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Constructing and storytelling: accommodating different play orientations in learning spatial thinking

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Spatial ability is malleable and belongs in the preschool. For preschoolers, many analytical activities with one correct answer such as tangram have been developed. Less is known about employing open-ended design assignments to creatively practice spatial thinking. Little attention has been paid to the mutual qualitative differences between children when engaged in spatial thinking and insight in children's motivation is lacking. As design and play have much in common, our first study investigated play orientations during free play of 49 Dutch preschoolers during free play in a low and a high SES school. Participative interviews and observations in the construction and home corners of two schools uncovered different play orientations– construction and pretend play - and either a focus on open-ended objects or on defined objects. In a subsequent study, the influence of these play and object orientations on how children design was investigated. This study with 13 children also used generative design research methods grounded in ethnographic research and therapeutic practices. Using an empathic, story-based, open-ended design challenge, results showed that play-orientations of children influence the length and nature of the design activities as well as the design outcomes. Children with a pretend-play orientation are longer engaged and talk more about the character involved. They usually built organic structures with a variety of objects, while construction-oriented children mainly built sturdy and geometrical structures and mainly used open-ended objects. In all play orientations, spatial thinking was practiced and children were spatially challenged. For example, in all orientations difficulties arose around getting the character in out the structure, however, as different structures were build, the nature of these difficulties were also different. Open-ended design activities that contain characters and problems children can empathize with are a valuable addition to the palette of activities to develop spatial thinking in early classrooms. Our study shows that design activities stimulate children to practice spatial thinking in a creative context and have the ability to engage children with a pretend-play orientation who are otherwise less engaged in construction. The play-orientations and object-orientations are informative for research and the development of spatial educational interventions aiming at a diversity of learners.

KEYWORDS

spatial thinking, design and technology education, preschool, construction play, pretend play, storytelling, empathy, generative design research

1 Introduction

Spatial toys and challenges have also been a part of early education ever since Fröbel, featuring mechanical spatial elements such as construction sets of wooden blocks, and doll's houses. Recently, the importance of developing spatial thinking has been recognized with the European Union stimulating its development at an early age. Spatial thinking helps young children in their everyday lives, for example in navigation and way finding abilities as well as in understanding how shapes may fit together when making a puzzle. Spatial reasoning is also strongly linked with achievement in mathematics (Hawes et al., 2022). In addition, students with high spatial ability are more likely to pursue STEM subjects and careers (Wai et al., 2009) and do better in engineering classes (Sorby et al., 2018). Spatial thinking is also considered an important skill that is needed to solve problems and construct solutions in design and technology education (Buckley et al., 2022).

As spatial thinking is malleable and spatial learning in early childhood seems even more effective than later in life (Yang et al., 2020), spatial skills should ideally be taught early. Many studies of ways to foster spatial thinking of young children have been conducted and provide valuable insights that can be used in preschool settings. Block play is among the most researched areas including free play as well as guided play in which children are copying structures from booklets or photographs. However, using design play as a vehicle for the development of spatial thinking in a preschool educational setting has not been researched so far, but is relevant to consider as it may attract and engage pupils and also because spatial skills are developed in the context of creative thinking – something that is needed within most STEM disciplines.

Learning through inquiry and by designing artifacts is becoming increasingly popular in the Netherlands and elsewhere, also in early childhood education. A central goal of this type of education is to stimulate curious, investigative and problem-solving attitudes in young children.

In inquiry-based learning, children engage in exploring and trying to find an answer to one or more questions. Design can be considered as a specific form of inquiry: central is a problem or wish and the creation of something novel that can solve the problem or satisfy the wish (Klapwijk, 2017; Klapwijk and Stables, 2023). Design and technology education seems a promising ways to develop spatial thinking.

In design and engineering, spatial thinking is required to imagine and visualize novel and creative solutions and products. In design, usually a great variety of solutions are pursued, because there is not just one single correct solution that can be given in advance. Central in design are creative processes that Bronowski describes as "the ability to visualize the future, to foresee what may happen and plan to anticipate it, and to represent it to ourselves as images that we project and move about inside our head" placing the ability to 'image" and 'model' as its core processes (Kimbell and Stables, 2007, p. 15).

Our study focuses on design play in preschool because we expect that playful design activities may offer an additional avenue to foster spatial thinking. What is special about design and engineering, is that spatial thinking is required to generate, imagine and visualize novel and creative solutions and products. Eisner (2002) emphasizes that there is a difference between creating images in our mind's eye of things that are not experienced before and recalling images of objects that one has experienced before. In design processes, images as well as sketches and prototypes are used to create and communicate about objects that have different shapes and forms than existing ones. What is also special about using spatial thinking in a design context, is that usually a great variety of solutions are pursued, because there is not just one single correct solution that can be given in advance. This differs from guided play that consists of analytic activities such as tangram, shape parades, finding the pair and similar puzzles (e.g., Cornu et al., 2019; Bower et al., 2020; Yang et al., 2020; Bower et al., 2021; Hawes et al., 2022), where a single 'correct' answer is known in advance, see Figure 1. Preschoolers in Bower et al. (2020) study constructed puzzles with foam shapes that matched an existing model composed of various geometric shapes, while in another study children had to find two shapes that are the same amongst distractor shapes (Cornu et al., 2019).

Because there is a need for creativity in our society (Voogt and Roblin, 2012) it would be valuable to use design play to nurture spatial thinking. During design play, children are invited to use their imagination and visualize and build novel artifacts, or at least artifacts that are new for them (Cropley and Urban, 2000; Klapwijk, 2017). Design play will allow children to practice spatial thinking in a creative context.

Our central aim is to develop educational innovations that stimulate spatial learning in the context of design play. We want to develop design play activities with a spatial element that are engaging for a diversity of learners and that are feasible to conduct in an early childhood educational setting. Using a human centered design approach to develop these design play activities, our first step is to understand our user group and the (classroom) context in order to be able to develop design play activities that preschoolers will enjoy and actively engage in. Although there is a clear shift to research in classroom contexts (Yang et al., 2020), little is known on individual differences in the way preschoolers engage in spatial activities. As most studies in the spatial discipline, have a quantitative nature, they do not describe the different ways children engage in spatial activities nor the learning processes and mechanisms. As a result, studies do not shed light on individual differences between children when they engage with spatial activities (Hawes et al., 2017; Yang et al., 2020). Even when studies account for gender, social economic status (SES) and the level of spatial ability, the results provide little guidance for the design of engaging spatial activities because there is no rich understanding of the user group. Although we could have focused on differences in the way girls and boys, low and high achievers or between low and high SES preschoolers, we expect that it is more beneficial for developing engaging design play activities to study play preferences of children. We conjecture that the way children play, may influence the way they design and subsequently also influence the way they will apply and develop spatial thinking. Diversity in terms of preferred ways of playing and designing, is the central theme of this study.

A more thorough, rich understanding of the variety of play and design among preschoolers is needed. Therefore, we will first present a study focusing on uncovering the diversity of individual orientations of children aged four to six during free play activities in schools in the Netherlands using qualitative user research methods from the design disciplines. The research results of this first study showed that play orientations differ on two axes. Whereas some children prefer construction play others prefer pretend play. And where some children

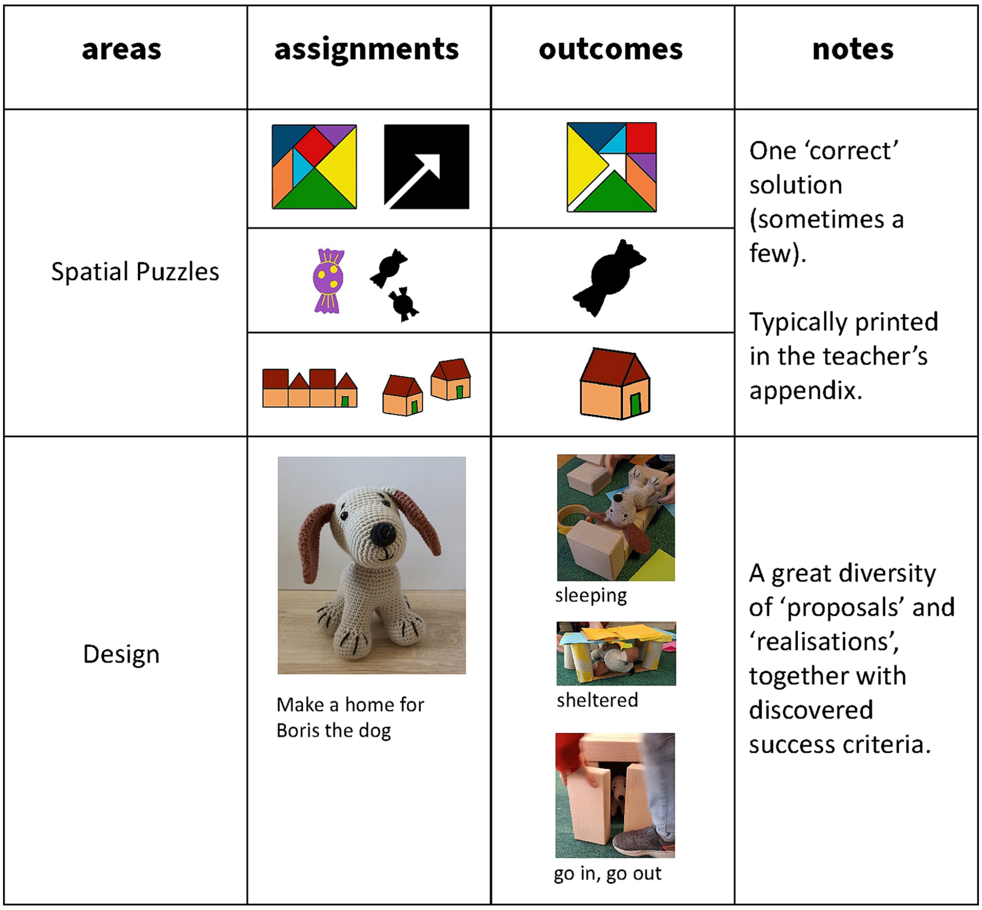

FIGURE 1
A spatial puzzle typically has a fixed solution whereas a design assignment typically has an open outcome.

prefer to play with undefined objects such as blocks other children prefer to play with defined objects such as a little cooking pan. Based on these play orientations, a design challenge for preschoolers has been developed and tested because we wanted to know how children with different play orientations would engage with the design assignment and if and how this influenced spatial thinking processes. Using a qualitative approach, we studied how children interacted with the design assignment, how long they played as well as the kind of solutions they have imagined and build. Our focus was especially on how children with a construction play orientation differ from those with a pretend play orientation when they design, make and think spatially.

1.1 Literature review

1.1.1 Design education

Across the world, countries have been introducing design education in primary and secondary schools under a diversity of labels, such as 'technology education' and 'maker education', or as part of science education, for example in Sweden, Ireland, Finland, the United Kingdom, Korea and China. In the Netherlands, learning to design is one of the core goals in the primary curriculum: "students learn to design, implement and evaluate solutions to technical problems" [SLO (Stichting Leerplan Ontwikkeling, Netherlands Institute for Curriculum Development), 2020].

There are different definitions of design available. Design is often defined as "the conception and realization of new things" (Cross, 2006). Design is not necessarily related to the material world. Everyone who devises courses of action aimed at changing existing situations into preferred ones is designing, one may design a new service or imagine a novel organizational structure.

In design several things are considered important (Lawson and Dorst, 2009; Dam and Siang, 2021; IDEO, 2023; Klapwijk and Stables, 2023). First, there is a process progressing through a sequence of phases: usually a design process begins with a problem exploration, then goals and design criteria are formulated after which one or more solutions are constructed. Second, progression goes in iterations: several steps are repeated as the insights grow, e.g., after developing a first series of solutions a new design criterion is discovered or it becomes clear that the problem is not yet well understood and new investigations in the problem are needed. Increasingly, and especially in the field of human centered design and context mapping, the importance of developing empathy for the target groups is emphasized as this will increase the likelihood that the designed solutions will match the users' needs and wishes and enhance people's life (Kouprie and Sleeswijk Visser, 2009). Figure 2 shows three models that are used in design practice and education of the past two decades.

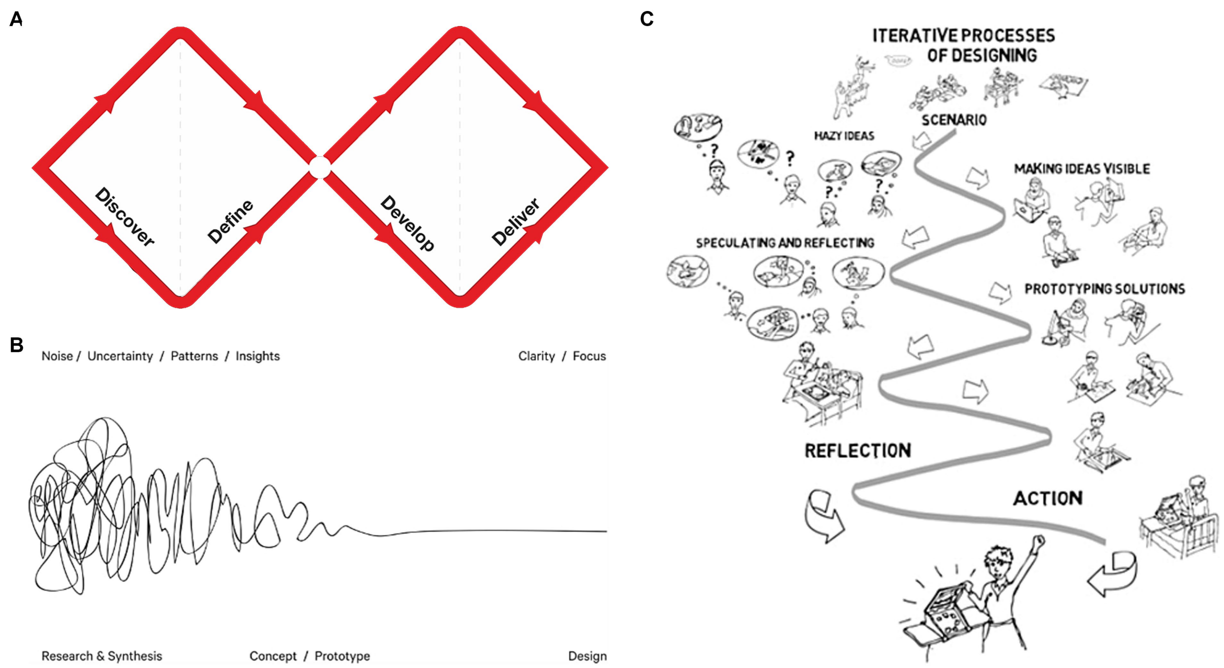

FIGURE 2
(A) Double Diamond by the Design Council (2007), **(B)** Design Squiggle by Newman (n.d.), **(C)** APU Model of Technology Practice (Kimbell and Stables, 2007; Klapwijk and Stables, 2023).

The "Double Diamond" (Design Council, 2007) clarifies the successive steps and the alternation of divergent – imaging novel ideas or objects – and convergent thinking which has an evaluative and elaborative element (Howard-Jones, 2002). The 'Design Squiggle' (attributed to Damien Newman, around 2000s) illustrates how the process begins with broad exploration and narrows down later on.

The APU model (Kimbell and Stables, 2007) emphasizes the alternation of reflection and action. On the left side of the model, the internal cognitive processes are depicted. These processes include imagining solutions and how they will work, in other words using the mind's eye to design. On the right side of the model, activities outside the head are depicted. These have usually a multi-modal nature, peer talk, gesturing as well expressive artifacts such as sketches, prototypes are applied (Van Mechelen, 2016). Thinking and doing are related in design. Donald Schön, professor in urban design, coined therefore the term "reflection-in-action." Designers will use sketches and 3D prototypes to develop and evaluate their design concepts. As he puts it "designers interact with these representations in a conversational way" (Schön, 1983). These conversations help to further develop design ideas. Spatial thinking does not only take place in the minds of the children, but also when they draw (two-dimensional, 2D) or when they manipulate materials (three dimensional, 3D). In spatial cognition literature, this multi-modal nature of design is known as distributed spatial sensemaking (Ramey and Uttal, 2017). Design has an embodied nature: from the earliest childhood, people and animals think with their bodies (Varela et al., 2017). Research on practical learning and embodied cognition, has shown that the mind and body working together in developing knowledge, skills and understandings and recognizes the complexity of human actions that link the 'doing' of the body with the "thinking" of the mind. Claxton et al. (2010) write; "Recent research also suggests that "doing" may even precede (nearly instantaneously) "thinking." The brain is designed to put "doing" before "seeing" or "thinking." We have evolved to be fundamentally active, not contemplative creatures. The idea that human cognition proceeds in linear sequence from Perceiving through Interpreting to Thinking, Deciding and then Acting is out of date. Before we open our eyes in the morning, our sensory systems are primed by what we want to do and what we are able to do, and the interaction between Wanting, Doing, Perceiving and Thinking is near instantaneous (within hundredths of a second) and continual" (p. 4).

Another important aspect in design processes is the presence of form-function thinking. Designers are searching for objects and forms that may fulfill certain functions or services (Gero and Kannengiesser, 2004). An example of a function of service is cracking a nut, this can be done with a screw mechanism, squeezing tongs, or with a hammer.

Summarizing, design is in the conception and realization of new artifacts and involves internal cognitive processes and external ones such as interactions with other people, materials, and representations. Various design models exist, all give some guidance to design activities and support novices in developing design capability, but should not been understood as a recipe prescribing a fixed set or order of activities.

1.2 Spatial thinking in a design context

Many definitions of spatial thinking exist. Carroll (1993) emphasized the aspect of spatial visualization, the process of searching "the visual field, apprehending the forms, shapes, and positions of objects as visually perceived, forming mental representations of those forms, shapes, and positions, and manipulating such representations 'mentally" (p. 304). For preschoolers, spatial reasoning includes position, direction, navigation, orientation, shapes of objects, shape properties and spatial structure, composition and decomposition of shapes, movement and rotation, symmetry, perspective-taking, and scaling (Gifford et al., 2022). Various studies have explored how spatial thinking is applied in STEM fields (Uttal and Cohen, 2012), only a few studies focus on how spatial thinking is applied in design (Berkowitz et al., 2021; Strand and Lutnæs, 2022; Darwish et al., 2023; Zhu et al., 2023, 2024), technology education (Solomon and Hall, 1996; Ramey and Uttal, 2017; Buckley et al., 2022) or maker education (Buckley, 2023).

In this article, we will use the definition proposed by Ramey and Uttal (2017) in a study on a summer engineering camp. They extended Carrol's definition "to include both internal cognitive processes (e.g., mental rotation of two-dimensional [2D] or three-dimensional [3D] figures) and thinking involving external objects or spatial representations, such as models and diagrams." This definition fits well with the way the earlier described models that envisage the design process as iterating between internal cognitive processes as well as the external processes using representations.

In design activities children use all different kinds of thinking processes, like creative thinking, critical thinking and prototyping. A lot of these processes require spatial thinking. From the seven design skills defined by Klapwijk et al. (2019) for primary education we will highlight five skills that are strongly related to spatial skills: divergent thinking, bringing ideas to life, sharing ideas, empathize and making productive mistakes. Divergent thinking, this is about generating and imagining many ideas and solutions and this could be about objects that are spatial in nature. For example, children: need to be able to design, in their heads, and then on paper, how an artifact can best be constructed so as to serve its purpose, such as withstanding forces acting from any direction or, if it has moving parts, how these can operate without knocking into the stationary parts (Solomon and Hall, 1996, p. 265). The second skill is bringing ideas to life, in order to bring an idea to life a preschooler has to translate its mental image into 2D and 3D representations (Anning, 1997; Fleer, 2022). During constructing children have to think in terms of space and shape, they need to work in three dimensions, and understand how flat shapes can be bent or folded so as to make space-filling objects (Solomon and Hall, 1996, p. 265). Productive mistakes is about reflecting on the objects made. Children have to think spatially when they diagnosis why a constructed object or a part of it is not operating well and how they can change this to better fulfill the desired functions. Furthermore, sharing ideas is important in design activities and preschoolers will need spatial language to communicate its ideas clearly to its peers. Language is vital for almost all learning, for describing shapes, anchoring concepts, and making the tacit articulated so that it is more easily retrieved from memory. Solomon and Hall (1996, p. 275) argue that language is likely to provide the key for linking thought to action. It is also thought that spatial language, when directed toward a relevant task, increases children's selective attention to spatial features and relations, leading to spatial learning (Miller and Simmering, 2018). In addition, the ability to learn to empathize is extremely relevant in design education (Klapwijk and Van Doorn, 2015). In order to empathize with the target group a preschooler needs to be able to take on different viewpoints and step in the shoes of someone else (Klapwijk and Stables, 2023). Occasionally this emphasizing process has a spatial nature, e.g., How does this doorway appear to a person in a wheelchair?

Several design researchers have argued that designers visualize and experiment in a different way than science oriented professions (Lawson, 1979; Lawson and Dorst, 2009). Lawson (1979) reported architectural design students' and science students' different approaches towards a spatial problem. To produce an optimal spatial arrangement using three-dimensional blocks, science students preferred to thoroughly examine the rules underlying the problem to define criteria for possible solutions, while architectural design students attempted different solutions to identify the best fit. Where scientists achieved a better understanding of the underlying rules, architecture students developed more optimal spatial arrangements given certain rules. Based on this block arrangement study it is worth speculating that the spatial problem solving processes involved in design activities may differ from solving tasks that have only one correct solutions such as tangrams or shape parades. This is another reason to use design and technology assignments to practice and nurture spatial thinking.

In summary, we define spatial thinking as a process of interwoven internal cognitive processes as well as constructing and manipulating external representations. Both are present in design processes. When making or designing, different distributed sources are connected by the children to develop spatial understanding of the construction, designing thus has the potential to practice and develop spatial thinking skills.

1.3 Playful design activities for young children

As most studies on spatial thinking in relation to design focus only on students from upper primary to university level and not on children from our target group, the four to six years olds, we will now explore how spatial thinking (including embodied spatial thinking) is present in design activities of younger children.

Design thinking is closely connected to play, especially for preschoolers, we will therefore first focus on what play is and then continue to describe how play and design often go hand in hand. Play is what drives preschoolers. Children's play has been operationalized as intrinsically motivating; pleasurable; freely chosen; non-literal and actively engaging (Hughes, 1999). According to Ginsburg et al. (2003) "play allows children to use their creativity while developing their imagination, dexterity, and physical, cognitive, and emotional strength" and "above all, play is a simple joy that is a cherished part of childhood." Different types of play have been distinguished: physical play, object play, symbolic play, pretend play and games with rules (Whitebread et al., 2012).

Preschoolers learn through play in an informal way. For example, as Ginsburg et al. (2003) describe: "4- and 5-year-old children engage in a considerable amount of everyday mathematics of various types during free play." They observed that preschoolers, among other things, explore patterns and spatial forms, magnitude and quantification.

Play also plays an important role when they do design activities. As described before, designers look for ways, objects and forms that can full fill certain functions. Designing is thus a purpose-driven activity. To start to design, children need to have a goal or wish that they want to pursue. Stories are often used in design activities with preschoolers. Fleer (2022) used the story of Robin Hood to introduce

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design challenges, such as getting the treasure back to the village. Play and designerly thinking were strongly connected. Fleer (2022) describes that "it was only possible to understand the development of designerly thinking when the child's leading activity for play was taken into account." Play amplified the design activities, e.g., through role play children were visualizing their designs and it also helped children to empathize with the people having the problem, resulting in a real need to want to solve the problem. Pretend play made the problem meaningful to the children.

Spatial learning can be playful as well. The Playful Learning Landscapes movement developed playful environments such a Parkopolis, a life-sized mathematical and spatial board game in a children's museum (Pritulsky et al., 2020). Playing in Parkopolis that led to increased spatial and mathematical talk.

2 Materials and methods

Because of the aforementioned reasons of the benefits of play and playful design, our research focuses on playful design. As, knowledge about how different children engage in play as well as in spatial learning is scarce, our first aim is to get an rich understanding of the variety of experiences preschoolers have when they apply spatial thinking during free play or during design activities. Insight in individual differences is not only scientifically relevant, but also socially relevant as it can be used to develop design activities to practice and develop spatial skills and can inform the development of other spatial learning activities. Our central research questions are: 1) How do preschoolers experience and use free play and design opportunities in a classroom and what are the underlying play orientations? 2) What are differences in the way preschoolers with different play preferences engage, play and interact with design assignments and how does this influence the way they practice spatial thinking?

Two studies were conducted. In the first study "Free play experiences" free play experiences of preschoolers were researched, as the activities they undertake during this time are most out of their own motivation and interest. The focus is on free play in the construction corner, home corner and LEGO and K'NEX activities. This first study led to the identification of various play orientations. In the second study "Diversity in Design Play," we explored how these different play orientations led to different interactions with a story-based design activity and how this may have influenced spatial thinking of the pupils. The pupils in both studies were from two Dutch preschools and four to six year old. Both studies use a generative design research with preschool students engaging in spatial play and design activities and were conducted with qualitative methods of human centered design research (Sanders and Stappers, 2012). The aim is to discover and articulate patterns of possibility. The first author participated in the classroom learning activities of the children, observed their activities and how they related to the class (space, other people, objects). She engaged with the children using open questions, evoking their opinions, experiences, and reasons why they did what they did. This mix of observation, talk, participation, reflection, and interaction is characteristic of explorative design research, and is meant to understand users and their context. The method is partly grounded in ethnography, partly builds on practices of therapeutic psychology to encourage participants to share stories about what matters to them. Both studies were reviewed and approved by the Human Research Ethics Committee of Delft University of Technology. The parents and guardians of the participants provided their written informed consent to participate in the studies.

2.1 Study 1: free play experiences

2.1.1 Participants

Two schools were contacted via the network of the Science Hub of the Delft University of Technology. The first school was located in Rotterdam, The Netherlands, in a multicultural neighborhood with children from relatively low SES backgrounds, and had a traditional educational approach. The class consisted of 23 children between 4 and 6 years old, 16 girls and 7 boys. The second school was located in a slightly smaller city in The Netherlands and mainly attended by children from relatively high SES backgrounds. The school applied a Freinet education approach. The class consisted of 26 children also between 4 and 6 years old, 9 girls and 17 boys. All for whom consent was obtained participated.

2.1.2 Study design and materials

It is custom in both schools that children have free play time each day. During this time the children can freely choose what they want to play with, with who and for how long. In order to get an understanding of the differences in play orientations the researcher observed and talked with the children during free play. The focus was on the construction corner, the home corner and other construction activities. No specific materials were provided, other than the ones already available in the schools.

2.1.3 Data collection

The researcher was introduced as a teacher to the children and it was explained that the researcher was curious to know what they did during the day and what they liked to play with. The children were told that if they liked they could share what they were doing with this new teacher. Two methods were used. First, joining the child while he or she is playing, with the goal to get a connection with the child without steering their play into another direction. Second, letting the child naturally come to the researcher with what he or she wanted to share. The following anecdote shows how this worked in practice:

> *Child 1: You are the teacher who writes down what we like and dislike right? I like the bicycles the most.*
> *Child 2: Yes and hitting other children is the stupidest thing.*

The children were asked for verbal permission to observe them and talk with them, e.g.,: "Can I sit here to see what you are building?." While the researcher was sitting or playing with the children small interviews were held. The following questions were asked:

- What do you enjoy most to play with in the classroom? Why? Can you show it to me?
- What do you not like to play with in the classroom? Why? Can you show it to me?
- Do you enjoy the construction corner or home corner more? Why?

Per situation and child it was decided which approach to connect, observe and talk would fit the child best, because the goal of this study was to obtain a deep understanding of the preschoolers. For this, it is needed to be flexible in approach and as a systematic comparison was not the aim, it was not needed to approach all children in the same way. In order to get a good understanding of the variety of the target group, the researcher sat with several children for about five to ten minutes, in which they continued with their play. While sitting with the child, the researcher also observed the kind of play, object manipulation, spatial language and use of gestures. Notes were taken. As this article focuses on play orientations of children, we will use mainly the data on the kind of play that took place and the short interviews on what children enjoy and do not enjoy.

In order to scope the research, the interviews took place in the home corner and the construction corner. The home corner is an area in the classroom that is decorated as a home; it has, among other things, a play kitchen, table and chairs, and dress up clothes. The construction corner contains wooden blocks of different sizes and shapes and 2D building examples. These two corners were chosen because they are distinct and represent different types of play. In addition, they are often clearly demarked and often a bit shielded corners and are present in most Dutch preschool classrooms. Other play materials do not have such clear designated areas. Also it was expected that all children would play in at least one of these corners. As many children in these corners also talked about playing with LEGO and K'NEX, the researcher also joined pupils who played with LEGO and K'NEX and had similar interviews when she connected with them.

2.1.4 Data analysis

Data where analyzed to understand play preferences of children. Often observations and talk were combined and also data from various days to give meaning to what a child said of did. Using an ethnographic context mapping approach, there were many differences observed and after some time it was decided to focus the analysis on those variations we thought that these were most interesting for the development of design play activities. Although we did not start from any specific play orientations theory, the two play preferences we found present in the data (object play and pretend play) were also mentioned by Whitebread et al. (2012). The other orientation we focused on in the analysis was the preference for open or defined toys.

2.2 Study 2: diversity in design play

2.2.1 Participants

The same schools participated in the second study a few weeks later. The framework of play orientations functioned as a starting point for selecting participants for the second study Diversity in Design Play. Figure 3 shows how the selected children are distributed over the framework, see 3.1.5 for an explanation of this framework. Children from school 1 are indicated with a uppercase letter (e.g., "A") and children from school 2 are indicated with a lowercase letter (e.g., d); gender with a symbol.

The children were selected by the teachers who used the framework and their experience with the children to indicate the play orientation of the children. In total 13 children aged 4 to 6 participated. From the school in Rotterdam 5 girls and 3 boys participated, and from the second school 1 girl and 4 boys participated. The aim was to have both girls and boys for each of the play orientation combinations, however due to missing informed consent and absent children, this was not possible during the days the researcher was present. The teachers however did initially select both girls and boys for each orientation combination.

2.2.2 Research design and materials

For the second study a design assignment around Boris the dog was developed by the first author which allowed for both construction play and pretend play, as well as the use of open-ended objects and defined objects. This approach to design was selected because the free play experiences showed that these were important elements in play orientations of the children. Next to this, storytelling and visual prompts provide a meaningful design context for preschoolers (Fleer, 2022). The materials consisted of a picture book of a dog called Boris made by the first author (which can be found in Supplementary Appendix S1) and a stuffed puppet of the dog. The story introduced the problem to the child and evoked empathy: The owner of Boris turned out to be allergic for dogs and therefore Boris could no longer live with the family, see Figure 4 on the left. Then the story gave aspects that the children could take into account, see Figure 4 on the right for one of the four examples: (1) if the sun is shining, it is very hot outside, (2) if it rains Boris gets wet, (3) if it's windy Boris gets almost blown away, and (4) outside there is only grass, which is quite boring. Then it is illustrated that Boris looked for and found materials to build with. The story ends with the design challenge for the pupil: Can you help Boris build a nice place to live? The assignment had an open outcome, so there was no fixed solution and there were no clues given towards a certain direction or outcome. The pupils themselves could translate the given aspects into design requirements, e.g., the aspect 'if it rains Boris gets wet', could result into 'I need to make a roof for Boris' or 'I need to make an umbrella for Boris'. However, the children themselves could decide if and how they wanted to take these aspects into account.

The researcher and a child worked one-on-one in the construction corner. In the first school, the construction corner was separate from the classroom and located in the hallway. The story was read to the child by the researcher (first author) and a stuffed puppet of the dog was given to the child. The child could use the blocks in the construction corner, empty toilet paper rolls, pieces of cardboard, colored post-its, and masking tape to build their designs. This approach to the design assignment was chosen because it allowed for construction play, pretend play, the use of open objects and defined objects and had the potential to engage pupils with different play orientations. The design challenge was conjectured to trigger construction play because the children were asked to build a place to live for Boris. It was also thought that it would serve pretend play as the children could use the stuffed puppet of Boris to play with. Via the stuffed puppet it could be observed if and how the child would take the dog, which is a defined object, and its dimensions into account. The other available materials were open objects so it could be observed how children would interact with those.

Based on the framework that was a result of the first study, it was conjectured that children with different play orientations would have different motivations and barriers during the interaction with the designed activity focused on spatial thinking. A child with a

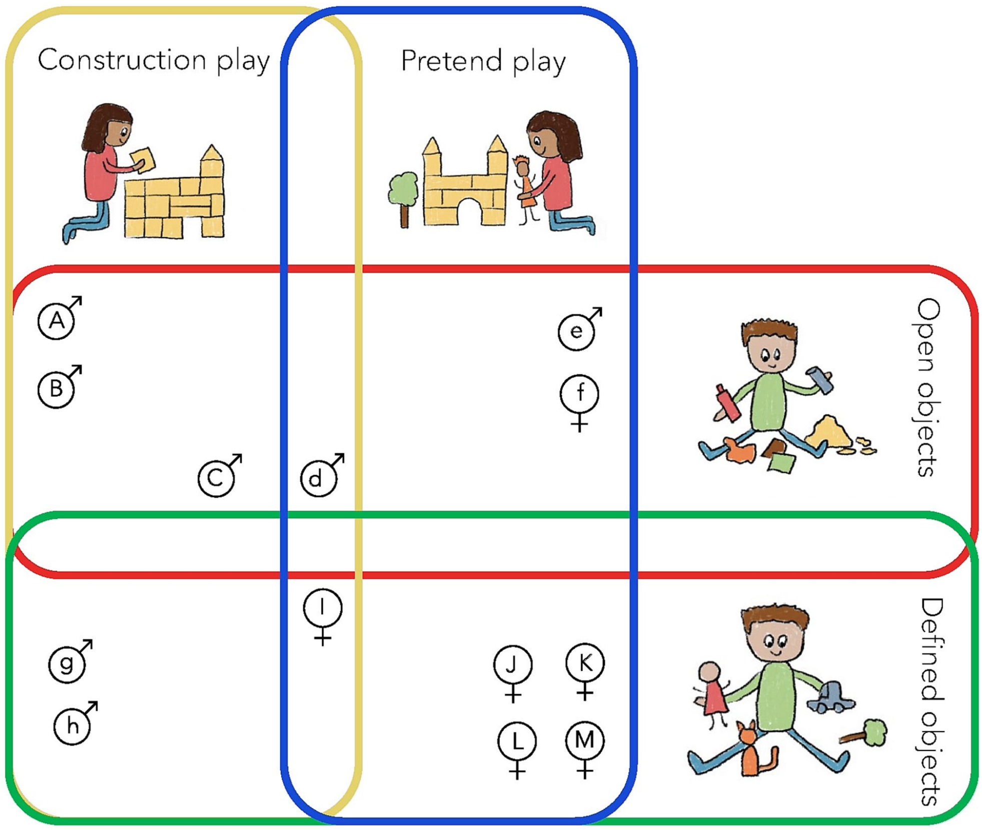


FIGURE 3
An overview of how the participants are distributed over the framework.

preference for construction play and open-ended objects might spend most of its time creating a well-constructed doghouse using blocks, while a child with a preference for pretend play and open-ended objects might quickly put something together and spend most time playing with the stuffed puppet of the dog and the built doghouse. A child with a preference for construction play and defined objects might spend its time on crafting concrete objects for the dog, e.g., a ball, food bowl, and leash. A child with a preference for pretend play and defined objects might look for objects that can function as concrete objects and start playing with those and the stuffed puppet of the dog.

The Boris the dog assignment was conducted with the selected eight participants from school 1. However, the teacher of school 2 preferred to do activities which were connected to the curriculum, instead of using the story of the dog. So the researcher did two types of activities with these 5 pupils.

Building a Castle for the Princess and the Frog. The day before the researcher came to the classroom the teacher had read the fairy tale the Frog-Prince by Grimm to the children. One of the tasks the preschoolers had to complete that week was to build a castle for the princess and the frog. The day the researcher came, the teacher showed a video of the story so the preschoolers were reminded of it again. During the individual sessions, two children were invited to build a castle.

Building for Your Own Toy. The other day the researcher was visiting, it was 'toy day', so each child brought its favorite toy to class. During these session, the researcher came up with a challenge based on the toy, e.g., build a cave for your dinosaur or a garage for your cars. Three children build something for their own toy.

Similar to the dog assignment, these activities were one-on-one with the researcher and children could use blocks, empty toilet paper rolls, pieces of cardboard, colored post-its and masking tape. The blocks were those available in the school. Stuffed puppets of the princess and frog were given and the own toy was present during the sessions. As it was not possible to do the Boris the Dog assignment in the second school, less children were invited to participate compared to the school in Rotterdam.

2.2.3 Data collection

The selected 13 children had an one-on-one session with the researcher. The session lasted 30 min maximum. If children were finished earlier or wanted to stop sooner, they were free to do so. A set up of the research can be found in Figure 5 which shows that the researcher was sitting on the floor together with the child. The materials were laying around the child.

It is important to know that as the generative design research approach was used, there was not a strict session plan or a prepared set of interview questions. The researcher followed her intuition and the child, e.g., some children wanted to build in silence, others had a lot of questions that they wanted to discuss. Some wanted to do everything on their own, others invited the researcher to help.

The audio was recorded and transcribed, and about every minute a picture was taken of what the child was building. It was decided to

FIGURE 4
Drawing on the left: Dad keeps sneezing, he is allergic for Boris. So Boris has to live outside. This creates empathy as Boris and the dad are both showing emotions that the child can relate to. Drawing on the right: showing that it's warm outside when the sun is shining. This is an aspect that the children can take into account and potentially can translate into a design requirement.

FIGURE 5
Set up of the research: the researcher was sitting on the floor with the child. Materials were lying around the child.

take no notes, because during the first study it was observed that this was distracting for children. Right after every session, the main observations were written down.

2.2.4 Data analysis

The focus in our analysis is mainly on the children who did the Boris the dog assignment, but episodes from the other assignments are used to show that play orientations also influenced the interactions with the other design assignments.

Although a lot of data was collected, it was also quite hard to make sense of the data because preschoolers talk in their own language and are in their own play world, so as an adult it can be hard to understand what they mean. Next to this, young children often make use of circle reasonings. So in order to make sense of the data we had to use a different approach than the standard context mapping approach in projects with adults (Sanders and Stappers, 2012). Timelines with pictures were made in order to see what children did during their design processes. This made it easier to see differences and similarities between the 13 children. Using these visual timelines, four interesting themes emerged:

- The outcomes and used materials.
- Building process and time spent.
- Types of (spatial) play.
- Talk about and focus on the dog (or other toys).

These themes were also related to conjectures the authors made beforehand. We expected differences on these themes as a result of the

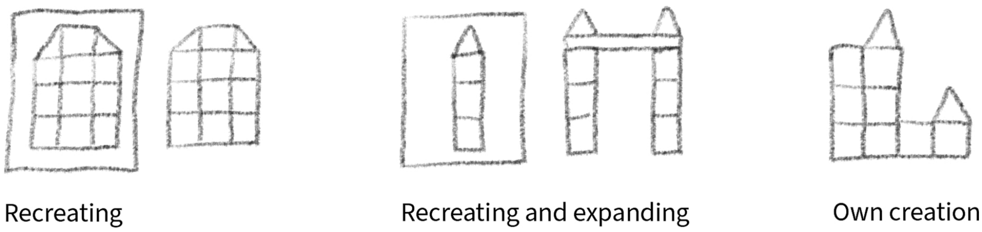


FIGURE 6
Three ways of building.

play orientations. As the analysis made the process and the children rather abstract and not rich, the first author also made a cartoon and synthetic quote of each child to capture the essence of the personality of each child in the design process. These cartoons not included in the results, but supported the interpretation of the data.

3 Results

In the following section the results of the Free Play Experience study are presented, followed by the results of the second study on Diversity in Design Play. In the Discussion both studies will be combined and reflected on.

3.1 Results study 1 free play experiences

The children were asked if they liked the construction corner or home corner more. The children themselves often also started talking about the LEGO and K'NEX, so this seemed important to them. Therefore those results are included as well. The following sections first present the reasons children gave to like or dislike the construction corner, followed by the likes and dislikes of the home corner, and LEGO and K'NEX.

3.1.1 Construction corner

Three ways of building were observed and are illustrated in Figure 6:

Rebuilding the 2D examples that are present in the construction corner. Rebuilding gives certainty of a good looking result, as the following quote shows:

> *It is fun to recreate things because then I know it will be beautiful.*

Rebuilding and then expanding further yourself, in this case 2D examples provide a starting point. For example, a child was rebuilding a swing. After a while the child said: *"Now I have a much stronger one."* He expanded the 2D example by adding triangles to the swing. Other children sometimes see this as 'wrong' because it does not look like the example, as the following quote shows:

> *Child 1: That is not right, this piece has to come off.*
> *Child 2: I know.*
> *Child 1: That is not right, make it differently.*
> *Child 2: I made it extra, like you made this [thing child 1 made] differently.*

Figuring out yourself what you are going to build. The children made all kind of different things, for example: high towers, a dinosaur park, and a chair. This way of building gives freedom and autonomy, as the following quote shows:

> *Researcher: What do you like in the construction corner?*
> *Child: To build.*
> *Researcher: And what do you build?*
> *Child: I do not know, just something, I just build.*

Children who like to play in the construction corner mentioned they enjoy it because you can build something yourself and they experience autonomy over what they can make and do.

Children who dislike the construction corner mentioned they experience less freedom to create their own stories and characters because the blocks are abstract. The following conversation shows that these children would have liked to adapt the blocks to create a character:

> *Child 1: While drawing you can make puppets with lip gloss.*
> *Researcher: Why is not that possible during building?*
> *Child 1: Because then it's not possible.*
> *Child 2: Because you must have pencils.*
> *Researcher: To draw?*
> *Child 1: Yes because you have to have a paper, you cannot have blocks with pencils, you have to have pencils with paper.*
> *Child 2: Because you cannot always do that.*
> *Researcher: Are not you always allowed to draw?*
> *Child 2: No, you are not always allowed to color on blocks.*
> *Researcher: Oh no, that's not allowed.*
> *Child 2: Because otherwise teachers and mamas get angry.*

However, there were a few blocks with a character drawn on it and this opened up possibilities for a story. For example, a child disliked to play with the blocks, but as soon as she found a block with a character drawn on it she started building attributes like a table and chair and used the block with the image as a character.

Finally, some children find the blocks boring because you have to build them up and so there is no "something" to start playing with right away, as the following quote illustrates:

> *The blocks are the stupidest because that's boring because you have to build everything and that takes sooo long.*

Both teachers mentioned that the children like to go to the construction corner, because it is located in the corridor. This is a more quiet place where children can get away for a while from the busy stimulating classroom environment. This shows how important it is to look at the context in which your participants are engaging with your research topic.

3.1.2 Home corner

Children who like the home corner mentioned they enjoy it because you can do 'real' things there like cooking, putting the dolls to bed, and being a vet. They enjoy taking on roles and playing a story. There is also a diversity of items you can create with and that gives opportunities for different stories to be played, as the following quote illustrates:

> *The house corner is the most fun because here I can put on the dress and play mummy and big sister. And I can cook, which is fun.*

Children who do not like the home corner mentioned it is because you are stuck in a role and therefore no freedom is experienced for own creations, as the following quote illustrates:

> *I do not like the home corner because you can only play mummy and daddy there and I want to be able to make and do things myself.*

3.1.3 LEGO and K'NEX

Children like construction kits LEGO and K'NEX for the same reasons as the construction corner. Also, these kits include figures of persons, animals, and plants. Children who value a story tend to prefer these kits over regular wooden blocks. It was also observed that children were lifting up their creations and walking around with them to play. For example, one boy made a round star-shaped object with K'NEX and carried it around in the classroom, changing the meaning of the object based on the story he engaged with:

> *Child: "He [the object] can turn and fly. And he can make someone slip.*
> *-a few seconds later:*
> *Child: Do you know what this is? A gun.*
> *Researcher: Do you want to shoot me?*
> *Child: He's fake. With this gun you can also do this [lets it drop]. He was getting longer and now he does not need it anymore now he just does not have anything.*
> *-a few seconds later:*
> *Child: Look now they [protrusions of the object] all go worms, now they all go into the other worm.*

In the construction corner it was not possible to lift up their creations as the wooden blocks were quite heavy to handle for preschoolers and the blocks did not stick together so the creation would fall apart once it would be lifted up.

LEGO and K'NEX seemed to provide a good middle ground between defined objects and open-ended objects as the sets contained both. They also allowed for construction play and pretend play.

A child who disliked the blocks because they were boring mentioned that she did like LEGO:

> *I like my LEGO because you can make aaaanything.*

3.1.4 Expressed values of play orientations

Behind the preferences preschoolers gave there are several expressed values that concern the type of play and the abstractness of the play materials.

First, there is a difference in the orientation for construction play versus pretend play.

Children who enjoy construction play value the building process itself and do not necessarily want to act out stories with the objects they have built. They value the freedom they experience by building whatever they want and the process of building itself, so also rebuilding and/or expanding an example. Children who do not like this type of play do not perceive this freedom, as they feel like they first have to build their play materials before they can start playing. These preschoolers are more likely to enjoy pretend play and acting out stories. They do not value the building process of the objects they need for their stories that much. This difference is also reflected in the reasons the children gave to like or dislike the home corner, a place where a lot of pretend play is happening. The children showed two different mindsets towards the roleplay: 'I can take on a role, so I can be and do whatever I want to be and do' versus 'I take on a role, so I can only be and do things that belong to that role'. This difference in mindset shows that some see a role as something that is open and gives them freedom while it is restricting for others.

Secondly, a difference was found in amount of abstractness the play materials should offer. Blocks are abstract materials and for some this abstractness gives freedom to build everything they want, these children enjoy to play with open-ended objects which do not represent a fixed concept. In this way they are the ones who can give meaning to the object and use it according to their imagination. For others this abstractness is a limitation because in their view there is no 'something' to start playing with right away. These children are in general more attracted to defined objects as they immediately provide starting points for stories.

3.1.5 Framework play orientations

To facilitate the development of spatial activities that engage a diversity of play orientations, a framework for play orientations was developed. As discussed above, children in the studies expressed a preference for construction play or for pretend play, and for open-ended objects or for defined objects. And although some combinations of preferences were more frequent, each combination seems possible (see Figure 7).

Construction play means that children are building or creating something. Examples are building garages, making a tower, or making tea and cooking.

Pretend play means that children take on a role of someone else. They act as another person. Examples are playing mummy and daddy, acting as a vet, or pretending to be a princess.

Open-ended objects are materials that children play with that do not represent a specific concept. Examples are blocks, LEGO, K'NEX and crafting materials.

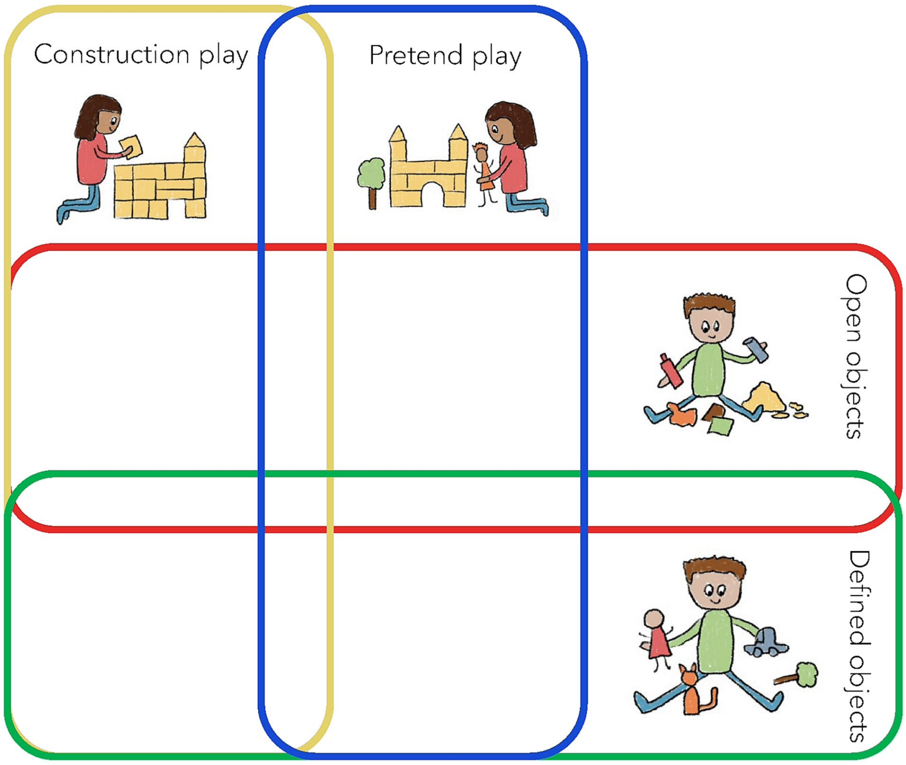


FIGURE 7
The designed framework in which each rectangle represents a play orientation.

Defined objects are materials that children play with that do represent a specific concept. Examples are household appliances, clothes, cars, dolls and LEGO figures.

Every play and object combination was observed in the two classrooms. The following anecdotes give two examples per combination:

1. *Open-ended object/construction play*: a few children were making a tower out of KAPLA, their goal was to make it a high as possible. Other children were using magnetic tiles to make a 'wall' between the legs of the table.
2. *Open-ended object/pretend play*: a child made a 'cookie-land' out of paper and empty toilet paper rolls and was playing with paper cookies in the land. Some other children were using empty toilet paper rolls as guns and shooting each other.
3. *Defined objects/construction play*: a child was playing with a balancing scale and trying out different combinations of objects to make it even. Other children were using wooden food objects to make a sandwich that was a high as possible.
4. *Defined objects/pretend play*: a pair of children was using a doll house and road rug and using it to bring their dolls to school. Other children made a zoo with stuffed animals and used hay to feed their animals.

Although most observed children had a preference for a certain quadrant, children play in various ways and we expect that they can be engaged in different types of play. The rectangles in the figure overlap meaning the use of different kinds of play and objects can happen at the same time.

3.2 Results study 2 diversity in design play

The framework of play orientations functioned as a starting point for the second study Diversity in Design Play. Figure 3 shows how the selected children are distributed over the framework, see 3.1.5 for an explanation of this framework. Children from school 1 are indicated with a uppercase letter (e.g., "A") and children from school 2 are indicated with a lowercase letter (e.g., d); gender with a symbol. The focus in our analysis is mainly on the children who did the Boris assignment, but episodes from the other assignments are used to show that play orientations also influenced the interactions with these assignments. The most notable differences were found between children with on the one side preference for construction play and open-ended objects and on the other side children with a preference for pretend play and defined objects, so the main focus will be on those. The children with these combinations of preferences all did the assignment with Boris the dog and are therefore also more easy to compare.

3.2.1 The outcomes and used materials

A difference in what the children built was observed between the children who like pretend play and the ones who enjoy construction play. Figure 8 shows the final building results of the children who did the dog

FIGURE 8
The diversity of what the children built. Some build geometrical structures, others organic. Some use mostly blocks, others use a mix of materials. **A–C** and **J–M** represent the children.

assignment. First of all, the children who enjoy construction play all used blocks for their main structure, while most children who enjoy pretend play (except K) used a combination of blocks, cardboard, empty toilet paper rolls, post-its and tape. Next to this, the built structures made by the children who enjoy construction play seemed structured and geometrical, while most of the structures made by the children who enjoy pretend play appeared to be more organic and unstructured.

The children of school 2 with a construction orientated also built geometric structures and mainly used KAPLA, while the children with a pretend play orientation built more organic structures. Child e (pretend play orientation) used all available materials while child f (pretend play orientation) only used KAPLA. This different outcome might be related to the teacher who emphasized the use of KAPLA.

3.2.2 Building process and time spent

Different approaches and attitudes towards the building process were observed. The children with a construction play/open-ended objects orientation stated at the start of the assignment that they did not know what to build. After a short thinking time and encouragement from the researcher they started building and making what they had in mind, as the following episode illustrates;

> *[Researcher finishes reading the story].*
> *Child C: Make a house.*
> *Researcher: Look here are all blocks and other stuff.*
> *Child C: I'm going to make house.*
> *Researcher: Yes, go make a house for Boris.*
> *Child C: Make big.*
> *Researcher: A big house?*
> *Child C: Yes, I cannot. A big house.*
> *Researcher: I think you can do that, though!*
> *Child C: Then he has to be a bit like that.*
> *[Child C builds in silence].*
> *Child C: He has to be a bit not pressed too much. No wrong, I do not know.*
> *Researcher: What's up? You can also use other blocks, maybe such a long one?*
> *[Child C picks up other blocks and builds in silence].*
> *Researcher: That's nice, a very tall house!*
> *Child C: [satisfied sigh] Done.*

Figure 9 shows the final design of child C.

All the children with a pretend play/defined objects orientation immediately knew what to build and during the process they were frequently brainstorming and diverging, as the following quotes show:

> *We also need a key and a doorknob for the key to go in. Otherwise the door cannot be opened. – Child J.*
> *We also need a playground!*
> *[A bit later] Boris also needs food.*
> *[A bit later] We also need a shower.*
> *[A bit later] We also need a door.*
> *[A bit later] We also need a small kennel, where he can sleep! – Child M*

Figure 10 shows the final design of child M.

As pretend play children were thinking of additional needs and things to build, they worked longer on the design assignment. Children with a pretend play/defined objects orientation spent about 26 min on average, while the children with a construction play/open objects orientation were finished after about 13 min on average. If the children with a pretend play orientation had not be stopped, many of them would have spent more than 30 min on the assignment.

Spending more or less time on the activity is not necessarily better or worse for the development of spatial thinking. This depends on how spatially challenging the play was. For example, child C (construction oriented) spent about 8 min on the activity and his spatial skills were challenged when he was trying to make a horizontal beam above the dog so the dog would not get wet if it was raining. He did not know how to do this, so he was trying and looking for solutions. Insight in how the blocks were moving while he wanted a stable structure was needed. While child L (pretend play oriented) who spend much more time - 25 min in total - on the activity was at least half of the time not spatially challenged because she was walking over a pavement of blocks that she had made and repeating the same movement.

Another striking difference between construction play/open-ended objects and pretend play/defined objects was how they took into account how the dog should get in and out of his house. The children with a construction play/open-ended objects orientation used the dog as a starting point and built the structure around it. They were focused on the dimensions of the dog and paid close attention to if Boris would fit in his house and if it would cover all of him. The children with a pretend play/defined objects orientation (except for K) started building the house and made an entrance later on in the process. They were more focused on all the needs of the dogs (like a place to sleep) and artifacts needed to achieve those needs and paid less attention to the dimensions of the dog.

FIGURE 9
The structure child C built.

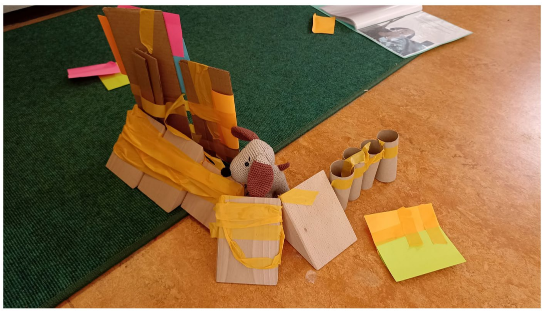


FIGURE 10
The structure built by child M.

This difference between the two groups was also observed by the children of school 2. The preschoolers with a construction orientation built a garage around their cars or airplane, while the children with a pretend play orientation built a castle first and added the princess when they were done building the castle.

Something almost all of the children who worked on the dog assignment (except A) had in common was that they faced an entrance problem: they had either enclosed the dog and did not know how to get it out, or they made a structure where the dog did not fit in. They asked the researcher for help and started looking for solutions as the following anecdotes illustrate:

> *Child K: Oh, how are we going to get Boris out now?*
> *Researcher: I do not know, how to do that?*
> *Child K: I think through the door here.*
> *Researcher: Okay you open the door there.*
> *Child K: I do not, I cannot [she notices the structure would collapse if she would take away the blocks].*
> *Researcher: Oh, then Boris should stay inside.*
> *Child K: Neh! Oh no, oh no!*
> *[the blocks fall].*
> *Researcher: Look it opens, that's handy!*
> *Child K: He just cannot get out.*
> *Researcher: Put your arm in it, can you feel Boris?*
> *Child G: Yes I have Boris!*
> *Child J: But how does Boris get inside?*
> *Researcher: You should tell Boris that.*
> *Child J: I paste it and I paste it [makes an entrance with paper and connects it to the structure].*
> *Researcher: All right, all together.*
> *Child J: No no, Boris goes in here and Boris goes out here [shows how to get in and out].*

3.2.3 Type of spatial play

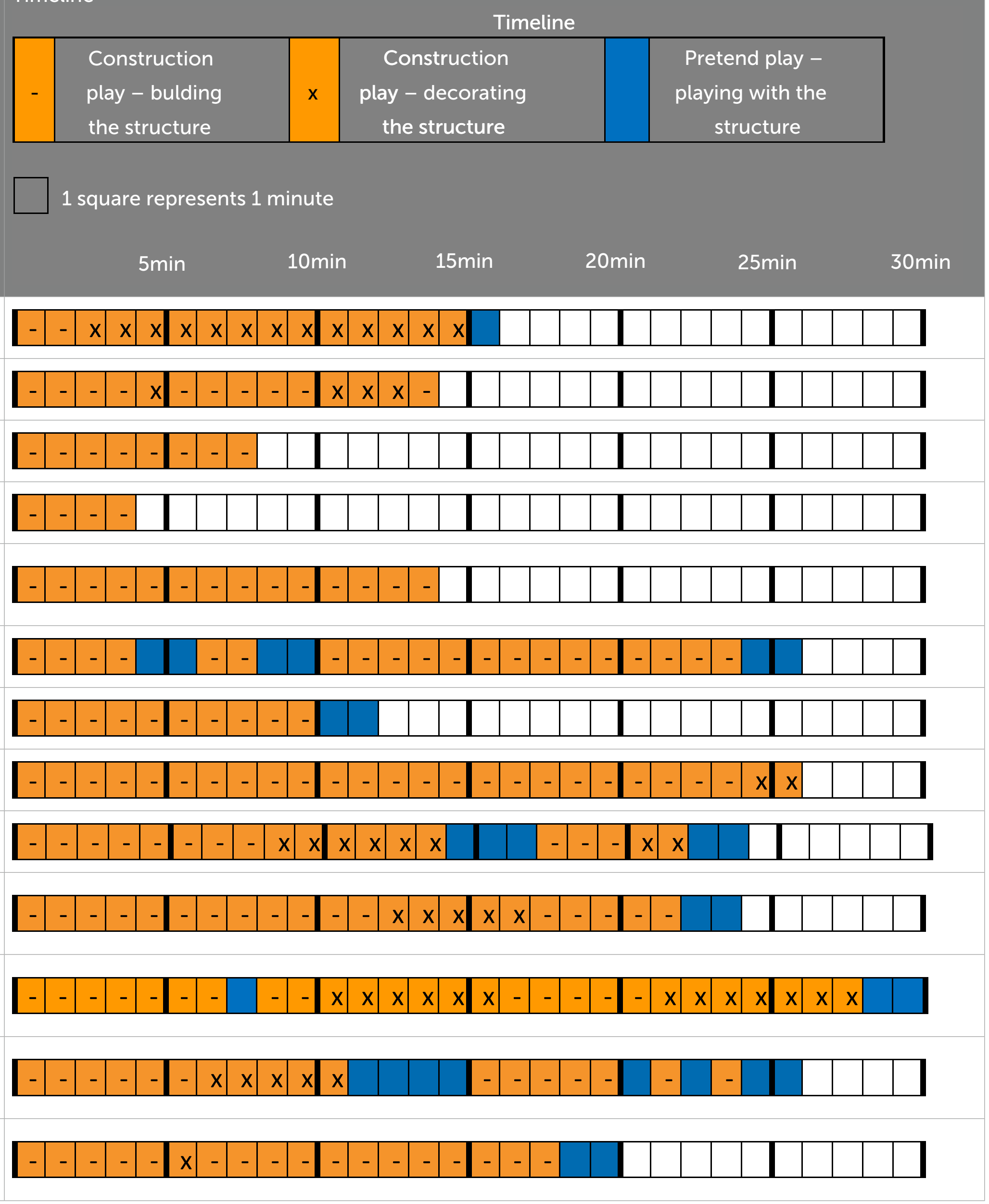
Two types of play were observed: construction play and pretend play. The construction play was divided into (1) building the structure, and (2) decorating the structure, as they raised different spatial questions for the children. In pretend play, the children where using the structure to play with.

These three types of play were mapped on timelines and can be seen in Table 1. The color of the line indicates in which type of play the child was engaged. As can be seen, all children engaged in construction play, they al build the structure, while almost half of them took time to decorate the structure. Many of the pretend oriented children played with the structure (all but e), and a few construction oriented children played a little bit with the structure once finished building (A,g).

TABLE 1 Overview of outcomes study 2: diversity in design play.

Preference of child for kind of play[a]	Preference of child for open objects or defined objects[a]	Child	Girl / Boy	Words used by the child to describe what he or she had made
Construction	Open	A	B	House, door, roof
Construction	Open	B	B	Roof, big house, decoration, binoculars, light
Construction	Open	C	B	Big house, roof
Both	Open	d	B	Dinosaur house, rock
Pretend	Open	e	B	Sturdy and beautiful castle, pistols, cannons that shoot colors, room for princess and king
Pretend	Open	f	G	Moat, bridge, path, crook scanner, castle, two towers, house
Construction	Defined	g	B	Garage, racing track
Construction	Defined	h	B	Garage, runway with bridge
Both	Defined	I	G	Valve to regulate temperature, feeding place, roof
Pretend	Defined	J	G	Door, two windows, roof, big door, key, doorknob, rainbowhouse, pencil, television, kitchen, place to sleep.
Pretend	Defined	K	G	Very high house with many places, house for herself, roof, ears, eyes, car booth, stepstones, door, 'things' that make dog drive fast
Pretend	Defined	L	G	Dark and yellow doghouse, slidestairs, wings, small toys, dogbed, long things to walk on top of
Pretend	Defined	M	G	Roof, big and colorful house, playground, food, shower, door, dog bedroom, flag, picture of parents of dog, decoration

Timeline



[a]The preference for the kind of play and objects was determined by the teacher of the child before it took part in the research, so it is not based on the outcomes of the exercise.

The following paragraph gives per type of play an example of the type of play and explains how the same type of play was both spatially challenging and unchallenging for the same child.

Construction play – building the structure: a child started with measuring how the dog would fit in his house, he was actively using his spatial skills in order to do this. Once he knew the dimensions he finished the structure by repetitively placing blocks on top of each other in the same way, as can be seen in Figure 11 on the left, this did not really challenge his spatial skills.

Construction play – decorating the structure: a child was covering the structure with post-it's, it was not spatially challenging because the same process was repeated over and over. Then, there were only a few post-it's left and the child was calculating and trying to imagine if there were enough post-it's to cover the side of the structure, as can be seen in Figure 11 in the middle, this challenged the spatial skills of the child.

Pretend play – using the structure to play: a child was talking about the house she had built for the dog and what kind of things she had made, she was not using spatial concepts. Then she grabbed the dog and realized that there was no way for the dog to enter the house and that she needed to make a door and explain to the dog how to get in, as can be seen in Figure 11 on the right, at this point she was using her spatial skills.

It was observed that one type of play is not necessarily 'more' spatial than another. Construction play as well as pretend play may appeal to spatial thinking. It depends on the kind of activity the child undertakes during the play. So the different types of play can all be used to train the spatial skills of students. This entails that independent of the play preference, a design assignment can be used to practice spatial reasoning. Allowing children to play with their construction seems to be an additional route to construction to foster spatial reasoning in early childhood.

3.2.4 Talk about and focus on the dog

It was observed that children with a pretend play orientation talk way more about and to the dog than the children with a construction play orientation. This is a signal of these children thinking from the perspective of the dog and therefore building things he might need, as the following quotes illustrate:

> *We also need a playground outside, because then he can play outside! – Child M.*
>
> *Oh it's so dark here, then the rain does not come inside and if it is dark then he can also sleep there – Child K.*
>
> *I need a door and two small windows, because then Boris [the dog] can see to one side and the other side- Child J.*

Because of this, the children with a pretend play orientation were more concerned if what they had built was good enough and if Boris the dog would like it, e.g.:

> *Are we going to show Boris what I made for Boris? No, no, no, this has to go [mumbles]. And to Boris, I just hope Boris likes it – Child J.*
>
> *Child: Of course we also need beautiful things.*
>
> *Researcher: Should his house be nicely decorated?*
>
> *Child: Yes.*
>
> *Researcher: Why is that important?*
>
> *Child: Because otherwise he does not like it, then we have to build again- Child M.*

Next, to this, they will often start to think spatially and practice perspective taking skills, because they have to think about the structure from inside and from the perspective of a small dog while they themselves are outside. For example, a child noticed that it was dark inside the house she built and mentioned that it would be good

FIGURE 11
Left: the child repetitively placed blocks on top of each other, which was not spatially challenging. Middle: the child was trying to imagine if she had enough post-it's to cover the side of her structure, which challenged her spatial skills. Right: the child was using her spatial skills while trying to figure out how to get the dog inside the house she had built.

for the dog, because then he could sleep well. This showed that the girl was able to stand in the shoes of the dog, realize that if she would be in the house she would be in a dark place, which helps to sleep better. Children with a construction play orientation talked less about the dog and also interacted less with him. The dog was often not in the center of their play and building area and often not lying in their field of view.

On the other hand, the children who enjoy construction play more were all pleased with what they had made. These children mostly build a house, a roof, and a door. The children who were engaged in pretend play built these things as well, but added a lot more specific and defined objects, for example: toys, a television, a bedroom, and a picture of the parents of the dog. This difference was also observed at school 2. Children with a construction play orientation built a garage and racing track or runway. Preschoolers with a pretend play orientation built more specific things like cannons that shoot colors, a crook scanner and a moat. This may have been influenced by the nature of the assignment as designing a racetrack for cars may evoke less empathy than designing a castle for a princes.

Table 1 shows the complete overview of the things the children mentioned. This clearly shows that the children with a pretend play orientation made more and more specific things than the children with a construction play orientation.

4 Discussion

This research aimed to get a richer understanding of the variety of play orientations among young children and if and how these influence the children's interaction with a design assignment, in order to support the development of educational innovations that stimulate spatial learning. Another important aim was to conduct the research in the actual educational context in which the children and teachers apply the to be designed spatialized activities. Although the study had a small group of participants of just two schools in a specific country, it provides qualitative insights which will be discussed in the following sections.

4.1 Differences in play- and object-orientations

The play orientations found in the two involved classrooms were either construction or pretend play, and the available materials that they could use, either open-ended or defined objects.

Preschoolers who liked construction play enjoyed the freedom to build whatever they want. They liked the construction process for itself. Three different types of construction play were observed: (1) rebuilding an example, (2) rebuilding an example and then expanding it yourself, and (3) figuring out yourself what you are going to build.

When children disliked construction play, this was usually related to the lack of possibilities for pretend play, e.g., the lack of characters to play with as the blocks are too abstract. These children experienced construction activities as a burden as they had to build something before they could start with pretend play. An interesting occurrence was noticed when a child with a pretend play orientation who did not like to play in the construction corner discovered a block with the image of a character drawn on it. This provoked her to build attributes like a table and chair using the block as a character.

Children with a pretend play orientation mentioned that in pretend play they had the freedom to be and do what they wanted to be and do during this type of play. For example, they played mummy and daddy or pretended to be a zookeeper and fed their stuffed animals. Children who do not like pretend play experienced this different, e.g., they felt stuck in a given role.

Another key-difference between preschoolers is a focus on either open-ended or defined materials.

Children who liked to play with open-ended materials enjoyed the freedom to build whatever they wanted with them. Children who enjoyed to play with defined objects valued that these toys provided immediate starting points for stories and pretend play.

These orientations were found in both the high and in the low SES setting. The conclusions on differences in play are visually represented in Figure 7.

Up till now, activities to spatialize the curriculum are mainly construction oriented and are less appealing to children with a pretend play orientation. Our next study was therefore a story based design activity as these might match the pretend play orientations better.

4.2 Play-orientations impact preschooler's design activities

The second study looked if these different play and object orientations had an influence on the way the preschoolers engaged with a story-based design activity that was meant to challenge their spatial skills. The provided design activity allowed for construction as well as pretend play, and both defined objects and open-ended objects could be used, although the toy-dog was the only provided defined object.

The results show that play orientations of the children in these two classrooms impact the length and nature of the design activities as well as the nature of the design outcomes.

Children with a construction play orientation usually needed some time to think about what to build. Once they had decided this they built geometrical structures and mainly used blocks. They built general components like an enclosure with a roof. Usually, they hardly talked about the dog and they were hardly focusing or thinking about his needs. Our observations during the design processes indicate that children with a construction play orientation seem to reflect mainly on the sturdiness of the building. They adjusted their designs accordingly and build relatively stable geometric structures.

On the other hand, children with a pretend play orientation immediately knew what they were going to build. They were more focused on the meaning of the artifact for the actors involved in the story, and – compared to the construction play oriented pupils - reflected more on the needs and wishes of Boris the dog. They showed more empathy and were taking the perspective of the dog during the design and make process. Their structures were less stable, they seem to focus less on sturdiness. Our qualitative results thus indicate that there are notable differences in the way construction oriented and pretend play oriented preschoolers approach and execute design processes.

The time spent on the assignment was also very different in the two groups (construction/open versus pretend/defined). Children with a construction orientation were finished after 13 min on average, while many of the children with a pretend play orientation were often not finished after 30 min. This was because children with a pretend play orientation played more with the dog and the structure and because they developed new wishes and ideas that they also built. In other words, they iterated more during the design process on the functions of the structure.

Our research findings thus shows that children react differently to stories and engage differently in story-based design activities. Our research results also indicate that story-based design activities will engage children with a pretend-play orientation more in construction play than the construction-tasks-for-the-sake-of-the-construction only that were on offer in their normal school environment.

Although there are differences, both play orientations were motivated to work on the assignment. This motivation is probably related to the fact that story-based design tasks combine the merits of pretend and construction play. This is in line with the findings of Schmitt et al. (2018) who provided preschool children with semi-structured block play assignments. When researchers used prompts containing a problem and target group such as "A mama duck and her ducklings are trying to cross the river and they need your help," they noticed that these design prompts may have facilitated more engagement than the non-design prompts. This might be because many children and adults like stories (Haven, 2007). Another reason could be that many children might be attracted to the open nature of the assignment as the prompt allows for various creations.

Our research also showed that pretend play and construction play go hand in hand during a design activity. Children use and manipulate objects in order to design, and objects give starting points for new ideas and stories. This is similar to Whitebread et al. (2012) statement that object play (rather similar to our construction play) and pretend play are often not separate categories since objects become part of pretend play.

4.3 Spatial challenges present for all play orientations

Spatial thinking was present during construction play (both during building and decorating) and pretend play, however, it was also often not present as well. It depends very much on the kind of specific activity children are involved in. Building, decorating and playing with the structure occasionally led to spatial reasoning.

Our research also suggests that play orientations may have influenced the way the preschoolers practiced spatial thinking. Children with a pretend play orientation talked more about Boris the dog than the other children. They continuously evaluated if the building met the needs of the dog. This kind of perspective taking and putting themselves in the shoes of the dog, led to different structures with more functions. As children with a construction play orientation talked less about Boris the dog, this might indicate that they are less prone to this type of perspective taking. These children were instead focused on creating and evaluating stable buildings which also requires spatial thinking from time to time.

To further answer the question is how story-based design activities and spatial thinking are related in the early classroom, we will discuss three types of activities that were present in the design activities by the preschoolers: 1) understanding the design problem and setting design goals, 2) imagining and modeling a solution and 3) testing and improving the solution. These activities resemble the general design model presented in Figure 2A.

4.3.1 Understanding the design problem and setting design goals

In the storybook, the drawings showed various needs, e.g., the dog becomes wet from the rain and very hot in the sun. Like professional designers, children engaged in determining the goals and functions the structure has to serve, this goal-setting activity had a spatial nature. All children were able to think about the need for a sort of roof and for an enclosure. However, they did not think of the need of an entrance. In the first design iteration, none of the buildings enabled the dog to go in or out of the structure. This shows that for young children it is challenging to think about this goal before the enclosure has been build. Some children were focusing on the fact that the dog should fit in his house and therefore paying close attention to its dimensions and the need for a structure covering the complete dog.

4.3.2 Imagining and modeling a solution

Once the preschoolers have defined the needs, they have to fulfill the needs of the target group with the available materials. Preschoolers usually do this through trial and error hence spatial thinking and doing are closely related. In the case of the 'Building a place to live for Boris'-assignment they for example had to think about: How big should the house be? How do I build an entrance? How do I keep the structure stable?

As described above the research results indicate that children with different play orientations select different design goals. This in turn leads to different kind of spatial challenges when imagining and modeling a solution. For example, children who enjoyed construction play were building sturdy structures and taking more often the dimensions of the dog into account while the children with a pretend play orientation did not always do this. So children with a construction play orientation are more prone to think about relations between objects (dog and structure). Most construction oriented children also strived for stable structures which requires spatial reasoning.

Children who enjoyed pretend play were thinking more from the perspective of the dog and trying to imagine what he might wanted and needed. They also had to imagine what he was seeing from the inside of the structure they built for him, while the children themselves were outside of the structure.

We conjecture that constructing from empathy might be a good way to practice spatial perspective taking. For example, a child said:

> *I need a door and two small windows, because then Boris [the dog] can see to one side and the other side- Child J.*

This child might imagine how it is for Boris to be inside the house and which changes can be made to the structure accordingly. She is testing the spatial structure in relation to the emphatically felt needs of the dog.

However, certain spatial challenges were present in all types of play, like the challenge to build a structure with an opening for the dog. Relating the size of the dog to the size of the structure or reasoning about how to use scarce materials is about using spatial skills to achieve a product or design with certain characteristics was also a challenge. For example, the shortage of available materials led to spatial reasoning by one of the children in order to use the available materials in the most optimal ways to achieve a beautiful house. This kind of reasoning is probably not related to a specific play orientation.

4.3.3 Testing and improving the solution

Finally, children evaluated their structures. They often come across things that do not work and finding solutions to these problems is often a spatial challenging process. Sometimes, the children would then look at the structure and the dog and would discover that the toy-dog was not able to go into the structure. Or they would suddenly realize that the dog could not go outside once they finished building. Other children did not observe this problem and were satisfied with the structure.

The kind of spatial thinking during these three design activities (1) understanding the design problem and setting design goals, 2) imagining and modeling a solution and 3) testing and improving the solution) is rather different analytical tasks like tangram, shape parades, looking for the odd shape etc. that have one correct answer. First, these analytical tasks with one correct answer require usually only decoding skills. Visual information is given and decoding skills are used to make sense of the given task. In contrast, designing needs encoding skills. Encoding generally occurs when pupils construct their own representations in order to solve a task (Lowrie, 2010). This requires a different skill set. Design often starts with encoding (setting goals and imaging a solution), but once a solution is build, children will need to evaluate it and this process resembles the decoding processes. Encoding requires a different skill set, according to Lowrie (2010) who studied this in the context of math education, and therefore students need to acquire spatial skill sets for both decoding and encoding. Second, the analytical exercises like tangram and shape parades (Yang et al., 2020) are usually done with rather flat shapes while the Boris design assignment was conducted with 3D materials. In addition, spatial thinking was often intertwined with the appliance of engineering thinking, e.g., system thinking about how blocks will work together or how the blocks will be stable given the forces that work on them (e.g., gravity and resistance).

4.4 Open-ended and defined objects

Unlike we tend to think, defined objects are a pathway to spatial thinking. In our study, children interacting with defined objects were frequently practicing to take object properties into account. They had to deal with the dimensions and weight of the defined object – the dog - and adjust their designs accordingly. However, if we had asked these children to build something for an imaginal or adjustable object they could change the object in order to make their design work instead of the other way around, e.g., if their design turns out to be smaller than expected, they may say something like: 'oh but then this design will be for a dog without legs'. So introducing tangible defined objects in a spatial design assignment will train children to take dimensions and other object properties into account.

The open-ended objects on the other hand stimulated the children to turn their ideas into 3D prototypes. In order to do this they had to give meaning to the open objects themselves. The open objects seemed inviting to use and to prototype with. We used the available materials in both of the classrooms, the materials gave the children a lot of design options, however, for learning to design or to think spatially, more research on optimal sets of materials is advised.

We expect that combinations of open-ended and defined objects are supportive in engaging all children in constructing, evaluating and re-constructing. Without defined objects, pretend play oriented children will not engage as much with construction. The defined object also gave children a much more tangible goal for their constructions. Open-ended objects are also supportive. Although building is possible with defined objects, the open-ended objects provide much more possibilities to design novel structures.

5 Final conclusions

Story-based design tasks combine the merits of pretend and construction play. There are also many indications that spatial skills are involved in design activities such as problem exploration, goal setting, imaging and modeling solutions as well as testing. Design play evoked empathic thinking and challenged the children to step into the shoes of someone else and look from different perspectives, while other children focused on building stable structures. The spatial skills are strongly intertwined with design activities and spatial skills are conditional or necessary in many stages of the design cycle. This aligns with the results of Zhu et al. (2024) who showed that many different types of spatial thinking skills were applied during a biomimicry design project by eleven and twelve year olds. Our research results suggest that design activities may lead to the development of different spatial skills than more traditional analytical puzzles. More research is however needed in the nature of spatial thinking in creative design contexts and especially how these assignments lead to the development of spatial thinking skills such as mental rotation and perspective taking.

In this study we discovered that play orientations influence the way children approach story-based design assignments. Children with a construction play orientation set different goals and built constructions while focusing on stability while children with a pretend play orientation think of many needs of the toy dog and build structures with many functions. Both children with a construction and pretend play orientation enjoyed the design assignments.

Several conclusions for developing a spatialized curriculum can be drawn. Firstly, besides the well-developed and studied free play and guided play, design play can be added as an additional strategy to spatialize the curriculum. Secondly, including story-based design activities will better serve preschoolers with a pretend play orientation, but also engage construction oriented players. All play activities during a design assignment – building, decorating and pretend play with the structure – may have a spatial nature but not necessarily, it depends if the specific construction or pretend play activity requires spatial reasoning. Our results also suggest that a specific skill spatial skill set needed to design and especially to construct internal and external representations that solve the design problem is needed, more research is needed on this point. Thirdly, when developing design activities, it is important to take play orientations into consideration because they influence motivation and also the way children interact with the assignment and develop spatial skills.

6 Limitations

This study was explorative, a limitation of this qualitative design-based research is that the group of participants was small and the research is only conducted in two schools in the Netherlands. This approach was used to explore the value of using play orientations in understanding how children interact with a design assignment.

Next, to this, in hindsight, the availability of defined objects during the assignment with Boris the dog might have been too limited, as the only defined object was the stuffed puppet of the dog. On the contrary, there were many open-ended objects the preschoolers could use: wooden blocks or KAPLA, sticky notes, masking tape, cardboard and empty toilet paper roles. Children might have interacted differently if there were more defined objects present like (fake) dog food, dog toys and a leash. One child mentioned that she could go inside the classroom to grab some toys for the dog, but that was not possible to do during the research session. So there were some cues that the presence of more defined objects would lead to different interactions. In a subsequent study the first author developed a story-based assignment on Boris with more defined objects (Sonneveld, 2023).

Also, the specific design assignment has also influenced the interactions. It would thus be valuable to conduct additional studies using other design assignments as well.

In addition, quantitative studies in which the spatial thinking of children with a pretend play orientation are compared with children with a construction play orientation are needed. They may score different on exercises related to spatial perspective taking and on other tasks such as mental rotation.

Finally, the play orientations were determined by the teachers building on their personal knowledge of the children. Scientific instruments using observation and talk could be developed to improve the reliability of the play orientation measurements.

As no videorecording or note-taking was allowed during the design assignment in the second study, spatial reasoning was not completely covered. Also, internal reasoning processes were not covered as not thinking aloud was applied during data collection.

7 Implications and further research

It would be interesting to have pupils with a construction play orientation and pupils with a pretend play orientation collaborate on a story-based design assignment. This might lead to more feasible and desirable outcomes as one student might bring the sturdy-building perspective whereas the other student might bring the empathic perspective. By working together they can integrate both perspectives into their design. It could also be conjectured that the students learn from each other: one learns to take the needs and wishes of the target group into account, and the other learns to build structures that actually work for their target group. The same goes for students with a preference for open-ended objects and defined objects.

Next, to this, our specific design assignment with a small toy provoked spatial thinking. It would be interesting to study what will happen if children react differently and think more or less spatially if they design for an animal that is bigger than a child, like an elephant, or the opposite: a small insect.

Furthermore, the framework of play orientations can guide the development of future educational activities that involve or train spatial skills and appeal to a greater variety of children. We propose to let one spatial learning goal be served by variations of assignments, each turned to different play orientations. In this way, pupils can choose which assignment they want to interact with, making it more likely they will engage with spatial activities driven by intrinsic motivation.

An example of such an approach was pursued by Sonneveld (2023).

In addition, discovering why children decide to undertake certain actions during open-ended assignments is relevant. So during or after the activity it can be discussed with the child what she had in mind during the assignment, why she choose to do it in this way and why she thinks that is the best way. This can then be a bridge to understand the cognitive processes she was going through and to make sense of her actions. Just evaluating the designed structures is not sufficient to understand the quality of the learning processes. Also, this information can be used to improve the scaffolding of both the creative design processes as well as the embedded spatial thinking processes. Finally, using spatial language, gestures and feedback are also strategies that are known to enhance spatial development (Yang et al., 2020) and are applicable to design. Gesturing is also one of the modes designers use to imagine as well as to communicate design ideas (Allan, 2013).

As spatial reasoning is an important skill for a STEM future and for daily life, we need to develop a spatial curriculum that that trains a wider variety of spatial skills and appeals to a greater group of students. Including design activities which are adapted to the different play orientations is a promising route to achieve this. When policymakers and educators are developing a spatialized curriculum, it seems promising to include design activities (1) to better serve preschoolers with a pretend play orientation and (2) because design activities are likely to train students in developing a creative-oriented spatial skill set.

Data availability statement

The datasets presented in this article are not readily available because the participants are identifiable. Requests to access the datasets should be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by the Human Research Ethics Committee of Delft University of Technology. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin.

Author contributions

LS: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Visualization, Writing – original draft, Writing – review & editing. RK: Conceptualization, Methodology, Resources, Writing – original draft, Writing – review & editing. PS: Conceptualization, Methodology, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

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References

Allan, E. G. (2013). Multimodal Rhetorics in the disciplines: available means of persuasion in an undergraduate architecture studio. *Across Discip.* 10, 1–20. doi: 10.37514/ATD-J.2013.10.2.04

Anning, A. (1997). Drawing out ideas: Graphicacy and young children. *Int. J. Technol. Des. Educ.* 7, 219–239. doi: 10.1023/A:1008824921210

Berkowitz, M., Gerber, A., Thurn, C. M., Emo, B., Hoelscher, C., and Stern, E. (2021). Spatial abilities for architecture: Cross sectional and longitudinal assessment with novel and existing spatial ability tests. *Front. Psychol.* 11:609363. doi: 10.3389/fpsyg.2020.609363

Bower, C. A., Zimmermann, L., Verdine, B. N., Pritulsky, C., Golinkoff, R. M., and Hirsh-Pasek, K. (2021). *Enhancing spatial skills of preschoolers from under-resourced backgrounds*. Temple University. Philadelphia, PA

Bower, C., Zimmermann, L., Verdine, B., Toub, T. S., Islam, S., Foster, L., et al. (2020). Piecing together the role of a spatial assembly intervention in preschoolers' spatial and mathematics learning: influences of gesture, spatial language, and socioeconomic status. *Dev. Psychol.* 56, 686–698. doi: 10.1037/dev0000899

Buckley, J. (2023). Reflecting on maker education as potential context for the development of spatial ability. In R. Klapwijk, J. Gu, Q. Yang and VriesM. J. De (Ed.), *Maker education meets technology education; reflections on good practices*:Brill, Leiden.

Buckley, J., Seery, N., Canty, D., and Gumaelius, L. (2022). The importance of spatial ability within technology education. In P. J. Williams and MengersenB. von (Eds.), *Applications of research in technology education: Helping teachers develop research-informed practice* (pp. 165–182). Singapore: Springer Nature Singapore.

Carroll, J. B. (1993). *Human cognitive abilities: A survey of factor-analytic studies*: Cambridge University Press, Cambridge.

Claxton, G., Lucas, B., and Webster, R. (2010). *Bodies of knowledge: How the learning sciences could transform practical and vocational education*. E. Foundation. Paris.

Cornu, V., Schiltz, C., Pazouki, T., and Martin, R. (2019). Training early visuo-spatial abilities: a controlled classroom-based intervention study. *Appl. Dev. Sci.* 23, 1–21. doi: 10.1080/10888691.2016.1276835

Cropley, A. J., and Urban, K. K. (2000). "Programs and strategies for nurturing creativity" in *International handbook of giftedness and talent, 2nd Edication (revised reprint)*. eds. F. J. M. K. A. Heller, R. J. Sternberg and R. F. Subotnik (Amsterdam: Elsevier), 485–498.

Cross, N. (2006). *Designerly ways of knowing*: Springer. Berlin.

Dam, R. F., and Siang, T. Y. (2021). *What is design thinking and why is it so popular?* Interaction Design Foundation. Aarhus.

Darwish, M., Kamel, S., and Assem, A. (2023). Extended reality for enhancing spatial ability in architecture design education. *Ain Shams Eng. J.* 14:102104. doi: 10.1016/j.asej.2022.102104

Design Council (2007). Eleven lessons: managing design in eleven global brands. A study of the design process. Available at: https://www.designcouncil.org.uk/resources/report/11-lessons-managing-design-global-brand

Eisner, E., (2002). *The arts and the creation of mind*. New Haven/London: Yale University Press.

Fleer, M. (2022). The genesis of design: learning about design, learning through design to learning design in play. *Int. J. Technol. Des. Educ.* 32, 1441–1468. doi: 10.1007/s10798-021-09670-w

Gero, J. S., and Kannengiesser, U. (2004). The situated function–behaviour–structure framework. *Des. Stud.* 25, 373–391. doi: 10.1016/j.destud.2003.10.010

Gifford, S., Gripton, C., Williams, H., Lancaster, A., Bates, K. E., Williams, A. Y., et al. (2022). *Spatial Reasoning in early childhood*. OSF, Charlottesville, VA.

Ginsburg, H. P., Lin, C. L., Ness, D., and Seo, K. H. (2003). Young American and Chinese children's everyday mathematical activity. *Math. Think. Learn.* 5, 235–258. doi: 10.1207/S15327833MTL0504_01

Haven, K. (2007). *Story proof: The science behind the startling power of story*. Bloomsbury Publishing. New York.

Hawes, Z. C. K., Gilligan-Lee, K. A., and Mix, K. S. (2022). Effects of spatial training on mathematics performance: a meta-analysis. *Dev. Psychol.* 58, 112–137. doi: 10.1037/dev0001281

Hawes, Z., Moss, J., Caswell, B., Naqvi, S., and MacKinnon, S. (2017). Enhancing children's spatial and numerical skills through a dynamic spatial approach to early geometry instruction: effects of a 32-week intervention. *Cogn. Instr.* 35, 236–264. doi: 10.1080/07370008.2017.1323902

Howard-Jones, P. (2002). A dual-state model of creative cognition for supporting strategies that Foster creativity in the classroom. *Int. J. Technol. Des. Educ.* 12, 215–226. doi: 10.1023/A:1020243429353

Hughes, F. P. (1999). *Children, play, and development* (*3rd*). Needham Heights, MA: Allyn & Bacon.

IDEO. (2023). IDEO | Design Thinking. Available at: https://designthinking.ideo.com/

Kimbell, R., and Stables, K. (2007). *Researching design learning: Issues and findings from two decades of research and development*, Springer Dordrecht.

Klapwijk, R. (2017). "Creativity in Design" in *Teaching Design and technology creatively*. eds. C. Benson and S. Lawson (London: Routledge), 51–72.

Klapwijk, R. M., Holla, E. M., and Stables, K. (2019). *Make Design Learning Visible*. Delft: Delft University of Technology.

Klapwijk, R., and Stables, K. (2023). "Design learning: pedagogic strategies that enable learners to develop their design capability" in *Bloomsbury handbook of technology education*. eds. D. Gill, D. Irving-Bell, M. McLain and D. Wooff (London: Bloomsbury Publishing), 271–289.

Klapwijk, R., and Van Doorn, F. (2015). Contextmapping in primary design and technology education: a fruitful method to develop empathy for and insight in user needs. *Int. J. Technol. Des. Educ.* 25, 151–167. doi: 10.1007/s10798-014-9279-7

Kouprie, M., and Sleeswijk Visser, F. (2009). A framework for empathy in design: stepping into and out of the user's life. *J. Eng. Des.* 20, 437–448. doi: 10.1080/09544820902875033

Lawson, B. R. (1979). Cognitive strategies in architectural design. *Ergonomics* 22, 59–68. doi: 10.1080/00140137908924589

Lawson, B., and Dorst, K. (2009). *Design expertise*: Routledge. London.

Lowrie, T. (2010). Primary students decoding mathematics tasks: The role of spatial reasoning. Research conference Teaching Mathematics make it count: What research tells about effective teaching and learning of mathematics.

Miller, H. E., and Simmering, V. R. (2018). Children's attention to task-relevant information accounts for relations between language and spatial cognition. *J. Exp. Child Psychol.* 172, 107–129.

Newman, D. (n.d.). The Squiggle. Available at: https://thedesignsquiggle.com/ Retrieved September 5, 2023.

Pritulsky, C., Morano, C., Odean, R., Bower, C., Hirsh-Pasek, K., and Michnick Golinkoff, R. (2020). Spatial thinking: why it belongs in the preschool classroom. *Transl. Issues Psychol. Sci.* 6, 271–282. doi: 10.1037/tps0000254

Ramey, K. E., and Uttal, D. H. (2017). Making sense of space: distributed spatial sensemaking in a middle school summer engineering camp. *J. Learn. Sci.* 26, 277–319. doi: 10.1080/10508406.2016.1277226

Sanders, L., and Stappers, P. J. (2012) *Convivial toolbox*. BIS Publishers, Amsterdam.

Schmitt, S. A., Korucu, I., Napoli, A. R., Bryant, L. M., and Purpura, D. J. (2018). Using block play to enhance preschool children's mathematics and executive functioning: a randomized controlled trial. *Early Child. Res. Q.* 44, 181–191. doi: 10.1016/j.ecresq.2018.04.006

Schön, D. A. (1983). *The reflective practitioner: How professionals think in action*. Basic Books. New York City.

SLO (Stichting Leerplan Ontwikkeling, Netherlands Institute for Curriculum Development), (2020). *Kerndoelen primair onderwijs 2006, Overdruk uit het kerndoelenboekje dat verscheen bij de introductie, inclusief latere wettelijke aanvullingen op deze kerndoelen*, Amersfoort. (Core-goals Primary Education).

Solomon, J., and Hall, S. (1996). An inquiry into progression in primary technology: a role for teaching. *Int. J. Technol. Des. Educ.* 6, 263–282. doi: 10.1007/BF00419883

Sonneveld, L. (2023). Accomodating individual play preferences of preschoolers in design education focused on spatial ability. Master thesis Industrial Design, TU Delft. Available at: https://repository.tudelft.nl/islandora/object/uuid%3A660c50e8-7202-4b1f-8d81-1fa8506f13f2?collection=education

Sorby, S., Veurink, N., and Streiner, S. (2018). Does spatial skills instruction improve STEM outcomes? The answer is 'yes.'. *Learn. Individ. Differ.* 67, 209–222. doi: 10.1016/j.lindif.2018.09.001

Strand, I., and Lutnæs, E. (2022). Developing spatial literacy through design of built environments: art and crafts teachers' strategies. *Design Technol. Edu.* 27, 36–57.

Uttal, D. H., and Cohen, C. A. (2012). "Spatial thinking and STEM education: when, why, and how?" in *Psychology of learning and motivation*. ed. B. H. Ross, vol. *57* (Cambridge, MA: Academic Press), 147–181.

Van Mechelen, M. (2016). Designing technologies for and with children: Theoretical reflections and a practical inquiry towards a co-design toolkit. *PhD thesis*. KU Leuven.

Varela, F. J., Thompson, E., and Rosch, E. (2017). *The embodied mind: Cognitive science and human experience*. MIT press, Cambridge, MA.

Voogt, J., and Roblin, N. P. (2012). A comparative analysis of international frameworks for 21st century competences: implications for national curriculum policies. *J. Curric. Stud.* 44, 299–321. doi: 10.1080/00220272.2012.668938

Wai, J., Lubinski, D., and Benbow, C. P. (2009). Spatial ability for STEM domains: aligning over 50 years of cumulative psychological knowledge solidifies its importance. *J. Educ. Psychol.* 101, 817–835. doi: 10.1037/a0016127

Whitebread, D., Basilio, M., Kuvalja, M., and Verma, M. (2012). *The importance of play: A report on the value of children's play with a series of policy recommendations*. Brussels: Toys Industries for Europe.

Yang, W., Liu, H., Chen, N., Xu, P., and Lin, X. (2020). Is early spatial skills training effective? A meta-analysis. *Front. Psychol.* 11:564679. doi: 10.3389/fpsyg.2020.01938

Zhu, C., Klapwijk, R. M., Silva-Ordaz, M., Spandaw, J., and De Vries, M. (2023). Cognitive and embodied mapping of data: an examination of Children's spatial thinking in data physicalization. *Front. Educ.* 8:1308117. doi: 10.3389/feduc.2023.1308117

Zhu, C., Klapwijk, R., Silva-Ordaz, M., Spandaw, J., and de Vries, M. J. (2024). Investigating the role of spatial thinking in children's design ideation through an open-ended design-by-analogy challenge. *Int. J. Technol. Des. Educ.* 8, 1–30. doi: 10.1007/s10798-024-09877-7