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The genesis of design: learning about design, learning through design to learning design in play

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Abstract
Learning about design and learning through design have emerged in the literature and important works show heuristics and matrices for design cognition and design processes. However, few studies have been directed to the early development of design. The purpose of this paper is to present the findings of a study that investigated the genesis of design, by following 13 children (3.0–5.8 yrs) as they became oriented to design thinking in contexts of design and technology education in a play-based setting. Different to previous studies that examine children's drawing of designs for the under five year olds, this study investigated both the motivating conditions and the motive orientation of the children as a process of engagement in design. Theorised from a cultural-historical perspective, the results show how play acts as both a psychological function and as a source of design cognition. The findings are shown through this psychological lens and thereby make visible how imagination in play created the conditions for the psychological development of children as design was meaningfully embodied, visualised, and resourced through expert designers and the storytelling of teachers. Rather than conceptualising design as the cognitive competence of an individual, it is argued that by studying the living actions of play that designerly thinking which is always in a process of change, can be better understood. In line with the existing literature, the study specifically reports on the dialectic between design and designerly thinking for the under fives, thus contributing to filling a gap in understandings about the beginning of the continuum of design cognition.

Keywords Design · Designerly thinking · Technology education · Early childhood · Cultural-historical · Development

Introduction

Design as a competence in technology education (Williams, 2000) does not exist in nature. It has been culturally developed in communities as an important competence for children to learn in schools and to use in their lives on graduation (Bartholomew et al., 2020). This

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means that studying design thinking from its beginnings as a culturally valued practice, must consider both the children's motive for design and the motivating conditions that teachers create in educational settings. Yet few studies have been directed to the genesis and development of children's design thinking (English et al., 2020).

The purpose of this article is to present the findings of a study that sought to study the genesis of design, and explore how very young children become oriented to design thinking in contexts of design and technology education in preschool settings. Whilst *design and technology* has a long history within the education system (Xu et al., 2020), comparatively little is known about how design competence begins for very young children. Knowing more about how children develop a motive towards design and build their competence over time can give insights into what might be the genesis of this unique form of thinking competence. This paper takes up this challenge by reporting on the results of a study of 13 children's designerly thinking as they were introduced to design over 10 weeks within a play-based setting. The motivating conditions of a Conceptual PlayWorld of Robin Hood framed the design experience in a unit of integrated engineering education. As an educational experiment (Hedegaard, 2008), problems were introduced which needed design solutions. Role playing solutions within the story of Robin Hood is characteristic of the early childhood period. The study drew upon cultural-historical concepts to frame the study and to present the outcomes.

The paper begins by reviewing what is known about the genesis of design thinking, but also looks to relevant studies outside of the early childhood period when directly relevant for understanding the continuum of design education. However, it is recognised that there are studies of older children sketching (Kelley & Sung, 2017), learning through design (Ariff et al., 2012), and conceptual modelling (Gilbert & Justi, 2016), that are related, but not all studies have been reviewed because the focus of this paper is on what is known in the prior to school period where free play practices dominate. This is followed by an overview of the cultural-historical concepts used, the details of the study undertaken, a presentation of an analysis of a series of children's designs, and a discussion of the results of the analysis. The paper concludes with a model that summarises the findings of the research. The research question posed in this paper is conceptualised through a cultural-historical theorising of the genesis and development of designerly thinking in the naturalistic contexts of play-based settings. What is learned from the research can thereby add to a continuum of understanding (Sung & Kelley, 2019) about the motives and motivating conditions that support design thinking. It is beyond the scope of this paper to comprehensively bring in the school-based design literature. What is unique about the review and the research of this paper, is that it is oriented to design in play and not to design in formal school settings, thus contributing to this body of work and thereby filling a gap in the continuum of design learning from preschool onwards.

What is known about the genesis and development of design thinking of children

Although there are many studies that focus on designerly thinking in educational settings (English et al., 2020), few of these have focused on the genesis and early development of children's design thinking. What is known has primarily come from a range of studies in contexts of engineering education (Blank & Lynch, 2018), arts education (Brooks, 2020; Zande et al., 2014), and technology education (Williams, 2000), where the concept

of design is surprising different (Dorst, 2011; Rodgers, 2013). What is missing from this research is how very young children in educational settings, such as childcare centres and preschools, begin their development of design thinking (Milne, 2013).

Whilst some things are known about early engineering and design (Blank & Lynch, 2018; Cinar, 2019), early technology and design (Milne, 2013; Parker-Rees, 1997), drawing in science (Delserieys et al., 2017; Georgantopoulou et al., 2016) and drawing for design (Anning, 1997; Benson & Treleven, 2011; Hope, 2000) for play-based settings, more needs to be known. Capturing the complexity, Crismond and Adams (2012) have undertaken a meta-analysis of the design literature and have developed a K to 16 matrixes, identifying for instance, understanding the challenge, representing the ideas, weighing up options and making decisions, and using designs to review/iterate. But knowing how these characteristics relate to designerly thinking and actions of children 5 years and below is less well understood. Consequently, a review of how design is conceptualised for the under fives can guide the present study, and can situate what is learned within a broader range of studies and contexts for older children (see Crismond & Adams, 2012). Knowing the literature landscape can help with identifying characteristics of what matters for the genesis of design thinking.

Three areas relevant for the focus of this paper are discussed: studies into children's drawings; studies into design cognition; and studies into learning through design.

Studies into children's drawings

There are studies that examined design in relation to children's drawings. Two kinds of interrelated approaches to studying children's drawings emerges. One is in relation to showing how student *drawings as design* act as indicators of students' competence to show STEM knowledge. These studies appear to trace across time how children's drawings develop in conceptual complexity in relation to discipline knowledge, such as science concepts (Delserieys et al., 2017; Georgantopoulou et al., 2016). The other kind of research which is more relevant to the focus of this paper, takes into account how drawings make student design competencies visible. This is termed in the literature as *sketching as designerly ways of thinking* and is viewed as a design competence/cognition.

Looking at this category of design competence, the foundational study of Hope (2000) argued that drawing can act as a design tool for thinking, "if only they [children] were shown how" (p. 106). In reviewing when and how these skills develop in early education settings, Hope (2000) identified that young children do not perceive drawing as a means of generating ideas, or even as a blueprint for construction. She challenged the notion that young children can effectively draw for future action. She said, "My own research suggests that amongst young children drawing ahead of a task can appropriately support idea generation but not detailed construction technique" (p. 111). Hope (2000) also noted that much of the literature suggested that perceptual and cognitive make up of children needed to be considered in relation to the expectations of design competence of young children under ten years of age. At the time, she argued that more needed to be known about the cognitive processes involved in drawing for design. In response to this research need, Hope (2005) took a collection of drawings and created a categorisation scheme that was not stage based or normed to particular ages. Her *Drawing Types* (picture, single-draw; multi-draw; multi-design; progressive and interactive) are organised as static containers for ideas (picture; single-draw; multi-draw) or as a vehicle for a design journey (multi-design; progressive and interactive). Hope (2005) argued that, "Young children will readily use drawing as a

container, but will not intuitively realise that it can be a part of their design journey and so support the development of their design ideas" (p. 46). Importantly, Hope (2000, 2005) draws attention to the *purpose of drawing* in children's conception of design thinking.

The purpose of drawing has also been identified in the research of Kelley (2017) and Kelley and Sung (2017) in researching *sketching for design* of much older children in educational settings. It has been argued by Kelley (2017) that *sketching for design* on its own (visualising from 2 to 3D, multi-view designs) does not create motivating conditions for children to become designers. In researching 91 Grade 3 students across 4 classrooms, Kelley and Sung (2017) identified that after 30 min of *sketching for design,* that of the 238 designs analysed, students demonstrated a shift from designing as a discrete task required, to sketching to support design thinking. In particular, Kelley and Sung (2017) identified "the potential of student design sketches as an indicator of students' design and science knowledge" (p. 279). Building on the foundational work of Hope (2005), they created a treatment which presented to students the purpose of sketching as a way of design thinking, they showed exemplars of design sketches where they highlighted techniques of using symbols, labels, and multi-views for communicating design ideas. Importantly they suggested using a structured set of questions to guide self-critique, such as, does the design idea meet the client's needs, can you simplify the design and still make it function, what is missing, what are the design specifications, such as materials needed for a prototype, and finally is it possible to build the protype?

Purpose has also been studied by Benson and Treleven (2011) in a nursery context where six activities were introduced to 3 and 4-year old children (slipper, truck, cup book gasses, toy) to develop their designerly thinking by focusing attention on the product and end user. Relevant to the focus of this paper, was the finding that no differences between the activities were noted, but an overall 44% increase in designerly thinking responses were found (references to product, user or purpose). Importantly, they noted that, "it appears that the activities were accessing and developing skills that the children already begun to acquire…and young children are already familiar with questions relating to the designed and made world" (p. 147).

Creating motivating conditions and a sense of purpose in drawing for design, has also featured in the research of Anning (1997) who critiqued the teaching of *design drawing* of 4- and 8-year old children. Different to Kelley and Sung (2017), whose research was oriented towards formal settings and much older children, Anning (1997) argued that in early education settings "many teachers are only vaguely aware of the complexity… [and] are unaware of the power of graphicacy as a tool for learning and for recording thinking in classrooms" (p. 219). In her seminal critique of the pedagogy and beliefs surrounding children's drawings she made several important observations that are still relevant today. She argued that there is an historical reticence of teachers to interfere in children's modes of representing that dates back to Rhonda Kellogg's (1969) study of a million children's drawings from 40 nations where she showed a 'natural unfolding' view of the genesis and development of children's drawings which she used to create a 'taxonomy of schemas'. Her central argument was that, "It seems self-evident that teaching young children drawing can improve their confidence and competence in graphicacy but teachers need to be trained to understand the value of graphicacy for learning and the processes by which children make progress in drawing" (p. 237) and the lack of systematic support leads to teachers asking children to draw a design without the background they need. Anning (1997) argued that design and technology in early education becomes constructed as "self-help zones" (p. 226). In line with Kelley and Sung (2017) and Hope (2000), she suggested that important for taking this forward, was for young children to recognise, like professionals,

that drawing and sketching needs genre training ("sketch pads, notebooks annotated drawings, story-boards, orthographic drawings, architectural or engineering drawings from the world of work, CAD designs", p. 231) and this gives possibilities for 1) representing and communicating ideas; 2) drawing as a valuable thinking tool, and 3) drawings as a rich source of evidence or window into the mind of the young child. However, graphic fluency is neglected or has low value in the education of young children.

In contrast to Annings (1997) and Hope (2000, 2005) who adopt a more cultural-historical perspective on the nature of a child's motives and the motivating environment for design, Milne's (2013) review of the literature is oriented towards the challenges children face on entering formal schooling where they are expected to turn 2D drawings into 3D objects. She argued that children 'frequently experience planning failure' because they (1) draw in relation to what they know rather than looking at the necessary detail needed for modelling/constructing; and (2) run out of room on the design page; (3) do not have the necessary 3D skills to inform prototyping, (4) have inexperience with the materials for making their design; and (5) cannot design with more than one variable in mind. To counter this, she suggested as others have (Benson & Treleven, 2011; Fleer, 1992, 2000), that children's first experiences of design and technology in formal school settings should give clarity of the purpose of drawing for design, which includes generating and communicating ideas, specific nature of drawing in design (e.g., labels, multi-views), and the need to explicitly teach these skills by teachers. Through studying 10 children's (5-year olds) design and technology experiences over two weeks, Milne (2013) confirmed that when a teacher has skills in design and technology, s/he can create motivating conditions where children are moved from a drawing to depict something to drawing as a purposeful plan and explain activity, and where increasing complexity in technical detail for realising their designed constructions emerges over time. This is consistent with previous longstanding research (Anning, 1997; Fleer, 1992, 2000).

What these studies collectively show is that drawing is a powerful source for analysing children's design competence, that the process of drawing/sketching itself is a key for designerly thinking, which has its own content that is beyond 2D to 3D, multi-view designs, and is a form of communicating. All these studies showed that drawing as designerly thinking has to be conceptualised in relation to a sense of purpose for the child. The studies also point to the challenges faced by young children, where design must be thought about as something that is learned and is not just a biological unfolding of inherent skills, but rather must be taught, and teachers need skills in knowing how best to teach design to children younger than 5 years of age.

Studies into design cognition

There is an abundance of research and conceptual work directed to what could be called the principles of design competence (Dorst, 2011; English et al., 2020; Razzouk & Shute, 2012). Studies reviewed feature design heuristics and show transformations of students' initial design concepts (enhancement of features, functions, aesthetics settings, materials sizes, organization and usability) (Leahy et al., 2019). Cognitive processes, such as preparation (constraints of problem, re-interpretation of initial idea, visualization, problem reformation), assimilation (making sense of solution, data, observation of designed environment), and strategic control have been identified (which idea to elaborate, constraints, priorities) (Razzouk & Shute, 2012). In addition, design competence has also been conceptualised by Dorst (1995) as a social activity, knowledge and information processing,

structure-building, and as a non-verbal process. What these researchers foreground is a competence relationship between the expert designer and the novice, where the latter developing competence signals what matters in design. Design competence has also been discussed in the literature as cognitive competence. However, no agreed universal set of principles of design competence have been reported. Closest has been that of Crismond and Adams (2012) whose matrix of design cognition reveals a beginning point. Some of these are summarised in Table 1 below. Relevant for the focus of this paper are those design characteristics (Column 1) that cluster at the beginning of the trajectory (Column 2) and make a comparison with the cognitive competence of informed designers (Column 3). However, what is missing from this matrix is the genesis of design cognition for children under five years.

Related to the identification of what is design cognition for children in educational settings, has been those studies of design that cross disciplines and professions by researching in contexts of bringing in design experts to act in partnership with young children and teachers. Studies have been undertaken that identify how experts show the relevance of fostering design thinking in the early phases of the design process (Haupt, 2015), and dialogue as key for cognitive competence (knowledge processing, critical thinking, creative thinking, metacognition) when comparing novice and experts, where conversation activities support mature design processes (applying domain knowledge, constructing analogies, arguing constructing mental simulations, constructing scenarios and building on these) (Kiernan et al., 2020). Relevant to the focus of this paper is the study of the participation of design experts as part of the primary students' collaborative design process (Kanga et al., 2013). By embedding disciplinary expertise into the classroom, Kanga et al. (2013) found that in the process of researching and designing lamps (aged 10–11) that experts (1) provided structure for the design task; (2) supported the generation of design ideas included sketching, authentic tool use for visualising, demonstration of skills needed; (3) facilitated design ideas elaboration, such as modelling alternative solutions, domain knowledge; and (4) gave professional support with techniques. They found that "The designer's participation opened up the world of designing for the students helping them to appropriate the basic tools and practices of professional designing" (p. 175) and that "deep understanding of designing requires acknowledging the iterative and embodied nature of the processes involved in designing" (p. 176). This solves the problem identified by Anning (1997), where competence in graphicacy, as "teacher's competencies can be complemented with co-teaching…and community partnerships" (p. 176).

What those studies relevant to the focus of this paper collectively report, is that design thinking is a cognitive process and that it features a broad set of competences as detailed above. Unfortunately, these papers have primarily focused on older children and adult competencies and do not show how the design thinking first appears or if some of these design competences are relevant for children under 5 years of age. But what they do point to, is the importance of partnerships between professional designers and teachers in supporting the design competence of children in educational settings.

Studies into learning through design

Another category evident in the literature foregrounds studying design competence as a process of designing, making and evaluating/appraising, where researchers have created motivating conditions which support designerly thinking as a process. English et al. (2020) have identified that whilst a lot of learning about design is featured in the literature, very

Table 1 Design cognition (based on Crismond & Adams, 2012, pp. 748–749)

Design strategies	Beginnings designers	Informed designers
Understanding the challenge	Design is thought about as a well-defined, clearly presented problem that the novice seeks to solve	Explores the challenge and tries to understand the problem better before making design decisions
Representing ideas	Ideas are based on a surface level knowledge of the system and design solutions would be difficult to realise/work	A broad range of representations and design ideas are developed from a deep inquiry into the system
Weighing up options and making decisions	Makes design decisions based on one or a few possibilities	Draws on graphicacy skills to explore options and makes decision according to benefits and tradeoffs of all ideas
Revising/iterating design solutions	Linear design steps or a more organic design approach	Managed design approach using back and forth feedback cycle for iterative improvement

little research is directed to what they call *learning through design,* particularly for the under fives. Examples include aerospace of 4th graders (English & King, 2015), events, such as making chocolates for Mother's Day (Milne & Edwards, 2013), songs such as the Wheels on the Bus of pre-schoolers (Rogers & Wallace, 2000), and stories, such as the Caring for a Lonely creature (Fleer, 2000). The studies collectively highlight an iterative process of designing, making and appraising/evaluating where working with materials makes an important difference to young children's design competence. This suggests that a focus on design alone will miss important potential capabilities of children as they progress through the processes of design and technology over time. This is supported by the historical and contemporary expansive review by Gilbert and Rosária (2016) who show primarily in secondary contexts how modelling in science is conceptually linked with both the identification of cognitive processes and the process of designing, making and evaluating through modelling. These studies collectively show that modelling with materials, such as, think aloud whist modelling of secondary students (Mentzer et al., 2015), and peer collaboration of 6-year-olds over time with brainstorming design ideas, presenting ideas; and constructing with materials and the finished product, are all key aspect of the iterative nature of design that has been undervalued in research. Therefore, more attention needs to be directed to the multiple processes of design as they are developing over time. In line with this synthesis, English et al. (2020) in reviewing the literature identified that design education should begin early, specifying that it should begin from Kindergarten. But not enough is yet known about this early period of education and even less in relation to learning *through* design for the under fives. Therefore, the study reported in this paper sought to contribute to filling this gap in the literature by generating understanding about the genesis and motivating conditions for design education for the under fives.

Theoretical orientation

The central cultural-historical concept used in this study to understand the genesis of design in play-based settings was the dialectical relations between *the ideal and real form of development*.

Vygotsky (1998) argued that, "the social environment is the source of the appearance of all specific human properties of the personality gradually acquired by the child or the source of social development of the child which is concluded in the process of actual interaction of "ideal" and present forms" (p. 203). Vygotsky argued that in social relations children and adults can together enact for instance, designerly thinking as part of the process of their interaction. He suggested that the *ideal form* must be available to the child in the environment from the very beginning of the developmental process. This suggests that research into the genesis of graphicacy and designerly thinking, needs to capture how teachers include in their own practices from the very beginning the ideal form of design that they hope children can achieve at the end. The *ideal form* of drawing types as described by Hope (2005) would not just be static representation of drawing types, but rather how they are used for enabling an ideal way of designerly thinking. Studying what is available from the beginning is important, such as focusing on the end user when beginning design work as outlined by Benson and Treleven (2011), or as shown through co-teaching models of Kanga et al. (2013) where design experts work with children to introduce technical skills of design and prototyping. Whilst there can be many graphicacy skills made available to the child in their environment, gaining insights into understanding *what exerts the most*

influence on the child is important to study. This points to not just studying what is available to the child from the beginning as the ideal form of design cognition/competence, but also researching at the same time the *real form* of the child's social engagement in play with *ideal forms* of design.

The higher form of human behaviour that Vygotsky draws attention to, is how in cooperation and social relations adults create conditions where culturally valued forms of knowledge, such as design, become available to the child. Vygotsky (1998) said, "The process of teaching itself is always done in the form of the child's cooperation with adults *and represents a partial case of the interaction of the ideal and real form*…as one of the most general laws of social development" (p. 204; my emphasis). Because play is the leading activity of the preschool child (Vygotsky, 1966), play exerts an influence on how the child pays attention (imitation) to design and designerly thinking. The genesis of design competence/cognition and designerly thinking must be studied in play as a process and as a relation between the ideal and real form of design, where markers of imitation can guide researchers in their analysis.

Study design

In this paper the research question that drove the study was "What constituted the genesis and development of design thinking of children aged five years in a context of an engineering unit?". This builds on previous research that examined the engineering principles and practices of the teachers (Fleer, 2020) but where children's designs were not studied.

To answer the research question driving the study, a cultural-historical methodology of an educational experiment (Hedegaard, 2008; Lindqvist, 1995) was used. Hedegaard (2008) has defined an educational experiment as an extended collaboration between teachers and researchers (e.g., ten weeks and up to a year). This kind of dialectical study method gave tools for creating conditions that could help with studying both children's play and the conceptual learning experiences in which design becomes personally meaningful to children. In line with cultural-historical theory, the *process* of the research and the *development* of a motive orientation to design are viewed as important as the *end result* (Vygotsky, 1997). Because the study was undertaken in a play-based setting, Lindqvist's (1995) approach for organising the educational experiment of a common playworld was drawn upon. Lindqvist's (1995) research focused primarily on play as the leading activity, but she did not examine the development of discipline concepts in relation to design in the context of an engineering curriculum. Rather she was interested to study the development of children's play through drama pedagogy. The study reported in this paper, sought to bring researchers and teachers into a collaboration to realise new design practices through the drama of storytelling and role-playing of Robin Hood (see "Appendix" for an overview). Therefore, both Lindqvist's (1995) and Hedegaard's (2008) conception of an educational experiment informed the methods adopted.

Research site

The research site is a preschool located on the school grounds of an independent school in Victoria, Australia. All participants consented to be involved in research and the University Ethics protocols were approved and followed.

Participant background

A total of 13 children (10 boys and 3 girls) and two teachers consented to participate in the study. The children were aged 3.0–5.8 years (mean age of 4.8). Participants were from European heritage backgrounds. Both teachers had university education and ten years of teaching experience.

Curriculum context

The overarching curriculum program began with the story reading and later ongoing story telling of the adventures of Robin Hood. The story gave the context and the narrative in which children role-played going back in time to Sherwood Forest to help the villagers rescue the treasure from the castle in order to re-distribute the wealth. In order to help the villagers, the children and teachers went into character, meeting the castle engineer to learn how they could solve the problem of lifting the drawbridge (and more). Going back to their own time, the children researched pulley systems, explored modern day cranes and simple machines, and designed escape routes based on researching castles and everyday life in the time of Robin Hood. The teachers and children used YouTubes, Google Earth to study existing castles, books, and invited in an expert designer to work with the children to support their designs. Both collective and individual designs emerged, model making took place alongside of role-playing as part of testing out designs. Details of planning are shown in Table 2 and the Conceptual PlayWorld model for teaching is summarised in "Appendix".

Data collection

As part of the educational experiment, the researchers met on a weekly basis with the teachers to co-plan the PlayWorld ("Appendix"). Data were collected over 7 weeks. Digital observations were made using two digital video cameras for still and video. Rather than transcriptions, digital video data were organised into digital folders, which could then be viewed with actions, intonation and expressions in relation to designs and models, as a meaningful data set. Children's designs were digitally photographed and tagged in relation to video data sets and field notes. A total of 1725 digital photographs, 153.3 h digital video observations and 100 h of field notes were gathered. One camera was mounted on a tripod and placed in close proximity to the group time area, whilst the second hand-held camera followed the children and teachers as they moved about the centre.

Data analysis

The designs and the processes of design thinking in play were studied through the lens of the concepts of imitation, and ideal and real form as was introduced earlier in the theoretical section. The video data and the photographs of designs (as products but also in the process of being drawn) and the field and planning documents were copied from the overall data set, and they were then edited into video segments and organised into digital folders in relation to design and designerly thinking. For example, in Fig. 1 the product of collective design is shown, whilst Fig. 2 shows how children enable their designs to be operationalised with materials, and Fig. 3 shows an array of displayed designs drawn by individual

Table 2 Planning for designerly play—creating the design need through a motivating narrative

Robin Hood Storyline	Creating the engineering playworld in the centre (designing, making, appraising)			
	Imagination "space"	Technological investigation	Scientific investigation	Replaying the play (digital abstractions)
Language to use:	Designing Being Engineers Team work	Technology as invention, as creating, as systems	Force as a push, pull (twist) Properties of materials as strength, flexibility (stretch)	Role-play Models Representations
Term 4				
Sherriff has imprisoned the dragon to guard the gold Dragon smuggles letter out with Friar Tuck to ask for help to be rescued with the treasure	Visit from an architect (Design Studio- learning about plan and side view) Visit(s) from Friar Tuck, bearing a letter from the dragon (to the 4/5 s) 3 s/4 s—An actual (soft toy) dragon appears in their castle over the holidays?	Imagining and designing a complex machine using what we know about simple machines (using plan and side views in our design) Further investigations to support this process	Further investigations into force and distance Making direction of force more conscious through use of symbols (arrows) on designs 3 s/4 s: The science of dragons: (using what we know about living creatures and imagining how this would be for dragons): How do they breath fire? Do they have a heart? How do they fly?	Set up GoPro camera in time machine as a security system to make sure no one uses time machine over the school holidays (captures Friar Tuck sneaking through with the letter from the dragon) Role playing being the complex machine Making a model of the complex machine Using the Simple Machines App to try out our understanding Storyboarding and making a video (and/or Augmented Reality App) with the researchers to show parents End of project celebration

Fig. 1 Castles for rest time

Fig. 2 Building castle using designs

children. Figure 2 is illustrative of digital data captured where children discussed how to build the drawbridges they had researched and drawn. Only data that showed the process of design and the product of design were organised in this way. All other data were not used.

Fig. 3 Castle designs

This represented a common sense interpretation of the raw data. This was followed up by organising the data into categories associated with design cognition/competence as has been identified in the literature (e.g., purpose, 3-D, plan-view, expert-novice, etc., Table 1), but always linked back to the play contexts from which they emerged (such as that shown in Fig. 2). Density of data related to interaction and design competence/cognition was sought. This represented a situated practice interpretation of the data sets that were emerging. Finally, the data sets were analysed in relation to the pre-defined cultural-historical theoretical concepts of imitation and ideal and real form, where the leading activity and psychological function of imagination and play were used to answer the research question that is the focus of this paper. This latter analysis process is a theoretical interpretation and involved an interactive process of looking at both the genesis and development of design in play (Table 1 and emergent concepts relevant for children's play, such as motive to help solve the problem through designing solutions, where 2-D and 3-D forms emerge).

Findings

The core outcome of the study was that it was only possible to understand the genesis of design and the development of designerly thinking when the child's leading activity for play was taken into account. This is exceedingly important because the review found an absence of studies focused on the nature of the play-based environments in which design was being researched and the lack of attention on play as the psychological function of children under five years of age (Vygotsky, 1966, 1987, 1998). From this cultural-historical standpoint, 2 major findings were identified:

1. Play amplified design cognition and design processes.
2. Play was the psychological function through which young children made sense of design.

These 2 overarching findings are presented in relation to the essence of the genesis and development of design for the under fives.

Play amplifies design cognition and design processes

It was identified in the literature that a purpose for design needs to be established, and there were several ways that researchers sought to do this, such as through introducing a problem to the children or through playing with materials, or through working with a client and thereby identifying the design needs. In this study, play was seen as the leading activity of the preschool child and the dominant way that children of this age interact with their world. In play children role-play and develop narratives. In line with this, story reading and role-playing of Robin Hood from Sherwood Forest was introduced. The story created the drama and the motivating conditions for collectively playing. Children were characters in the story trying to help the villagers back in time. According to Vygotsky (1966), in play children create imaginary situations, change the meaning of actions and objects and become part of the story 'as if' characters in the story, designers, engineers or scientists. It is through the act of changing the meaning of their environment that children are already visualising designs and embodying through their role-play actions as possible solutions and representations that go beyond 3-D form.

In Table 2 is the planning framework that was developed as part of the educational experiment between researchers and teachers. It was found that that the play narrative acted as the glue to hold the conceptual learning from the different discipline areas (Columns 2–4), but as is important for the focus of this paper, play acted as the source of development for design (5th column, preparing "Models, Representations"). Rather than play being conceptualised as a biological unfolding as Annings (1997) has warned about for drawing, play as a psychological function must be planned for and developed over time (Column 1 and 5). For instance, the "Dragon smuggles letter out with Friar Tuck to ask for help to be rescued with the treasure" and this needs an escape plan. The content of the play (Column 1) and the design cognition/competence (Column 5) are not just *reproduced* as the story of Robin Hood, but *produced* through a series of dramatic narratives which amplify the need for designed solutions (Column 1) to progress the children's play.

Play narratives morph into design narratives

The play narrative that was planned and developed over ten weeks through the Conceptual PlayWorld of Robin Hood can also be conceptualised as a design narrative. The design narrative was captured in the planning of the teachers (Table 2), not for creating purpose, but rather as a holistic frame that united all the children into a shared play narrative—something difficult to do with pre-schoolers—and in this shared narrative the children were role-playing 'as if' characters in the story. The drama of the story amplified the need for finding solutions to the problem that had arisen in the story. For example, "This money has to go to the farmer/villagers/peasant … How do I get the money out?". Examples of the play narratives planned as part of the weekly teacher-researcher sessions give an indication of how play continually morphed into design narratives, as extracts from the data show:

> *Problem*: We need to go back in time…. because we need to see the castle… there's a lot of things we don't know…

Friar Tuck will visit: Talk about not killing, who is he? What does he do? Why does he work with Robin Hood? Rescue and escape.

This money has to go to the farmer/villagers/peasant … How do I get the money out?

Look at the peasants…they're sick…they're hungry….what can we do? Stealing but not murdering… I don't want to hurt anyone to get it back because the poor peasants are heavily taxed. How do I get the money out of the castle? But I'm trying to think of, how do I get in? Ruth will position herself with the children. Friar Tuck will position above to explicitly teach.

We want to help the peasants to live but what in the right way? I'm worried about the peasants. They've paid their taxes and they have no money to live. What can we do? The money is kept in the castle. How can we do it, so that we can give it back?

The problems that emerge: How do we get to the treasure room? To then how do we get it out? Friar Tuck would be able to get into the castle?

Way to resolve it: Climb up the wall/tunnel up the moat/could they talk to someone from the castle to find the secret entrances- hidden door-trap door-hidden wall; tunnel from under the moat. Will Bob play Scarlett. He will offer scientific/engineering explanations about how the castle will /won't work.

Drama: problems arise in role play which are supported by designed solutions

The study identified three different ways that the play amplified the development of the children's designerly thinking and design competence/cognition. The first type related to problems the teachers introduced, such as those shown in Table 2 and discussed in weekly planning sessions. For instance, "How do we get into the treasure room?". The introduction of problems as part of the play were designed to deepen the play and create drama that needed design solutions. A sense of urgency or drama emerged as part of the children's play and a real need to want to solve the problem.

The second type related to problems that arose when children were role-playing, and creating their environments when playing, as are shown in Fig. 1 above where the children used boxes (and later blocks) to build a castle for rest time. The children transformed their rest area so that it could have the features of the castles that they were looking at in books, as well as google earth images of famous castles from around the world, such as Balmoral Castle. In Fig. 2 are shown examples of prototyping of a castle in unstructured play time where children included a drawbridge. The children used their designs to support their build. Some of the examples of castle designs are shown in Fig. 3 as part of the ongoing documentation of the children's designerly thinking over the 7 weeks. These are working examples of designing as embedded in the play narrative of Robin Hood.

The third type of design that emerged in play was when the children designed an escape plan to take with them when returning to Sherwood Forest back in time—as one of many adventures of Robin Hood. The teacher's annotations with each of the set of sequenced designs gives directions for the escape route (see Fig. 4).

It was in this context that drawing for design became personally meaningful for the children. The children were able to share their individual thoughts as well as co-design solutions through discussion and through drawing.

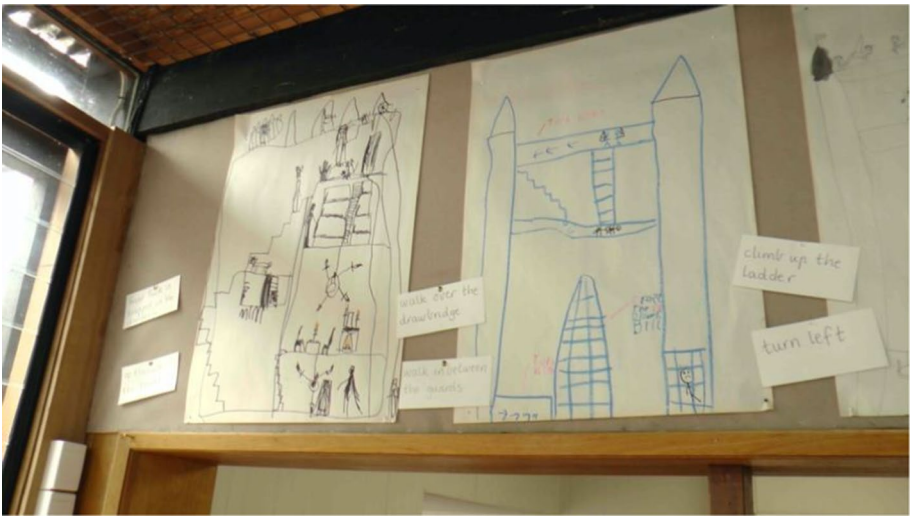

Fig. 4 Drama of the story—rescuing the treasure: Escape plan

The fourth type of design problem to emerge in play related to the children's development of play resources to support the growing narrative that emerged as part of the social problem of rescuing the dragon. In both generating designs and later in prototyping their designed solution of a grabby hand machine for going down into the dungeon to rescue the dragon or to get the treasure out to give back to the villagers, design problems continually emerged. The design problems and the question they collectively identified were put together as a letter for Bob the Castle Engineer (Fig. 5). For example, "How do we

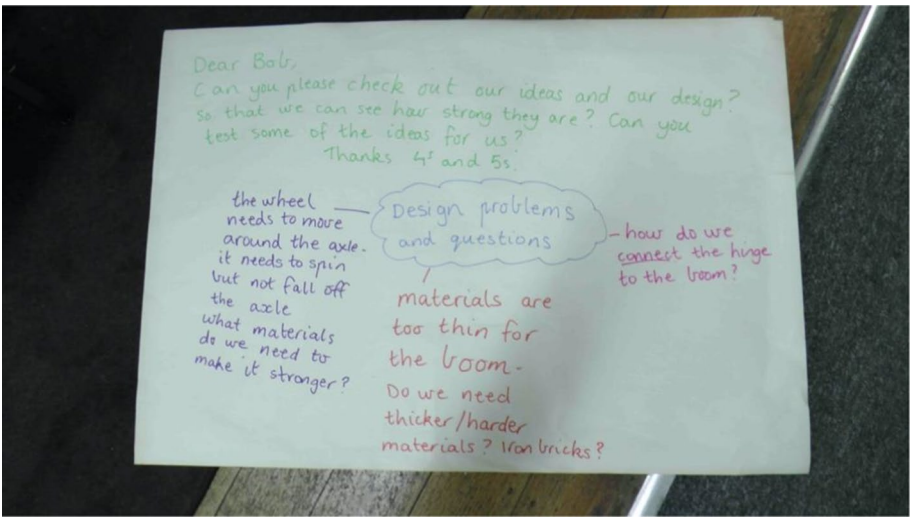

Fig. 5 Problems posed/identified in play that create drama and which drives design

connect the hinge to the boom?". They took this letter back in time and asked for help from the castle engineer. This role-playing and imagining supported the refinement of their designs and growing need to research for information to support their play.

What was learned from the study was that design problems can be both posed in relation to children's play narrative or identified by children in their play. But it seemed that the drama of the story appeared to drive design work. Creating dramatic conditions in play means children are constantly in a zone of proximal development and this means that development in design is a fuzzy zone between children's play motive and a need for learning design (which means learning design competence). Vygotsky (1998) argued that a change in motives, such as from play to learning, is an indicator of a child's development.

Design concepts are introduced as part of the children's play

In keeping with the play narrative for designerly thinking that was developing over time, the teachers invited an expert (see Table 2, Column 2) to teach the skills needed by the children. In line with the co-teaching idea identified in the literature (Kanga et al., 2013), the teachers and expert designer worked with the children's play narrative to introduce a plan view as 'a dragon's eye view' (Fig. 6), and a side elevation in relation to an additional storyline that the children introduced of 'a wolf's eye view' (Fig. 7). The transcript of the expert introducing two key design concepts follows:

> *Plan view:* "Dragon's-eye view—I imagine I'm a dragon in the sky and looking down on it. Look at it with my dragon eyes and start unravelling it. Start with a square in the middle. Then my dragon eyes unravel the next piece—next I see a bigger square. Then with my dragon eyes I see these lines that go from the little square to the bigger square. When I draw these, I pretend that this is flat. [Continues to count and add bigger squares.] That is a birds-eye view, or in architectural language = a plan view. When I look at that and want to draw a plan view I pretend it's squashed, I pretend an elephant stood on it and flattened it. Model is 3D, plan is 2D and flat. I flattened it".
> *Side elevation:* "This time we can draw a side elevation. It would be a wolf's-eye view if the wolf was smaller than it. So from a wolf's eye view I can see the top is flat, so I draw that, then I can see these side bits—they are slightly curved. If the

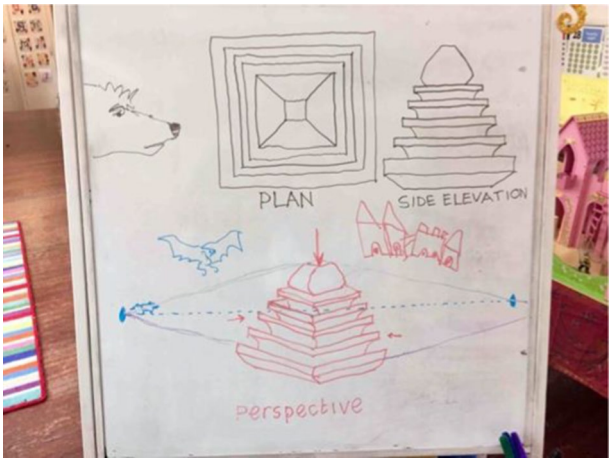

Fig. 6 Ideal form of design

Fig. 7 The real form of design

wolf looks very closely they can see those bits tucked in. Then the wolf looks closely and he sees there's a line there. If the wolf looks closely he can see scoop-outs, little curves and they look like that. Then we're drawing that bit now—so the wolf's breaking it down and unravelling and drawing that next bit. Etc etc. It's getting bigger isn't it?".

The literature has consistently shown that children need active support with design competence. Annings (1997) has argued that if children are to design effectively then they must not be left in self-help zones. In this study it was identified that expert knowledge of graphacacy was needed. However, rather than introduce design skills in a context of meeting the needs of an external audience as Benson and Treleven (2011) suggested, design skills were introduced in support of developing the children's play. For instance, the design expert begins with the narrative that the children introduced of a dragon to introduce a plan view: "Dragon's-eye view—I imagine I'm a dragon in the sky and looking down on it". This was deemed to be in keeping with the psychological development of preschool children and was consistent with the institutional practices of play-based settings. Rather than a discrete skill to be introduced at the beginning of the lesson sequence, the children's motive for play framed the need for design skills in order to better design the solution to the problem they had in their play—of how to rescue the dragon/treasure and save the villagers.

Play as the leading psychological function of the preschool child

The study found that play acted as the genesis and source for the amplification of both design cognition and designerly thinking. But a simplistic reading of play does not capture the psychological functioning and development of the preschool child in relation to design. What was learned was much more complex and represents a new way of conceptualising the genesis of design in ways that give more meaning to what is already known from matrices of design cognition for older children/students. This complexity is shown first as a dynamic model, where the core psychological functioning of the children in this study is central (Fig. 8), followed by examples of planning and play practices that illustrate the nature of designerly thinking through individual and collective design examples. Figure 8 is illustrative of the practices of designerly play from which the examples that follow should be read.

Importance of imagination in design

In this study it was found that designing for the children was about imagining something that did not yet exist, so it could be realised in a drawing. But also, the graphicacy skills to be learned also needed to be framed within a context of imagining. For example, the design expert introduced to the children the concept of 4D.

> 4D = Close your eyes and imagine space going on and on and on. Imagine space as your canvas, but instead of a canvas being flat and 2 dimensional, your canvas is vast and black and is actually 4 dimensional.

This dimension of design was under reported in the matrices or the heuristics of older children. For children whose leading activity is to be involved in imaginary play, the concept of imagining is a key psychological function that develops from infancy and is actively used as a tool for the thinking of pre-schoolers in their play. Imagining a blank canvas as 4-D is

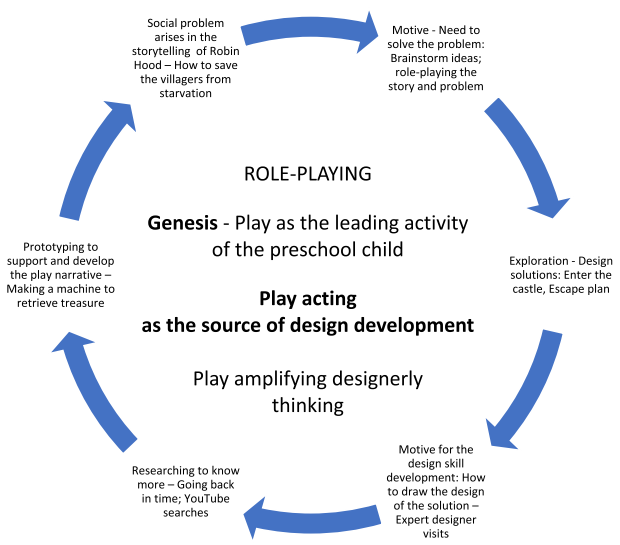

Fig. 8 Designerly play

illustrative of this. Further, imagining being in a rocket so a plan view is seen, is a way to support the introduction of a concept that needs to be explicitly introduced to young children for successful design (Anning, 1997), and this was undertaken by the design expert:

> 3D = Can you imagine a rocket, floating around in space. It's little cargo thing is floating in space. That cargo thing is 3 dimensional.

Something that does not feature in the literature is the introduction of 1D. This concept was also introduced by the design expert into the imaginings of the children:

> 1D = It's like a dot. But if I was a little ant and I was flying through space to get to my dot, I want to imagine I get smaller and smaller and smaller so I can land on my dot.

Finally, the design expert also supported the children to think about all of the perspectives together by inviting the children to imagine floating so they could see all sides of a 3-D shape, as shown in the transcript below.

> 2D = A flat piece of paper. It's big that way, but if I look at it the other way it's very thin. We can think about ourselves as 3D. We occupy space, so we are 3D in 4 dimensional space. *When we design, we imagine 3 dimensional objects in 4 dimensional space.* Then we're going to imagine looking at 3 dimensional objects from above, and from the side and going to represent them in 2D (on paper).

Imagining was brought into the centre by the design expert as a resource. Not only were the graphicacy skills introduced through imagining, but the actual designing was also introduced through imagining. For instance, the ideal form of imagining involved both the design graphicacy of perspective, but also what the designed object might look like before beginning to draw a design. But what is especially interesting to note is how the introduction of imagining by the design expert (Fig. 9) as an ideal form of design concepts is later shown in the practices of the children in their day-to-day role playing in the adventures of Robin Hood (Fig. 10) and through the children's real form of design competence/cognition (Figs. 6, 7, 11, 12). That is, the ideal and real form of design thinking were constantly in dynamic relations because the children could over the duration of the study, imagine, discuss and draw aspects of their play adventures of Robin Hood as their play developed. This can be seen in how the children explicitly show the different perspectives in their drawings

Fig. 9 Imagining with an expert designer

Fig. 10 Imagining in everyday practices of the centre

Fig. 11 Individual design

(Figs. 6, 7) but also this is shown further below in how individual design competence is explored through side elevations, cross sections, labelling (Figs. 11, 12) and also it was common for symbols to show the direction of some of the forces acting in their design through the use of arrows (Figs. 3, 4).

A further important finding identified from this study was how technical language became embedded in the practices of the teachers and in the children's designs. The planning is shown in Table 3 and the actual connections between the design concepts and the

Fig. 12 Collective design

Table 3 Architecture and design language

Dimensions	
4D	Space
3D	Object in space
2D	Paper
1D	Dot

Table 4 Dialectical relations between ideal and real form of technical design language

Architecture and design language	Everyday (playworld) language	Dimensions
Model		3D
Plan	Dragons-eye view	2D
Side-elevation	Wolf's-eye view	2D
Perspective		2D representation of 3D object

everyday conceptions realised in design are shown in Table 4. Important was how imaginary play (Robin Hood) created the conditions for introducing everyday conceptions of design language as dimensions of the story lines, such as a dragon-eye view (Column 2), but also how the existing storylines gave context for understanding design language, such as plan view (Columns 1 and 3). This dialectical relation can be explained as the imaginary story creating a pathway for the design language, whilst at the same time the expert resourced the children's imagining by giving them technical terms to describe the everyday concepts of a dragon-eye view and a wolf's eye view. Imagination, imagined concepts and imagining in design, were being nourished through the play. Both imagination and designerly thinking were being developed through the storying and role-playing contexts that were amplified through the design expert who visited and gave meaningful instruction.

Play narrative creates sense of collective design

Children had to imagine new design ideas in solving the problems of their play, such as, how to create a machine to retrieve the treasure from the castle, or how to escape from the castle once you had the treasure. It was found that an iterative process of drawing designs was always evident throughout the imaginary play of Robin Hood. In Fig. 11 is an example of an individual design, where components of the design (see caterpillar wheels in both) were brought to the collective designing of the children (shown in Fig. 12). In Fig. 12 the children are collectively designing a grabby hand machine as their solution for retrieving the treasure.

The children created a prototype using their collective design and they used their prototype in their play. Both the designs and the prototype resourced the children's imaginary play. Drawing designs gave ways of communicating their ideas which has been shown to be important in the literature (Kelly, 2017). Imaginary play created the purpose and the process of drawing designs as one form of expression of their ideas also noted in the literature (Kelly & Sung, 2017). Imaginary play also gave possibilities for role-playing the scenes they were imagining. The designs and designed solutions for an escape plan for instance, were resourcing their play and this meant they embodied the design ideas through play. That is, they both imagined what they needed for their play, whilst also using what they had designed and made to enrich their play and in so doing, had created an authentic appraisal/evaluation experience of their design and designed solution.

It was found that play acted as a source of development of design. Play was creating the conditions for giving purpose for design. Play gave possibilities to extend children's designed solutions, but also to iteratively develop their design ideas. Different to what is discussed in the literature for young children and design (Hope, 2000; Milne, 2013), is the finding that the children had a common imaginary play context of Robin Hood, and this could more easily realise a common design solution. The children's client was the players in the imaginary play. This finding has not been previously reported in the literature for children under five, and gives new understandings about the nature and genesis of design and designerly thinking of children within the early childhood period. Linked with other studies in formal school settings (Crismond & Adams, 2012; Haupt, 2018; Sung & Kelley, 2019), the findings of this research foregrounds how play in preschool settings would appear to be ideal early context in which design and designerly thinking can be supported.

Discussion

When the results of the study are brought together, insights can be gained into the genesis of design thinking. Different to previous studies that examine children's drawing of designs, this study investigated both the motivating conditions and the motive orientation of the children as a process of engagement in design. The central finding of this study was that play is both the primary psychological function of the preschool child, at the same time as acting as the source of the child's development of design. In this reading, design and designerly thinking must be conceptualised together as a dialectical relationship. Five key ideas that elaborate this dialectic were identified.

First the study found that the play narrative of Robin Hood with its embedded design problems introduced by teachers or by the children at different moments gave purpose and a

way of expressing design ideas—something that was identified as important for under fives. This is captured as design for the under fives through the term *Design narrative.*

Second the study determined that play amplified both design cognition and design processes. The research showed that design thinking could be realised in play, but it was always shown in the process of developing—in motion and not a static end point. This process is evident in the literature, but not in relation to children's play in preschool settings. Therefore, this thinking is captured as *Designerly play.*

Third design thinking could be seen through the children's drawings, as was expected, but it was also shown in how design became an embodiment of ideas in play and through role-playing the story of Robin Hood. Design was furnishing the play in ways that united the narrative of the group of children towards a common design goal. What emerged was a play theme that created a sense of collective design. *Collective design* is something that is difficult to achieve in play-based settings for children aged five and younger. In line with design-based learning approaches for school contexts, this is an important finding for teachers interested in supporting children's design work in preschool settings.

Fourth the study noted that when design concepts were introduced as part of the children's play, this gave a level of authenticity, a sense of drama, and importantly it developed a motive orientation towards design. Design has to be seen as personally meaningful for children, as has been reported by Benson and Treleven (2011), who showed that children design as a step, but do not necessarily go back to their designs in supporting their build or prototyping. In this study there was a reason to engage in design for the children. Design and creating design ideas as part of the storying of Robin Hood, enriched the children's play. The children were both architects of their designs at the same time as being users/clients of their designs. This is referenced as a *Design motive.*

Fifth a further outcome of the study related to the significance of bringing into the teaching context someone with design expertise, as has been reported widely in the literature as important for supporting graphicacy and design work of young children (Anning, 1997; Kanga et al., 2013). In those studies, the ideal form of design was introduced to children as part of the process of developing designing thinking. But in this study not only could this be observed when the concept of imitation was deployed on the designs and the design process, but it was shown in how the children in their play used their design and this gave insights into their real form of competence—such as when the design expert says, "This time we can draw a side elevation. It would be a wolf's-eye view if wolf was smaller than it". This important finding would appear to be unique to design thinking and conceptual

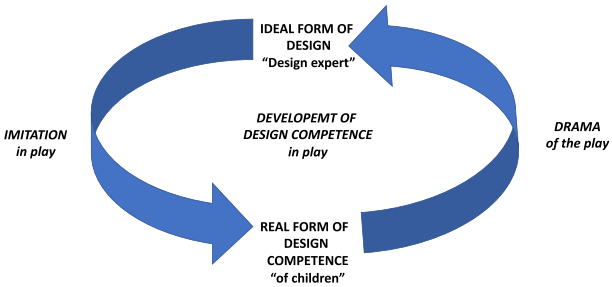

Fig. 13 Dialectics in design

development in design of the under fives and is represented as *Dialectics in Design*. This relationship is shown in Fig. 13 below.

It can be theorised that in the dynamics of the play-based settings, children's motive for design becomes visible and acts as a mirror of their thinking in their play. Figure 8 captures the dynamics of both the genesis of design in preschool children's play at the same time as capturing in motion, how designerly thinking is acting in relation to their play narrative. In this context, Fig. 13 theorises the interaction of ideal and real form of design cognition/competence as part of a play practice in preschool settings and is representative of the psychological development of children aged 5 years and younger. Both models (Figs. 13 and 8), not only capture the complexity of design competence in play-based settings, but they give directions for research and practice. Linked with conceptual design cognition for school and professional design settings (see Hay et al., 2017), the findings of this study show the genesis of design for children under five, and this support a continuum in understanding of the development in design thinking.

Conclusion

Theorised from a cultural-historical perspective, this study found that designerly thinking was always in motion (Fig. 8). Play appeared to give purpose for design. Playful design was not just an end product, it was also the process. Authenticity of design was realised in the play itself, where the client is the child, who is both designing to think and communicating design ideas, but also designing and prototyping to enrich play. This aligns with studies of older children in design based learning, but adds to this by foregrounding play.

Captured as a dialectic (Fig. 13), design experts as co-partners with teachers, created conditions for the rich realisation of the ideal and real forms of design in children's play. That is, in play design was found to be meaningfully embodied, visualised, and resourced through expert designers and the storytelling of teachers. Few studies in design for the under fives have examined how design cognition or design processes dialectally develop when design experts are invited in to preschools to create ideal forms of design.

English et al. (2020) have identified from the design literature a separation of categories as learning *about* design and learning *through* design. But in this study it was found that the development and genesis of design for children five years and younger, as was the focus of this study, needed different concepts to explain design in play-based settings. It is suggested that the genesis and development of design can be captured through the concepts of *Design narrative, Designerly play*, *Collective design, Design motive, and Dialectics in Design* for the under fives. These terms give more meaning to the purpose of design (Benson & Treleven, 2011), design competence (Hope, 2005), and contribute to the design matrices of older children/students (Crismond & Adams, 2012; Strimel et al., 2020). In so doing, the findings advance scholarship by going beyond learning *about* design and learning *through* design to learning *design in play* for children under five.

Appendix: Motivating conditions for design—conceptual *PlayWorlds*

Motivating practices	Pedagogical characteristic
The story creates motivating and emotionally charged conditions for solving a social problem	Using an engaging story with a social problem that needs to be solved
Teachers create an imaginary engineering situation of Sherwood forest	Designing an imaginary PlayWorld (e.g., outdoor area becomes Sherwood Forest, Fort becomes the castle)
The teacher together with the children change the meaning of the wooden fort in the outdoor area from a climbing frame into a time machine	Planning the entry and exit into the Engineering PlayWorld (e.g., time machine)
The teachers use the children's interest in getting the treasure to introduce the idea of being an engineer to solve the problem situation (Maid Marion is the head engineer, and she worries about the hungry villagers)	Planning the engineering problem to be encountered and solved inside of the Engineering PlayWorld (e.g., how to get the treasure out of the castle)
Teachers take an active role by being play partners and co-researcher with the children investigating engineering solutions	Planning teacher interactions (being an engineer, being Friar Tuck asking for help)
Children build conceptual knowledge as part of the research process (e.g., plan view perspective, cross sections of castles)	Researching in teams
Children evaluate the outcomes of their research and consciously consider engineering concepts in their models/prototypes/designs (e.g., using arrows to represent Force, testing prototypes—can they lift the treasure box?)	Engineering modelling in teams
Children use their theoretical knowledge in child-initiated play during free play periods in the preschool (e.g., becoming the dragon and climbing the fort to gain a bird's eye view for planning an escape route),	Developing the engineering play motive of the children

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