered in support of their Conceptual PlayWorld, and examples of children's models associated with the story they had chosen.

4.5 Analysis

We drew upon the five characteristics of a Conceptual PlayWorld (Column 1) in order to organise the data sets into digital folders. This gave insights into how early childhood teachers made sense of the new practices (Column 2).

Table 2

Common sense interpretation

Characteristics of a Conceptual PlayWorld	**Examples of microgenetic data**
Selecting a children's book for the Conceptual PlayWorld	"*The Wizard is distressed. The Wizard can't do magic until the hat is found"*
Creating an imaginary Conceptual PlayWorld space	*When you lose your hat, how does it feel?*
Teachers and children entering and exiting the Conceptual PlayWorld together	*So, then we would have to say the magic words and the hat turns into a big boat, so then we cross the river, then we get to something else, and then there is another problem, we can turn the hat into something else to, to get through.*
Problems arise in the Conceptual PlayWorld that need to be solved	*So, what's your concept then? What is the question for the children?*
Teachers take different roles in the Conceptual PlayWorld to actively support children's play development—subject positioning	*If you are a hat, what kind of hat would you be?*

In bringing together the digital folders associated with the characteristics of a Conceptual PlayWorld for the intentional teaching of science, we further analysed the data in relation to the literature that captured the unique conditions for early childhood teacher confidence and competence in the teaching of science. These are summarised in Table 2 (Column 1) and they acted as a next point of interpretation (Column 2) to guide our thematic analysis.

Table 3

Thematic interpretation

Teacher confidence and competence in science in the literature	**Examples of microgenetic data**
Science knowledge (Barenthien et al., 2020a; Garbett, 2003; Nilsson & Elm, 2017; Tuttle et al., 2016)	*Go into the [concept of] materials [and their properties]. What is waterproof?*
Teacher motives for science (Barenthien et al., 2020b; Nuttall, 2013; Nuttall et al., 2015; Park et al., 2017)	*We already had some things we had planned (Easter hats and Easter parade). But we hadn't thought about it as conceptual play (summarises discussions).*
PD in science - positive relationship between in-service PD courses and teachers' self-efficacy beliefs, enthusiasm and science-specific content knowledge (Barenthien et al., 2020b; Park et al., 2017; Piasta et al., 2015)	*And the children were so EAGER to get into the PlayWorld.*
Teacher beliefs about learning science concepts in early childhood (Simoncini & Lasen, 2018)	*And have some knowledge of materials and constructing.*
Early childhood science models based on relevant research (Author 1 2019; Blake &Howitt, 2012; Campbell & Spelderwinde, 2018; Siry &Kremer, 2011; Howitt et al., 2011)	Table 1
*Unique nature of play-based settings for science/mathematics (*Andersson & Gulberg, 2014; Brenneman et al., 2019; Campbell & Spelderwinde, 2018; Oppermann et al., 2016)	*The Wizard is distressed. The Wizard can't do magic until the hat is found.*

The results of the thematic interpretation (Column 2) were further analysed in relation to the research questions and in the context of a theoretical interpretation (Column 1) in order to solve the problem of how teachers bring science concepts into play-based settings.

Table 4

Theoretical interpretation

Theoretical concepts	**Examples of microgenetic data**
Concept of crisis	*So, we are talking about the problem [looking dissatisfied]. Why?*

The dialectical concept of the ideal and real form of development	*[ideal Table 1]: So, our story line, to make it exciting and interest to carry it over, what could that be? Could each animal…* *[real form]: T3: We have a problem, as we said.* *Senior teacher: No, the concept?*

5. Findings

The purpose of this paper is to answer an empirical question and solve the theoretical problem that was identified from a synthesis of the literature in relation to early childhood teacher competence and confidence in science education. In this section we tackle this dual problem by presenting the results of a microgenetic analysis of how a group of early childhood teachers enter into the practices of a professional development program over four periods as they meet the new demands of planning and implementing a Conceptual Playworld where science concepts are the focus.

In line with previous research which centres on teacher knowledge of science, we introduce typical examples from the data set where conceptual discussions emerge (empirical question). However, unlike the existing literature, we frame our microgenetic analysis through the Vygotskian concept of crisis in order to bring into focus the societal need for more science teaching in early childhood settings, the institutional demands on teachers to create new pedagogical practices for science education, and the personal motives and values of the early childhood teachers towards play and science (theoretical problem). The empirical results show 5 themes which are presented and discussed as a series of theoretical models. They are:

1. *Concept crisis* – what is the science concept to be taught?
2. *Problem crisis* – what is the problem to be solved by the children?
3. *Crisis of professional practice* – how to introduce the concept into children's play?
4. *Theoretical problem* – what are the relations between play and learning science?

In all the vignettes presented below, we follow the same teachers as they enter into and meet the new demands of planning and implementing a Conceptual PlayWorld where science concepts are the focus.

5.1 *Concept crisis* – what is the science concept and what is the question?

Four teachers are working in a small group. They are one of many groups in the room working. The teachers have just finished listening to Rebecca who has stepped them through what is a Conceptual PlayWorld and how to plan for one. They have observed each of five characteristics of a Conceptual PlayWorld through the video content and through presentation of key practices (Table 1). Each teacher has access to a planning proforma, which summarises the practices and gives examples. All teachers have chosen the children's book, The Magic Hat by Mem Fox, to plan for the intentional teaching of science through a conceptual PlayWorld model.

In the first vignette is a typical extract observed across groups and also within groups over an extended period as the teachers examined each pedagogical characteristic in turn, and brainstormed in their small groups how to plan and implement their Magic Hat Conceptual PlayWorld. In Vignette 1 they discuss how to develop a new practice tradition by introducing into their play-based program more conceptual learning of science. They begin by discussing the possible science concepts that could be drawn out of the storybook of The Magic Hat. The teachers experience a crisis when trying to determine the relevant science concepts that could be used to plan for the intentional teaching of science in play-based setting. What unfolds is different to these studies reported in the literature about teachers not being able to identify science concepts.

Vignette 1: what is the concept and what is the question that comes from the story?

T3: What is the question for the children. What is a hat? What is a hat that could blow off the heads like that?
T4: We could…
T2: Heavy… So maybe the science
T4: We could look at X, so if your hat's Y material, would it get crinkled? …would it…
T3: So, is that were we start? What is our hat made out of? What would it look like? You know how you were saying, "How do we become a hat?". Do we start with that conversation, and then bring in the material, that's the conversation on the materials [and their properties]?
T2: If you are a hat, what kind of hat would you be?
T4: Would you be the hat, or would you be the character wearing the hat? You are making that prop, that hat? (reference: 3.35+)

Early childhood teachers comfortable with children's books, are shown in this typical example to struggle with where to begin setting up an inquiry, "*What is the question for the children. What is a hat?".* They fix on the content of the book – the Wizard's hat – and then try to link the content of the book in some way to science, "*What is a hat that could blow off the heads like that?*". Materials and their properties emerge as the first idea, with explicit reference to science as a field of knowledge, "*Heavy… So maybe the science*". They collectively support each other to build the science narrative, "*So, is that were we start?".* With this as the start, the analysis of the teachers immediately jumps to materials, "*What is our hat made out of?".* Contrary to the literature (Garbett, 2003), the teachers resolve their crisis quite quickly, and successfully identify the science concept that could be drawn from the children's book. The crisis initially appears as the concept, but on deeper analysis it is evident that the crisis is centered around how to create a narrative that introduces the science concept, for instance, when T 3 asks the group, "*Do we start with that conversation, and then bring in the material, that's the conversation on the materials?* And T2 responds, *"If you are a hat, what kind of hat would you be?".* Some researchers have identified that teachers cannot introduce concepts and principles into the practices of play-based settings (Oppermann et al., 2016; Lippard et al., 2017). Like Barenthien et al. (2020a), what our study has shown is that teachers can identify the possible science concepts. Theoretically, what initially emerges from this crisis is a binary in the teachers' conception of the problem of introducing science concepts into the narrative of a children's book. At one end of the binary is the science concept and at the other end is the narrative of the story in the children's book.

The crisis brings these points together as a synthesis, and this creates a new condition for the teachers' thinking about the problem –that is, making the learning of the science concept personally meaningful to the children. There is almost a conceptual catharsis. The synthesis of the problem is shown in Figure 1. A dialectical relation between the science concepts and the narrative is resolved by bringing forward a new problem of how to make the concepts personally meaningful to preschool children. This is a very different reading of teacher confidence and competence in the teaching of science to preschool children. This suggests that *the teacher crisis is in relation to how to make science discipline concepts personally meaningful for children, so they are presented with the science concept as part of the narrative of the story.*

Fig. 1. *Concept crisis – what is the science concept and what is the question?*

5.2 *Problem crisis* – what is the problem to be solved?

In the next vignette we identify another kind of contradiction that becomes resolved by the teachers as they experience the crisis of trying to identify and create in the narrative an engaging and enduring science problem for the children to solve over time.

Vignette 2: What is the problem to be solved?

T1: When you lose your hat, how does it feel?

T2: So, when you solve that problem, extend it to make your own hat. Why did that work, why did that not work?

T3: Go into the materials. What is waterproof? Then testing it. Pouring water over it [hat]. That to see if that repel or whether it soaks in. So, you are talking about those concepts

T4: Then if you go down that path, have the construction materials …. And have some knowledge of materials and constructing.

T2: So, knowing that not so much glue on to the hat (role-plays by tilting head to show the problem as though she has a hat on with too much glue)

T1: So, we are talking about the problem [looking dissatisfied]. Why? What is it made of? (reference: 10.14+)

In this example the teachers have successfully identified the science concept ("*Go into the materials"*), have in place the narrative of the hat and what kinds of materials it is made from ("*When you lose your hat, how does it feel?*"), but now they meet the crisis of how to create an enduring problem that children will want to solve. That is, developing an enduring motive for children to learn science. The teachers successfully identify how to frame the science problem as an experiment, as suggested by T3, *What is waterproof? Then testing it. Pouring water over it [hat]. That to see if that repel or whether it soaks in. So, you are talking about those concepts".* The teachers worry about how to build the narrative so that there is a complex problem to solve, as is identified by T1 "*So, we are talking about the problem. Why?*". The one-off lessons (*What is waterproof)* with some testing of materials does not seem motivating or dramatic enough for the children. The teachers' dissatisfaction creates a crisis around what is the enduring problem in the role-playing of the story that will motivate the children's motives towards learning science concepts. How can the testing of waterproofing build the children's play in relation to building up a meaningful narrative around the science concept within the story where more problems can arise, as is characteristic of a Conceptual PlayWorld?

Theoretically, the drama of losing your hat (the problem), and the binary of the science concept and the story return as the teachers meet the crisis of how to set up an enduring and dramatic science problem for the children. The current solution is not solved as a one-off lesson of testing materials. The magic of the imaginary play is lost, and for teachers with deep knowledge of play-based settings, they are challenged at this moment. All the groups appeared to go through this kind of crisis as they moved from identifying the concept in the story to setting up an enduring problem. This is captured in Figure 2. The teachers appeared stuck when conceptualising the challenge as a binary, as they could not generate a satisfying solution.

Fig. 2. *Problem crisis – what is the problem to be solved?*

When we take just these two key dimensions that are core to a Conceptual PlayWorld (concepts linked to the story, and the enduring and dramatic problem to be solved) we can see the early forms of teachers' development in conceptualising new practices for teaching science concepts. Yet the crises are not related to identifying science concepts as reported in the literature (Andersson & Gulberg, 2014), or their competence and confidence in science (Barenthien et al., 2020b). But rather, *the crisis is in relation to how to create motivating and dramatic conditions for children within the narrative of the story for meaningfully engaging them with science concepts.*

5.3 *Crisis of professional practice* – how to introduce the concept into children's play?

In Vignette 3 a senior teacher joins the small group and explores along with the teachers how to bring science into the children's Conceptual PlayWorld of the Magic Hat. We note that the senior teacher capably lists all of the science practices that could be linked to the story (as with Vignette 1), but then in discussion with the teachers comes to realise that the science concepts sit outside of the storying and role-playing of the Magic Hat (also seen in Vignette 2). In Vignette 3 we identified that teachers were really keen to embed scientific concepts inside the narrative and imaginary play, but initially struggled to imagine what this would look like in practice.

Vignette 3 (extract): Crisis 1 – Imagining the concept inside of the play (Not having the concept inside the play)

Senior teacher: So, what are you doing here?
T3: We already had some things we had planned (Easter hats and Easter parade). But we hadn't thought about it as conceptual play (summarises discussions).
Senior teacher: So, what's your concept then?
T3: We have a problem, as we said.
Senior teacher: No, the concept?
T1: Materials
Senior teacher: So that's the properties of materials then.
T1: Yes, and designing [hats].
T2: Design and construction.
Senior teacher then discusses the properties of materials and possible experiments to test the materials (reference: 26:26). Also discusses using a fan to support the experiments she is suggesting.
Ts: Laugher.

Senior teacher: So that's force. So, what's that material, as opposed to, if I put a rock on there [hat]. *If you put that on your hat it is light and it is going to fly away. It's that kind of conversation when they are doing their own hats. [she pauses and appears to reflect] So that was doing it outside the play. It wasn't actually doing it in the play. How would you introduce that kind of concept in the play? That's the kind of thing for us to do.*
Teacher 2: Yep.
Senior teacher: We are used to planning it. But getting better[at] get it into our PlayWorld is a harder thing. I just did that then [not have the problem in the imaginary play]. So, when they are making their research and looking at hats, wondering, testing, but that's outside the play. But into the play is the transition (reference: 25+).

As with Vignettes 1 and 2, the senior teacher begins her interactions with the teachers by asking them to identify the science concepts (*So what's your concept then?*). This moves the discussion towards how to present the science learning through setting up some form of testing (*discusses the properties of materials and possible experiments to test the materials*). The crisis for the senior teacher is the identification that what she is suggesting sits outside of the children's play (*So, when they are making their research and looking at hats, wondering, testing, but that's outside the play)*. It might connect with the narrative of the story (hats), but it is not linked with an enduring problem (Vignette 2 crisis). The binary that is set up by her does not solve the problem. But importantly, the senior teacher's crisis takes the group forward, as she identifies that the science experiments should be in the context of the imaginary play of the children (*I just did that then)*. Once again, it is not teacher competence and confidence in science, but *the challenge for the teachers is how to bring into the imaginary play science concepts, so they are meaningful and enduring (rather than a one-off experiment).* This is theoretically captured in Figure 3.

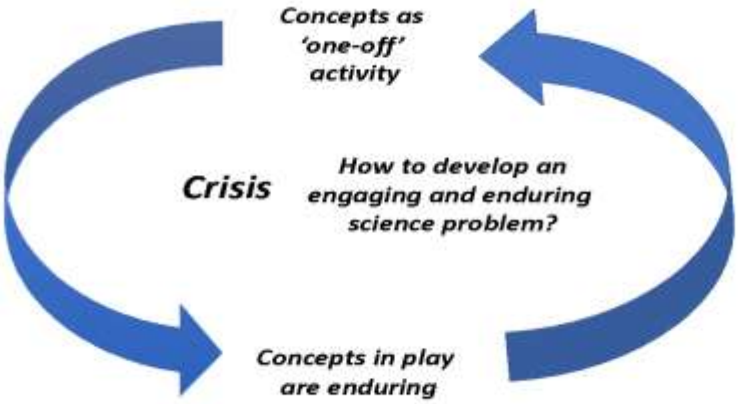

Fig. 3. *Crisis of professional practice – how to introduce the concept into children's play?*

5.4 *Theoretical problem* – what are the relations between play and learning?

Captured in Vignette 4 is another kind of crisis that emerged for the teachers. Until this point, the teachers had moved their thinking from the science concept and how to connect it to the story (as being outside of the conceptual PlayWorld) through to reconceptualising their discussions as a problem in the story that could propel the children's thinking in science forward. Rebecca joins the teachers on the heels of the discussion with the senior teacher and explicitly asks them to tell her "*What's the problem"* that is to drive the Conceptual PlayWorld? As will be noted, Rebecca reframes the teachers' imagined Conceptual PlayWorld practices constantly during her interactions with them. As with Vignettes 3, the Vignette that follows is illustrative of the struggle and challenge of bringing into teacher planning of a Conceptual

PlayWorld a narrative that can be dramatic, can be solved with science concepts, and can be extended over days, weeks and even months.

Vignette 4 (extract): Creating the drama

Rebecca: How's it going?

Teacher 1: We talked about force. Why the hat? The wind? Different things on the hat. To test it.

Rebecca: So, what's the problem?

Teacher 1: So, the problem is that the hat's blown away.

Teacher 4: How to keep the hat on the head.

*Rebecca: So, **remember we want to come back to the drama** [Characteristic 1: Drama of the story]. That **problem is not exciting enough** [Characteristic 4: Problem] to take children for five weeks. So how to keep the hat on the head. So you have to keep hat on, has it blown away, **has it been somewhere, where there is the drama**?*

Teacher 2: So maybe the hat has blown away, like to the jungle, and maybe the animals fear the hat in the jungle (Looking unsure)? So, have to go on a bear hunt to try and to find the hat.

How could you alter that plan? Does the Wizard need the hat back?

Teacher 2: Could the hat turn into different things? We could find the hat. But we are stuck on one side of the river. So, then we would have to say the magic words and the hat turns into a big boat, so then we cross the river, then we get to something else, and then there is another problem, we can turn the hat into something else to, to get through. Or is that just too many things going on? [Characteristic 2 Imaginary situation & Characteristic 3: Enter/Exist]

Rebecca: You could go either way.

Teacher 3: 'Cause this is the bit where we get to a subject, and we start going, oh we could do this, or we could do that, and this [gesturing with fingers to make smaller] needs to go in. To cut it down.

Rebecca: You are looking at the characters. [Characteristic 3: Enter/exit play] But it could even be something else. Do hats fly?

Teacher 4: So, the wind is forcing the hat off.

Teacher 1: So, what's the problem? [Characteristic 4: Problem]

*Teacher 3: **So, the problem would be**, the wind has come, and we don't know where the hat's gone?*

*Rebecca: The Wizard could appear. You could be the Wizard. **The Wizard is distressed. The Wizard can't do magic until the hat is found.** [Characteristic 1: Drama & Characteristic 4: Problem]*

Teacher 3: [all excited, leaning forward]

Teacher 2: So, our story line, to make it exciting and interest to carry it over, what could that be? Could each animal… (reference: 31.05)

Rebecca identifies the challenge for the teachers from the crisis of Vignette 3, "*So, remember we want to come back to the drama".* She names this in relation to the characteristics of the Conceptual PlayWorld of the drama of the story. She also foregrounds why, "*That problem is not exciting enough to take children for five weeks".* She operationalises for the teachers the practice, "***has it been somewhere, where there is the drama****?*". This triggers T2 to frame the problem more dramatically, "*So maybe the hat has blown away, like to the jungle, and maybe the animals fear the hat in the jungle (Looking unsure)? So, have to go on a bear hunt to try and to find the hat".* The teachers begin to build a dramatic story, but remind each other to stay with 'the problem' so that the science can emerge within the imaginary play, as is seen through their exchange between them:

Teacher 4: So, the wind is forcing the hat off.

Teacher 1: So, what's the problem?
Teacher 3: So, the problem would be, the wind has come, and we don't know where the hat's gone?

The feeling of the drama, as the teachers imagine the Conceptual PlayWorld in action (Authors 1, under review) becomes evident, when Rebecca suggests, "*The Wizard is distressed. The Wizard can't do magic until the hat is found".* This support the teachers further, because Rebecca amplifies the drama by reframing their ideas, and this direction is taken up immediately by the teachers, "*So our story line, to make it exciting and interest to carry it over, what could that be?*". This movement from the science concept, to the problem, to the problem inside the imaginary play amplified through the drama of story, is captured in this vignette and is theorised in Figure 4. Once again, the crisis for the teachers is not the science concept, but rather creating the drama and the excitement within the imaginary play, where problems arise that need science solutions so the play can continue. With the support of Rebecca, the teachers' crises are resolved as they bring the science concept, problem, drama and play into unity (Figure 4).

Fig. 4. *Theoretical problem – what are the relations between play and learning science?*

6. Discussion

In this study, we determined through a microgenetic analysis of teachers' professional development, four major crises:

1. *Concept crisis* – what is the science concept to be taught?
2. *Problem crisis* – what is the problem to be solved by the children?
3. *Crisis of professional practice* – how to introduce the concept into children's play?
4. *Theoretical problem* – what are the relations between play and learning science?

What our study showed was that these crises were all related to a theoretical problem about how to introduce science concepts into children's play in ways that were sensitive to children's leading motive to play, the institutional practices of preschools for play-based programming and activity, and for a longstanding focus by early childhood teachers on children's psychological development of imaginary play. When these are taken together, we were able to resolve the problem of how to bring science concepts into play-based settings.

First, the study found that by examining the different crises that emerged in the PD, that teachers brought forward the pedagogical challenges associated with the core theoretical problem that the early childhood education research academy has been trying to solve – that is, how to introduce more concepts and outcomes in preschool settings in Western contexts where greater demands for learning discipline concepts are increasingly being expected (OECD, 2012). This is a different problem to what is in the science education literature, where the worry has been about teachers' competence and thereby their confidence in teaching science to young children. There the problem is teacher knowledge of science concepts (Sackes, 2014). In this study, the problem of increasing the amount of science being taught into preschools was identified as a pedagogical problem, rather than a teacher knowledge problem.

Second, whilst the early childhood education literature and the science education literature are generally united in their goal for more teaching of science concepts, how the problem is constructed in the literature has led to very different assumptions about the nature of the problem and how to solve it. In this study, it was also found that by analysing at the microgenetic level teachers' crises of bringing concepts into play practice, that teacher thinking appeared to change and this was important for realising how to deal with the pedagogical problem of introducing science concepts into play-based settings.

Important foundational insights into the core problem of teaching more science concepts in play was in relation to how teachers developed their theoretical thinking through the crises they experienced as a collective. The iterative models (Figures 1-4) show how teachers' thinking waxed and waned. It becomes possible to showcase through these models how teacher thinking of the intentional teaching of science through a conceptual PlayWorld changed over time. As teachers resolved one crisis, another emerged. But through the iterative cycles of crises, the teachers moved from a rudimentary conceptualisation of framing the problem as a binary to a synthesis, where dialectical thinking about how to meaningfully introduce science concepts into children's play emerged. In the binary mode of thinking it was very difficult for the teachers to be able plan how they could introduce science into a play-based setting. However, the Conceptual PlayWorld for the intentional teaching of science gave teachers a resource to refocus their thinking in relation to solving the pedagogical problem of how play and science concepts are meaningfully brought together in practice for very young children.

Third, the study also found that the teachers' thinking about the pedagogical problem turned into a conscious realisation that a static conception of science concepts was not the solution to the practice problem. There was a need to conceptualise the pedagogical practice as a dramatic introduction of a problem where science concepts act in service of the children's play. Importantly, theoretical thinking was needed when considering how to introduce science concepts into play-based programs because the problem was not teacher knowledge of the concept, but rather it was knowing how to create new pedagogical conditions that supported the practice tradition of play in the institution, whilst meeting the new societal demand for increasing young children's knowledge of science in play.

Teachers had to solve the pedagogical problem by using theoretical thinking to bring into unity all the characteristics of a Conceptual PlayWorld for the intentional teaching of science. We show this unit of play and learning in science in Figure 5 below. This captures how the teachers made meaning in the PD program by using theoretical thinking in relation to the intentional teaching of science in a play-based setting.

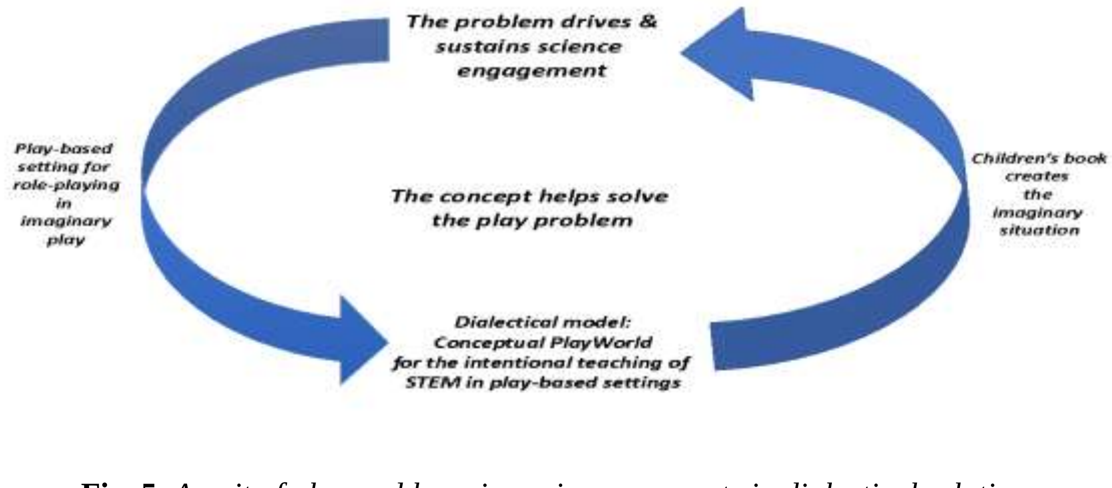

Fig. 5. *A unit of play and learning science concepts in dialectical relations*

We found that **when** teachers draw on theoretical thinking, they went beyond thinking of the problem as simply a narrative of the story, and moved forward in their explanations of the problem of practice, to conceptualising the problem as a relational model (Figure 5). In addition, we also learned that rather than attending PD, where the expectation is to simply learn one characteristics or fact after and another, like building blocks or steps of how to plan for the intentional teaching of science concepts, these teachers engaged in a pedagogical problem of practice and the theoretical problem of the relations between play and learning science. To distinguish this, Davydov (2008) has said that empirical facts are like building blocks, stacked one on top of the other, whilst theoretical thinking is considered as the relations between these blocks. It is in bringing the *building block* of the concept, with the *building block* of the problem, that science becomes personally meaningful to preschool children. Further, it was when the *building block* of the drama of the problem becomes the *building block* of a motive for learning science concepts to solve the problem, that the teachers could see the problem of play and science concepts dialectically.

Building capacity in theorical knowledge, means that PD programs are not only a reflection on practice (Hadley, et al., 2015; Hoffman-Kipp et al., 2003), but rather that teachers engaged in a theoretical problem that is genuine and that the academy continues to struggle with. When the leading motive of children is to play, and the practice tradition of the preschool is to design play programs, the introduction of learning a science concept sets up a major crisis – as was shown in this study. But what has emerged through the PD, is early childhood teachers' capacity for engaging theoretically with this problem. When the problem is conceptualised as a binary it is difficult to move forward. But when a series of iterative crises emerge, a new form of thinking also emerges for solving a foundational problem of how to introduce science concepts into children's play to enrich their imagination and to help them to think abstractly with scientific concepts.

7. Conclusion

The purpose of the study was to understand how early childhood teachers involved in PD solve the problem of how to pedagogically amplify science concepts in play-based settings. The longstanding and recent literature has conceptualised the problem theoretically within a constructivist tradition of identifying what do teachers know about science concepts (Traianou, 2006). By drawing attention to teacher knowledge of science (Kambouri, 2016) and how they feel about teaching science (Fraser et al., 2019) a picture has been built that the problem lies with the teacher. More recently researchers have started to also include in their studies more contextual information, such as the broad range of qualifications of early teachers (Barenthien et al., 2020a, b) and the teachers' practice motive of play pedagogy (Brenneman et al., 2019; Oppermann et al., 2016; Simoncini & Lasen, 2018). These studies broaden the lens from the person to include a recognition of the institution where a tradition for learning science concepts is relatively new for early childhood teachers (Barenthien et al., 2020a, b).

Whilst the recent studies continue to explain the problem in relation to teacher knowledge of science, the solutions have tended to be oriented towards having prospective teachers do more science courses before university (Kambouri, 2016), to undertake more PD (Park et al., 2017), and to ensure that PD for early childhood teachers is oriented to their motive object of practice (Nuttall et al., 2015). That is, the literature has primarily focused the problem on how to increase teacher knowledge of science concepts by fixing up teachers.

The major finding of this study is that the problem of increasing early childhood teacher teaching of science appears not to be related to their competence in science discipline knowledge alone as the literature suggests should be expected. But rather, the problem is pedagogical. Our findings show that the conditions for PD need to build on teacher strengths in play practice (Wingrave & McMahon, 2016), and to draw on a credit model of practice that is oriented to the unique conditions of early childhood education. In introducing a Conceptual PlayWorlds model of practice into the PD, teachers used theoretical thinking to pedagogically positions science in play-based settings for motivating and sustaining children's engagement in science. In light of the findings, previous studies may need to be revisited and new conceptualisation of the problem presented, so that research can include and build on teacher strengths rather than blaming them as the problem.

What this study showcases, is how the literature has asked the wrong question about teacher confidence and competence in science. It is not about the science concept, but rather it is a pedagogical problem that needs dialectical thinking to find solutions. This has implications for how studies in science education may be designed in the future, as well as how PD is planned and implemented for early childhood teachers. By looking at the problem as a problem of practice and not a problem of teacher knowledge, different kinds of research questions may be asked, and different types of studies undertaken.

Future research across a larger sample of teachers and a broader international community of early childhood educators, may add to what was learned in this study about science teaching in preschool settings through PD. Nevertheless, this study contributes to the literature by drawing attention to how *professional crisis* does appear to be an important condition for propelling teachers forward into engaging in theoretical thinking about the problem of teaching more science in early childhood settings. The teachers in our study showcase through their struggles and crises, the pivotal points of practice change, and the theoretical thinking needed to solve the age-old problem of the relationship between play and the learning of science concepts.

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