Research on the interplay between preschool teachers' dispositions, practice and children's learning in block play

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Abstract

Previous research has shown the importance of early science, technology, engineering, and math education for children’s knowledge, as it establishes a groundwork for their later learning and academic achievement. However, the engagement of preschool teachers especially in science learning activities is infrequent, and some teachers still pronounce the belief that science education is inappropriate for the early childhood years. Furthermore, there is a lack of clarity regarding the connections between teachers' attitudes (including their knowledge, beliefs, and willingness) towards teaching early science and their actual teaching practice, as well as the subsequent effects of teacher practice on children's learning outcomes. This dissertation primarily aims to clarify these associations. Block play offers the possibility to link scientific concepts (e.g., stability) to children’s everyday activities and thus represents an age-appropriate way to examine young children’s STEM-learning. The present dissertation encompasses three research articles, focusing specifically on the interplay between preschool teachers’ dispositions and practice in block play and 4- to 6-year old children’s knowledge. The first article focused on the validation of a self-developed instrument to assess preschool teachers’ willingness to engage in science teaching and examined the predictive power of teachers’ willingness for teachers’ practice. Results suggested that the instrument measured teachers’ willingness reliably and validly, however, teachers’ willingness did not predict their practice in block play. The second article examined the relationship between the preschool teachers’ instructional quality during block play and various aspects of children's knowledge. Specifically, the study explored how instructional quality in block play influenced children's knowledge in stability, math, and spatial language. Additionally, children’s academic self-concept and cognitive aspects (i.e., intelligence, working memory) were considered. Results implied that preschool teachers’ scaffolding activities were related to children’s stability knowledge in block play. Moreover, teachers’ instructional quality was positively correlated with children’s academic self-concept in block play. The primary focus of the third article was on implementing a block play curriculum. Therefore, study 3 employed a longitudinal design to assess the effectiveness of a teacher training on teachers’ practice with the curriculum, which included both, guided and free play. Teachers were randomly assigned to either a control group or an experimental group. The experimental groups received training with the block play curriculum, while the control group did not receive any training. Results showed no change in teachers’ knowledge before and after training. Nonetheless, teachers in the experimental group applied more scaffolding after the training. Furthermore, preschool teachers applied more scaffolding during guided than during free play. Children’s math score in the experimental group, but not in the control group, significantly improved from pre- to post-test. In the general discussion, the findings of the three articles are reflected in the light of the interplay between teachers’ dispositions and their teaching practice as well as the impact of teacher practice on children’s knowledge. Besides, the discussion reflects on methodological difficulties of empirical studies in early childcare settings, providing a prospective view on multimethod approaches for future research. Taken together, the present dissertation contributes to a more profound understanding of how teacher practices and children's knowledge interact. Further, the research holds great relevance for practical application as it illustrates the differential effects of teacher training on preschool teachers’ knowledge and their teaching practice.

General Introduction

Promoting children's science skills has been identified as one core aspect of early childhood education (e.g., Anders & Rossbach, 2015; Piasta et al., 2014). Empirical findings suggest that young children, given the necessary opportunities, can perform a variety of cognitive tasks (i.e., hypothesizing, predicting) that constitute the basis of scientific thinking and learning (e.g., Trundle & Saçkes, 2015). Preschool teachers play a central role in providing, structuring and stimulating learning opportunities and in supporting children's learning processes. One important aspect of early childhood education is science (e.g., Piasta et al., 2014; Trundle & Saçkes, 2015). Providing high quality science education is an important, yet complex task, that requires teachers to reflect on their own knowledge, beliefs and teaching practice. Besides, they need to consider children's prior knowledge and developmental constraints to foster children's learning by age-adequate means (Trundle & Saçkes, 2015). Thus, fostering children's science education in a developmentally appropriate manner places high demands on preschool teachers' competences. Consequently, preschool teachers encounter difficulties in supporting young children's learning, particularly in the STEM fields, as they feel inadequately prepared for this task (Spektor-Levy et al., 2013) and complain about a lack of time to engage in early science teaching (e.g., Sandstrom, 2012).

Research has shown that preschool teachers' content knowledge in the early science domains is limited (e.g., Barenthien et al., 2018; Garbett, 2003; Kallery and Psillos, 2001; Yildirim, 2021). Additionally, the time spent with preacademic learning seems to be relatively small (Chien et al., 2010). Some preschool teachers still believe that science learning is inappropriate for the early childhood years (Park et al., 2017). Furthermore, research on preschool teachers' instructional quality in early science has revealed significant variation in teachers' science teaching practice and knowledge (e.g., Barenthien et al., 2018; Pianta et al., 2008). However, many factors influence teachers' practice and the variation in teaching approaches among preschool teachers might thus not be solely attributed to differences in their beliefs or in their science knowledge. The degree to which teachers' dispositions (i.e., knowledge in early science, beliefs about early science) manifest in their teaching practices or their willingness to engage in science teaching, is not yet fully understood.

One approach to improving the quality of early science teaching and learning in preschool education has been the introduction of validated and play-based science and math curricula. A prominent early childhood curriculum is *Building Blocks* (Clements & Sarama, 2007), which has proven to be effective in fostering children's mathematical learning (Clements & Sarama, 2008). Block play is an everyday kindergarten activity that can be supported by preschool teachers and has been widely investigated in early childhood research (e.g., Cohen & Uhry, 2011; Simoncini et al., 2020; Trawick-Smith et al., 2017; Weber et al., 2020; Weber & Leuchter, 2020; Wolfgang et al., 2001; Zhu et al., 2021). Block Play offers the opportunity to foster children's spatial language (e.g., talking about shapes and distances; Ferrara et al., 2011), mathematical skills (e.g., Klibanoff et al., 2006) and physical concepts (e.g., stability; Bonawitz et al., 2012). To further enhance children's early science learning, preschool teachers might provide material support (e.g., blocks), verbal support (scaffolding; e.g., van de Pol et al., 2010; Weisberg et al., 2016) or combine both. Nevertheless, evidence suggests that preschool teachers rarely scaffold children's learning in everyday situations or in science teaching (Cabell et al., 2013; von Suchodoletz et al., 2014).

Drawing from the abovementioned findings, the following research questions arise: (1) What are the professional skills and competences that preschool teachers possess in the context of block play? (2) How is preschool teachers' instructional quality in block play associated with children's knowledge? (3) Can an easily accessible curriculum material promote the professional competence of preschool teachers in supporting learning through play, especially in block play? If so, does implementing the curriculum material affect children's knowledge?

On the backdrop of the abovementioned research questions, in study I, an instrument to assess preschool teachers’ willingness to engage in scaffolding and diagnostic activities in the context of early science was validated. Further, the interplay between willingness, learning beliefs, knowledge and teacher practice in the context of block play was studied. Study II was concerned with the examination of preschool teachers’ instructional quality in a free block play episode and its’ associations with children’s knowledge and academic self-concept. Study III focused on the implementation of a parsimonious block play curriculum and investigated its association with children's learning in stability, spatial language, and math.

1. Preschool teachers' dispositions and practice in early childhood

1.1 STEM education in early childhood

In the recent decade, there has been a significant increase in both national and international research on the importance of STEM (Science, Technology, Engineering and Math) in early childhood and enhancing the quality of STEM education (Zendler et al., 2018). The term STEM refers to a pedagogical approach, which combines and integrates different aspects of teaching and learning (e.g., Wan et al., 2021; Zendler et al., 2018). Zendler and colleagues (2018) have differentiated between a learner's perspective on STEM education (i.e., learners' understanding of concepts) and a teacher's perspective on STEM education (i.e., the provision of learning support). For teachers, the careful selection of instructional methods that effectively enhance learners' understanding is a crucial aspect when teaching STEM subjects (e.g., Zendler et al., 2018). Preschool teachers have to keep in mind children's individual differences and developmental limitations to align their teaching practices to children's current level of performance (e.g., van de Pol et al., 2010). This places significant demands on teachers' competences (i.e., content knowledge (CK) and pedagogical content knowledge (PCK)).

Studies have shown that children are able to engage in complex and abstract thinking during play (e.g., block play; see Otsuka & Jay, 2017) and advocate for the importance of early experiences with STEM (e.g., Campbell & Speldewinde, 2022; Chesloff, 2013). Therefore, the inclusion of high-quality STEM-learning experiences in preschool settings is considered a fundamental element of early education (e.g., Anders et al., 2013).

The long-term impact of early education on children's cognitive abilities and later academic achievement has been shown consistently in the field of language and literacy (e.g., Betts et al., 2009; Duncan et al., 2007), math (e.g., Betts et al., 2009; Duncan et al., 2007; Romano et al., 2010), and spatial skills (e.g., Bower et al., 2020; Uttal & Cohen, 2012). Moreover, longitudinal studies confirm the predictive power of children's early science learning for later achievement (e.g., Kaderavek et al., 2020), albeit with rather small effect sizes. Morgan and colleagues (2016) have shown that children's knowledge disparities in STEM at the start of kindergarten strongly contribute to knowledge gaps in STEM fields during the first grade, which subsequently has a strong impact on science achievement gaps by third grade. Furthermore, from third to eighth grades, lower levels of reading and math achievement significantly predicted the continued persistence of these science achievement gaps. In contrast, Saçkes and colleagues (2011) found children's exposure to early science to be a weak predictor of immediate or later science achievement. However, the time spent with science was also found to be generally low, which mirrors previous research on the limited amount of time spent with early science in kindergartens (e.g., Early et al., 2010). Taken together, the results of empirical studies generally underpin the importance of early STEM education for children's skill development, especially for at-risk-learners (e.g., Morgan et al., 2016). Given research indicating that preschool teachers complain about a lack of time to implement early science, engaging in a common activity like block play to teach early science holds significant merit.

1.1.1 Block play in early science

To examine children's science knowledge as a part of their STEM knowledge in an age-appropriate manner, their developmental limitations and motivation to learn about science should be considered (e.g., Copple & Bredenkamp, 2009). An effective approach to introduce early science learning involves linking scientific concepts to children's everyday activities, which aligns with developmentally appropriate practice (Copple & Bredenkamp, 2009). Block play is commonly viewed as an everyday activity in kindergarten settings and offers a valuable access for teachers to introduce early science learning, supporting the knowledge achievement of children in stability, spatial skills, and mathematical concepts (e.g., Bonawitz et al., 2012; Borriello & Liben, 2018, Casey et al., 2008; Lee & Kim, 2018; Levine et al., 2012; Park et al., 2008). Besides, it offers the opportunity to foster children's process-related skills (e.g., hypothesizing, predicting; e.g., Weber et al., 2020). Five key developmental skills, which can be fostered through block play, can be derived from the literature:

1. Cognitive development: Block play fosters the development of problem-solving skills and abstract thinking (e.g., Otsuka & Jay, 2017).

2. Development of spatial skills: Playing with blocks fosters children's spatial skills as they learn to understand spatial concepts and spatial language (e.g., by comparing sizes of block buildings; see Ferrara et al., 2011; Yang & Pan, 2021).

3. Development of math knowledge and science concepts: Block play can provide an opportunity to learn math (e.g., by adding and subtracting blocks) and science concepts (e.g., stability through physical manipulation of block structures; see Bagiati & Evangelou, 2016; Newman et al., 2021; Park et al., 2008; Trawick-Smith et al., 2017).

4. Development of early literacy skills: Joint adult-child block play can foster children's early literacy skills (e.g., Christakis et al., 2007).

5. Development of social skills: Block play helps to develop social skills (e.g., cooperative behavior; see Rogers, 1987).

Overall, research demonstrates the importance of block play in fostering various aspects of early childhood development on a cognitive, skill and social level. This dissertation mainly focuses on children's theories about stability in block play (i.e., science concepts) and their spatial (i.e., spatial language) and math development over time.

1.2 Preschool teachers' professional competences

Preschool teachers' professional competence is a central topic of the discussion on professionalization and reform of teacher education programs, particularly the controversy about quality insurance through educational training standards (e.g., Lillvist et al., 2014). In Europe, early education programs for 3- to 6-year-old children represent the first stage of the education system and should foster children's school readiness (e.g., Lillvist et al., 2014). As previously mentioned, research has indicated that children's later academic achievement is associated with their early learning experiences in preschool (e.g., Betts et al., 2009; Duncan et al., 2007; Melhuish et al., 2008). Thus, there is a considerable need for highly qualified preschool teachers, who are able to effectively support and enhance children's learning. Nevertheless, training of teachers in Early Childhood Education and Care (ECEC) varies widely across countries (e.g., Darling-Hammond & Bransford, 2005; Lillvist et al., 2014) and formal educational degrees have shown to be poor predictors for the quality of teacher-child interactions (Early et al., 2007). Teachers' professional competences have been widely investigated in the field of early childhood education (e.g., Lillvist et al., 2014). Roth (1971) was the first to introduce the term "competence" in pedagogy and has divided competence into a triad of personal, professional and social competence (e.g., Fröhlich-Gildhoff et al., 2011). This division of competence into three subfacets has been an important reference point for existing competence models to date (e.g., Fröhlich-Gildhoff et al., 2011).

A generic model of teachers' professional competence has been proposed by Baumert and Kunter (2006). In this model, competence comprises teachers' knowledge, self-regulation, self-efficacy, motivation and beliefs. Teachers' knowledge is differentiated in *content knowledge* (CK), *pedagogical content knowledge* (PCK) and *general pedagogical knowledge* (PK). This classification follows the categorization of Shulman (1987), which has been widely adopted for classifying teacher knowledge (e.g., Dunekacke et al., 2015; Dunekacke et al., 2021; Fröhlich-Gildhoff et al., 2011; Leuchter et al., 2020). CK refers to teachers' knowledge of the subject matter, whereas PK refers to teachers' knowledge about basic pedagogical principles (i.e., classroom management; Shulman, 1987). PCK refers to teachers' understanding of the subject matters' concepts, principles and theories and represents a conglomerate of teachers' PK and CK (Shulman, 1987). Teachers with higher PCK should have a deeper understanding for the implementation of a specific topic, its arrangement to tailor it to learners' interests and skills and the occurrence and solution of typical problems. PCK thus represents a distinctive feature between highly qualified teachers and less qualified teachers (Shulman, 1987). Until now, PCK has primarily been studied as the foundation for teachers' instructional quality, but mainly within the context of primary or secondary schools (e.g., Leuchter et al., 2020). Nonetheless, PCK is a very important dimension of preschool teachers' professional competence which might differ from primary or secondary school teachers' PCK, as preschool teachers' have to know about children's intuitive concepts about science and consider developmental constraints (e.g., Trundle & Saçkes, 2015).

Fröhlich-Gildhoff and colleagues (2011) adapted the generic model of Baumert and Kunter (2006) and proposed a model of preschool teachers' professional competences (see figure 1). A separate model for preschool teachers is particularly important, as situations in early childhood education are characterized by low standardization and involve highly complex interactions that are difficult to predict (Fröhlich-Gildhoff et al., 2011). In the model of Fröhlich-Gildhoff and colleagues (2011), teachers' dispositions (i.e., individual prerequisites) are distinguished from teachers' performance (i.e., behaviors or teaching practice). Preschool teachers' dispositions are built upon two interconnected pillars that form an integral part of their competence. The first pillar is habitual knowledge, which encompasses beliefs primarily shaped by experience. The second pillar is context-specific knowledge, predominantly acquired through teacher preparation programs. To effectively facilitate children's learning by using age-appropriate methods, teachers must engage in continuous reflection of their own routines, skills, and beliefs (e.g., Fröhlich-Gildhoff et al., 2011). This self-evaluating component thus explains how teachers build and expand their planning of action and experiential knowledge through a feedback process.

Summarizing, the basis for teachers' teaching practice results from the interplay of (a) explicit and theoretical knowledge, (b) implicit, experiential knowledge and (c) skills and abilities of methodical or didactic nature (Fröhlich-Gildhoff et al., 2011). The connection between teachers' dispositions and their actual practice relies on their intention to engage in specific teaching behaviors. However, in the model of Fröhlich-Gildhoff and colleagues (2011), this concept of intention remains rather unspecific and it has seen limited conceptualization in empirical research so far. Dunekacke and colleagues (2015) have applied the model of competence of Fröhlich-Gildhoff and colleagues (2011) and examined whether preschool teachers mathematical content knowledge predicted teachers' perception of mathematical learning situations and their ability to plan educational activities to foster children's learning. They found that preschool teachers' content knowledge significantly predicted both, teachers' perception skills and their planning of action.

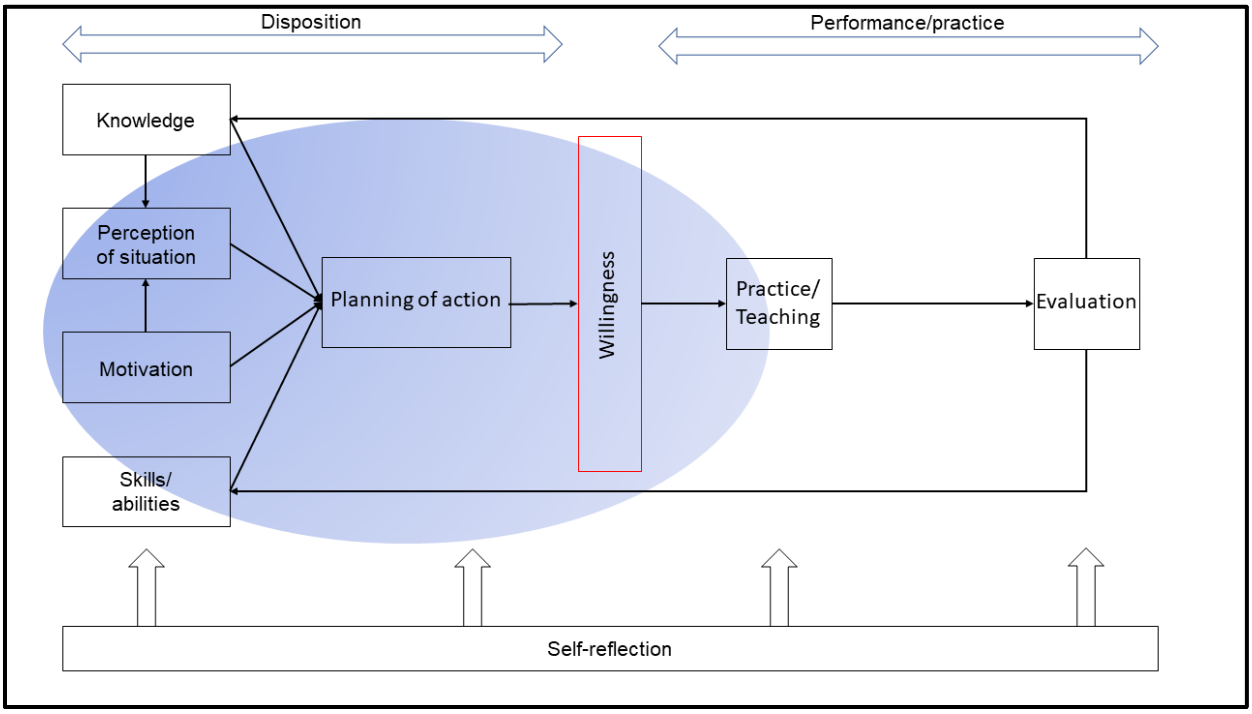

Figure 1. Competence model adapted from Fröhlich-Gildhoff and colleagues (2011). A willingness component was added to bridge the gap between disposition and practice.

The current dissertation builds upon the model proposed by Fröhlich-Gildhoff and colleagues (2011) and aims to bridge the gap between teachers' dispositions and their practice. Empirical studies do not support the expectation that teachers' dispositions directly translate into their actual practice. (e.g., Akerson et al., 2010; Liu, 2011; Wilcox-Herzog, 2002). For example, teachers were found to hold adequate views about nature of science (NOS), however, these views did not impact their frequency of NOS teaching (Akerson et al., 2010). Thus, the model of Fröhlich-Gildhoff and colleagues (2011) is expanded by the introduction of a willingness component, which conceptualizes teachers' intention as a predictor for their teaching practice.

1.2.1 Preschool teachers' willingness

The construct of willingness is derived from the theory of planned behavior (Fishbein & Ajzen, 2010) According to this theory, teachers' beliefs influence their attitudes, situation perception, and perceived behavioral control, which, in turn, shape their intentions to engage in specific behaviors within their professional practice (Heuckmann et al., 2019). Importantly, teacher intention is the only predictor of their actual classroom behavior, determining whether they will carry out those intended actions or not. In comparison to intention, however, willingness is understood as "a more specific measure of intention" (Heuckmann, 2020, p. 119), since it always refers to teachers' readiness to engage in a specific practice in a concrete context. In the present dissertation, the term *willingness* is used to refer to teachers' inner readiness to engage in early science teaching. The predictive power of the theory of planned behavior has been widely demonstrated across various contexts (Armitage et al., 2014; Darker et al., 2010; Sheeran & Silverman, 2003; Zoellner et al., 2013). However, in the context of teaching, the predictive power of willingness for teacher behavior might be less evident compared to other domains, due to the presence of multiple influencing factors that need to be considered, such as self-efficacy, beliefs, CK, and PCK (Chan & Lay, 2021; Lee et al., 2010; van Aalderen-Smeets et al., 2012). Teachers' willingness may therefore depend on whether teachers have sufficient CK and PCK or hold adequate beliefs about science teaching and learning to implement their intentions.

To date, however, there is still a lack of reliable and valid instruments for measuring willingness in specific teaching contexts (e.g., willingness to engage in early science teaching). As the preceding discussion illustrates, incorporating willingness into theoretical models of preschool teachers' professional competence might be essential to drawing important conclusions of the relationships between dispositions and behaviors. Thus, the present dissertation addresses this research gap in study 1.

1.2.2 Preschool teacher's knowledge in early science

An important subfacet of preschool teachers' professional competence is knowledge. As pointed out earlier, teachers' knowledge is usually categorized into content knowledge (CK), pedagogical content knowledge (PCK) and (general) pedagogical knowledge (PK). Research indicates that preschool teachers' knowledge might have a significant impact on the quality and frequency of their science teaching (Kallery & Psillos, 2001; McCray & Chen, 2012). However, empirical evidence has shown significant disparities in preschool teachers' science-specific knowledge, and their teaching practice (Barenthien et al., 2018; Pianta et al., 2008).

Research conducted on preschool teachers' CK has indicated that their understanding of science and math concepts is rather limited or low and that teachers held misconceptions about scientific phenomena (Garbett, 2003; Kallery & Psillos, 2001; Yildirim, 2021). Moreover, preschool teachers reported to feel ill-prepared to teach science (Spektor-Levy et al., 2013; Yildirim, 2021). A recent study has found that a majority of preschool teachers expressed limited confidence in their comprehension of spatial reasoning and its underlying concepts, even though teachers realized that spatial reasoning is an important aspect of science learning (Bates et al., 2023). According to this, there might be a notable disparity between the expectations outlined in national reform documents for elementary science teachers and the qualifications and readiness of teachers to teach elementary science. This misalignment between the intended teaching standards and teachers' actual practice, specifically teachers' lack of CK, might have detrimental effects on children's learning and negatively influences preschool teachers' practice. For example, Leuchter and Saalbach (2014) have examined preschool and elementary teachers' practice and knowledge in a floating and sinking task. They have shown that preschool teachers' made content related errors, which were negatively associated with children's learning progress. Further, another study has shown that preschool teachers' CK in math was an important predictor for their ability to recognize mathematical learning opportunities (Dunekacke et al., 2015). Teachers with limited CK missed out on possibilities to foster children's math knowledge (Dunekacke et al., 2015). This observation aligns with previous studies on science learning, that have identified limited science knowledge as one of the primary factors contributing to restricted time spent with science teaching (Appleton, 1992; Kallery and Psillos, 2001).

PCK is an important predictor of teacher instructional quality and learners' progress (Kunter, 2013; McCray & Chen, 2012). Further, PCK is considered a prerequisite for preschool teachers' ability to diagnose children's current level of knowledge and to provide adequate scaffolding techniques throughout the learning process (Leuchter et al., 2020; van de Pol, 2010). Dunekacke and colleagues (2021) have shown that there are positive relations between teachers' learning opportunities and their PK. However, research suggests that preschool teachers have limited PCK to effectively enhance science-specific procedural skills and to scaffold children's learning (Barenthien et al., 2020; Piasta et al., 2014; Roth, 2014). Consistent with this, in a floating and sinking task, scaffolding techniques requiring high PCK were less frequently observed compared to less demanding forms of teacher support (Leuchter & Saalbach, 2014). Furthermore, studies have indicated that preschool teachers rarely employed diagnosing or scaffolding techniques in their teaching practices (Cabell et al., 2013; Leuchter & Saalbach, 2014; von Suchodoletz et al., 2014) and that they tend to prioritize organizing play over supporting children's learning through diagnostic assessments and scaffolding techniques (Leuchter & Saalbach, 2014; Sylva et al., 2007). Despite these findings, there is evidence that teachers' CK and PCK are malleable can be improved through training (e.g., Saçkes, 2014). Further, the amount of science courses was a significant predictor for the frequency of preschool teachers' engagement in science teaching (e.g., Saçkes, 2014).

Taken together, research has shown that preschool teachers' CK and PCK in science is rather low. However, as stated by Barenthien and colleagues (2020), the variability in the conceptualization of teacher PCK may contribute to divergent outcomes and conclusions within the field of research on teacher knowledge. Given the high subject-dependency and contextual relevance of PCK and CK in science teaching and learning, it seems valuable to define teachers' knowledge in a specific and well-defined context (i.e., stability) to examine its influence on teaching practice. To date, there have been no studies investigating teachers' PCK and CK in the physics domain (e.g., stability), which is closely related to block play.

1.2.3 Teacher beliefs

Teacher beliefs regarding teaching and learning are essential components of teacher professional competences (Buehl & Beck, 2015; Leuchter et al., 2020), and are thought to have a significant impact on teachers' professional practice (Richardson, 2003; Wilkins, 2008). Beliefs are viewed to be part of a complex, interconnected, and multidimensional system, allowing for the coexistence of contradictory beliefs (Buehl & Beck, 2015). According to some researchers, teacher beliefs serve as both, amplifiers and filters, which shape teachers' instructional approaches (Buehl & Beck, 2015; Leuchter et al., 2020). Specifically, teacher beliefs are thought to influence (1) teachers' filtering and interpretation of information, (2) teachers' planning and structuring of lessons, and (3) teachers' teaching practice (Buehl & Beck, 2015).

To date, there have been multiple approaches and instruments to assess teacher beliefs (e.g., Buehl & Beck, 2015). This dissertation employs the three-dimensional categorization system of Schmidt and Smidt (2021). The first category comprises co-constructivist beliefs, which emphasize the significance of a dialogic and collaborative relationship between teachers and children in knowledge construction (Chi & Menekse, 2015; Schmidt & Smidt, 2021). Within this framework, it is assumed that children actively restructure their knowledge through the guidance and support provided by the teacher. This process enables children to develop coherent explanations and understanding of concepts (Schmidt & Smidt, 2021). Constructivist beliefs are often contrasted with the second category, instructivist beliefs, which prioritize the transmission of knowledge by teachers to children (Leuchter et al., 2020; Schmidt & Smidt, 2021). Instructivist beliefs are viewed as incongruent with the contemporary understanding of effective science education, which emphasizes the importance of inquiry-based approaches and highlights the active role of children in the learning process (Duit & Treatgust, 2003; Saçkes et al., 2011). Instructivist beliefs typically promote a more passive learning experience, where knowledge is transmitted without much emphasis on children's active hands-on exploration or the promotion of sustained shared thinking. The third category of teacher beliefs proposed by Schmidt and Smidt (2021) are autonomy beliefs, which place a strong emphasis on children's socio-emotional development, while the development of early academic skills is considered less important. These beliefs stem from a situation-oriented approach, which places a strong emphasis on children's socio-emotional development (ECEC/OECD, Anders, 2015; Merkel, 2013). This approach is prevalent in many ECEC settings in Germany (ECEC/OECD, Anders, 2015). In this context, the situation-oriented approach prioritizes creating learning environments and experiences that promote social interaction, cooperation, and a sense of responsibility among young children (ECEC/OECD, Anders, 2015).

Even though beliefs are discussed as important precursors for teacher behavior, the influence of teacher beliefs on their teaching practice has been discussed controversially and empirical evidence concerning these associations is ambiguous. For example, Liu (2011) found that the majority of teachers held learner-centered beliefs, however, their teaching was mainly instructive and did not integrate co-constructivist practice. Leuchter and colleagues (2020) conducted a latent profile analysis in a Swiss sample of 104 preschool teachers with a floating and sinking task and found three belief patterns (high co-constructivist, hands on, low co-constructivist). Results has shown that teachers in the high co-constructivist pattern had more PCK concerning children's conceptions about the topic of floating and sinking, albeit the difference in PCK compared to the other groups was not statistically significant (Leuchter et al., 2020). Moreover, teachers' scaffolding activities were rare, and correlations between co-

constructivist beliefs and teachers' use of scaffolding were missing. In line with this, a recent study has also revealed a notable inconsistency between beliefs and practices of preschool teachers in Ethiopia, regarding developmentally appropriate Practice (DAP). Although the participating teachers held strong and positive beliefs about DAP, their beliefs did not have a direct influence on their actual classroom practices (Mengstie, 2022). Other findings have also indicated that the association between teacher beliefs and teaching practice is rather limited (Jorgensen et al., 2010; Liu, 2011; Mohamed & Al-Qaryouti, 2016; Stipek & Byler, 1997).

Nevertheless, other studies suggest a relationship between teacher beliefs and (self-reported) teaching practice (e.g., Perren et al., 2017; Quance et al., 2008; Tsai, 2006). For example, Perren and colleagues (2017) have found that teacher self-efficacy beliefs were a mediating factor between teachers' domain-specific knowledge, early educational setting, and teachers' practice. However, teacher beliefs related to attitudes were weak predictors of teaching practice. The authors hypothesize that self-efficacy beliefs might play a crucial role in guiding immediate teaching practice, whereas beliefs related attitudes might rather serve as a framework for interpreting and understanding relevant situations (Perren et al., 2017). Thus, self-efficacy might act as a mediating factor between teaching practice and attitudes and might thereby contribute to the overall lens through which teachers view their teaching. The consideration of this dichotomy between self-efficacy and attitudes in teacher beliefs might explain the contradictory findings concerning the association between teacher beliefs and teaching practice.

Another explanation for the contradictory findings might be found when considering reciprocal relationships between teachers' beliefs and practices, as stated by Basturkmen (2012). The strength of the relationship between teachers' beliefs and their practice may differ depending on individual teacher characteristics (e.g., experience), the subject being taught, as well as the specific beliefs and practice, which are examined (Basturkmen, 2012). In line with this, empirical research suggests that effects associated with different teacher beliefs and their implementation in practice strongly diverge (e.g., Mansour, 2013; Pendergast et al., 2017). The connection between co-constructivist beliefs and teachers' practice appears to be less strong compared to the association observed for instructivist beliefs and teacher practice (Mansour, 2013). This weaker connection may be attributed to the substantial demands placed on teachers' competence when translating co-constructivist beliefs into teaching practice. Further, feelings of discomfort or low self-efficacy may play a crucial role, especially when it comes to science teaching (e.g., Pendergast et al., 2017), which might weaken the association between beliefs and practice as well. Taken together, these findings underline the importance of professional development to build upon teachers’ knowledge and beliefs on science teaching, to enable teachers to implement inquiry-based approaches into early science.

1.2.4 Preschool teachers’ practice in early science

Preschool teachers’ dispositions, including their CK, PCK, and beliefs, seem to shape how teachers perceive and implement science instruction, ultimately impacting the quality of science learning experiences for young children.. Nevertheless, there is limited agreement regarding the conceptualization of instructional quality, particularly regarding its contextual specificity (i.e., its dependence on the subject being taught), dimensionality (i.e., whether it encompasses multiple facets and which dimensions should be considered), and observed practice (see review by Senden et al., 2022). Previous research has primarily focused on rather generic aspects of instructional quality, albeit the behaviors of teachers in specific situations, such as their instructional practices and teaching methods in specific situations, are considered crucial for child outcomes due to its proximity to children's outcomes (e.g., Jenßen et al., 2016; Pohle et al., 2022). Thus, domain-specific aspects of instructional quality in well-defined content areas should be considered (Pohle et al., 2022).

Generic aspects of instructional quality refer to common characteristics carried out by teachers across different subjects and situations (e.g., Pohle et al., 2022). For example, empirical findings suggest that the quality of preschool teachers' language and literacy instruction is related to children's vocabulary development (Guo et al., 2011). Additionally, research has indicated that teachers' overall language use is associated with children's academic outcomes, such as reading and word comprehension (Dickinson & Porche, 2011). Moreover, preschool teacher should provide warm and responsive interactions to foster children’s cognitive growth (e.g., Burns et al., 2023). Furthermore, teachers' sensitivity in offering responsive feedback and establishing warm interactions are considered as crucial elements of effective preschool teaching (e.g., Birch & Ladd, 1997). There is evidence that sensitive and stimulating interactions foster children's language acquisition and pre-academic skills (Burchinal et al., 2008). Moreover, within early science learning, experts argue that preschool teachers should create a joyful atmosphere to better integrate scientific concepts into children's play (e.g., Samuelsson & Johansson, 2006).

Domain-specific aspects of teachers' instructional quality refer to the unique characteristics that are specific to particular teaching contents (e.g., Pohle et al., 2022). In contrast to generic aspects of instructional quality, domain-specific aspects are situation-bound and have to be adaptive to the children's effort and skill level. Domain-specific aspects can be conceptualized as teachers’ verbal support during children’s learning, which comprises the use of scaffolding techniques and content-focused language. For block play, content-focused language comprises the use of scaffolding (e.g., Weber et al., 2020), spatial language (e.g., Ferrara et al., 2011) or math language (Klibanoff et al., 2006). The following subchapters will focus on teachers’ verbal support more in-depth.

Research on preschool teachers’ teaching practice has demonstrated that they rarely encourage children’s engagement in playful science learning (e.g., Nayfeld et al., 2011; Saçkes et al., 2011). Moreover, preschool teachers seem to employ ineffective teaching practices when they teach science and math concepts (Engel et al., 2013; Tu, 2006). For example, in math, teachers reported devoting the majority of their time (i.e., approximately 13 days per month) to teaching basic counting and shapes, although a majority of the children had already mastered counting and shapes (Engel et al., 2013). Moreover, repeated exposure to content, that children have already learned, was negatively associated with children’s test scores at the end of the kindergarten year, which underlines the importance of aligning teaching practice with children’s knowledge (Engel et al., 2013). The authors argue that this misalignment might result from a) teachers’ lack of knowledge in math, b) their discomfort with teaching math or c) their unawareness about children’s math skills (Engel et al., 2013).

Tu (2006) has shown that a majority of preschool teachers’ activities, which were labeled as science, were in fact unrelated to science, despite more than half of the observed classrooms in the study being staffed with adequate materials. Although current literature on early science teaching suggests using appropriate materials to enrich children’s learning experiences (e.g., Saçkes et al., 2011), findings suggest that many preschool teachers do not make use of the science equipment that is available to them, which might lower the quality of early science learning as well (e.g., about 50% of the teachers did not use the water and sand table and about 36% the science or nature area; Saçkes et al., 2011).

Empirical evidence on the causal relationship between instructional quality and children's knowledge remains ambiguous. Some studies did not find significant associations between teachers’ instructional quality and children’s learning (e.g., Duncan et al., 2015; Weiland et al., 2013), while other findings suggest that instructional quality significantly influences children’s immediate or later achievement (e.g., Guo et al., 2011; Mashburn et al., 2008; Pohle et al., 2022). For example, Pohle and colleagues (2022) have examined 25 preschool teachers’ instructional quality in math and its impact on children’s math learning in a longitudinal design. They found that (a) children’s level of math knowledge was dependent on group membership (i.e., children’s preschool teacher) and that (b) children’s growth rate, but not their initial math score was significantly associated with teachers’ instructional quality. On the other hand, the findings of Weiland and colleagues (2013) have suggested that indicators of classroom quality in preschool settings had either small or negligible associations with children's knowledge gains.

An explanation for the contradictory findings was provided by Hall-Kenyon and colleagues (2009). They suggest that the impact of instructional quality on children's achievements may be subject-specific rather than generic, and influenced by other confounding variables such as children’s participation in learning situations, full-day versus half-day classrooms, and children's attentiveness and social background. Moreover, contradictory findings might result from different operationalizations of teachers’ instructional quality or children’s outcome measure (i.e., broadly vs. narrowly defined outcomes or specific vs. generic measures; Pohle et al., 2022). Further, some authors have stressed the malleability of instructional quality across different situations or contexts; hence, instructional quality should not be seen as a stable trait but rather as a situation-specific disposition (e.g., Pohle et al., 2022). Thus, teachers’ instructional quality might strongly differ between different content areas. Moreover, the perspective of Pohle and colleagues (2022) on instructional quality suggests that it is subject to change and can be improved through professional development courses or training. This recognition offers promising opportunities for enhancing instructional quality through targeted interventions and ongoing professional growth.

To date, little is known about preschool teachers’ practice in teaching stability, and studies hardly provide an exhaustive review of preschool teachers’ instructional quality in block play. More specific, research on teachers’ instructional quality in the stability domain can be defined as a major research desideratum. Thus, to provide initial insights into the association of teachers’ instructional quality and children’s knowledge, study 2 encompasses generic and context-specific conceptualizations of instructional quality. The second article focuses on preschool teachers’ instructional quality in block play and defines children’s outcomes in the terms of stability knowledge, math knowledge and spatial language and considers children’s academic self-concept.

1.2.5 Scaffolding

As outlined earlier, teachers' context-specific instructional quality depends on the provision of verbal support. Scaffolding can be considered as one major aspect of teachers' learning support in early science teaching. The concept of scaffolding is closely associated with Vygotsky's socio-cultural theory (Vygotsky, 1967). From this point of view, a scaffold is a structure used to facilitate children's learning and refers to the temporary support provided to learners to help them accomplish tasks they might not be able to achieve on their own. Wood and colleagues (1976) adopted the scaffolding metaphor to explain how adults can assist children in joint problem-solving activities. Scaffolding can be provided in various ways, including modelling, asking questions, prompting assumptions or encouraging comparisons (e.g., Belland et al., 2013; Reiser, 2004; van de Pol et al., 2010; Weber et al., 2020). A conceptual model of scaffolding has been proposed by van de Pol and colleagues (2010) and encompasses three key features: (a) contingency between learners' knowledge and responsibility and teacher's support, (b) a gradual withdrawal of teachers' support (i.e., fading) and (c) an increase in learners' responsibility over time as learner's knowledge improves (i.e., transfer of responsibility). In order to offer appropriate and effective support, teachers have to assess children's current level of competence, which allows them to tailor their scaffolding contingently to the learners' knowledge (van de Pol et al., 2010). In this context, the importance of teachers' diagnostic competence in assessing children's knowledge and skills to align their teaching practice consistent with learners' knowledge has been stressed (e.g., Macrine & Sabbatino, 2008; van de Pol et al., 2010). A study by Engel and colleagues (2013) has shown that advanced children with advanced math knowledge did not benefit from exposure to basic math content, which highlights not only the importance of teachers' diagnostic skills to assess children's knowledge, but also the aspect of providing verbal support, which is aligned with children's level of expertise (i.e., contingency).

Teachers' scaffolding can either be material (i.e., curriculum materials; Kleickmann et al., 2016; Weber et al., 2020) or verbal (i.e., scaffolding children's knowledge by referring to prior knowledge; Belland et al., 2013; van de Pol et al., 2010; Weber et al., 2020). In block play, material scaffolding encompasses the provision of building blocks of different shapes and sizes. Adequate materials might facilitate children's recognition of counterevidence to their theories and help preschool teachers to structure their playful interventions (Weisberg et al., 2016). Nevertheless, providing children with adequate materials is only a first step to foster early science learning and should be accompanied by verbal scaffolds. Verbal scaffolds should encourage children's higher order thinking and be adapted to their current level of knowledge (e.g., van de Pol et al., 2010).

In the literature, various conceptualizations of verbal scaffolding have been established, yet, the present dissertation employs a categorization system following Weber and colleagues (2020), which, in turn, is derived from the frameworks of van de Pol and colleagues (2010) and Hogan and Pressley (1997). The categories encompassed (a) linking new information to children's prior knowledge, (b) asking for children's reasoning, (c) providing explanations, (d) encouraging comparisons, and (e) modelling. The names of the categories were slightly changed to better emphasize their meaning (see Appendix E). Moreover, three additional scaffolds were added: (a) reflecting back children's statements, (b) encouraging children's higher order thinking and (c) drawing attention towards relevant aspects (verbally and via gestures).

The effectiveness of verbal scaffolding in fostering children's stability knowledge in block play has been shown by Weber and colleagues (2020). In block play, preschool teachers might ask children whether they had already played with building blocks or whether they had seen a certain structure before. By prompting questions directed towards children, teachers can refer to children's prior knowledge, which helps assimilating new information into existing mental frameworks or theories (e.g., Weber et al., 2020; Weinert & Helmke, 1998). Moreover, teachers can provide explanations to assist children in integrating their observations into their understanding of stability (Renkl, 2002). These explanations should follow certain principles and it is crucial that these explanations are presented in a manner that is easily comprehensible and accessible to the learners (e.g., self-explanation over instructional explication, providing feedback, provision of explanations on learner demand, minimalist instruction and progressive help, for an overview see Renkl, 2002). Murphy and Messer (2000) have examined the benefits of explanations in a study with 5- to 7-year-old children. Children were given the task of selecting a symmetrical or asymmetrical object and to balance it on a fulcrum. After having achieved the task, the children were asked to explain their approach while balancing the object. However, many of the children struggled to articulate their thinking. In a next step, the experimenter provided an explanation and used the child's initial explanation as a groundwork for the scaffolded instruction (Murphy & Messer, 2000). Children receiving explanations were more successful in balancing unfamiliar wooden beams than children receiving no explanations. This result shows that children are able to apply knowledge, which they have acquired through an adult’s explanation to solve unknown problems.

Nonetheless, preschool teachers can also employ various other scaffolding techniques to support children in their learning process. For example, preschool teachers can encourage comparisons between different objects to help children in their understanding of similarities and differences and to integrate this into their mental concepts (Hsin & Wu, 2011). In doing so, teachers might draw children’s attention to relevant aspects of the comparison by verbal means or by gestures (e.g., pointing on a stabilizing block) or reflect back important statements (e.g., *can you repeat what you have said before?*). Moreover, during block play, teachers can also prompt comparisons between stable and unstable objects and thus foster children’s understanding of stability (e.g., Weber et al., 2020). Furthermore, teachers can encourage children to explain their reasoning and their assumptions and thus foster children’s higher order thinking (Hsin & Wu, 2011). Additionally, modelling, which involves a teacher or an adult demonstrating correct behaviors (e.g., stabilizing a block structure by adding a block) helps children to build consistent explanations for a phenomenon or to imitate an adult's behavior (Chinn & Hung, 2007; Hmelo-Silver et al., 2007).

Research has indicated that scaffolding has a positive impact on children's learning in various domains (e.g., Hadzigeorgiou, 2002; Mermelshtine, 2017; Leuchter & Naber, 2019; Pine et al., 1999; Weber et al., 2020). However, teachers only rarely scaffold children's learning (e.g., Cabell et al., 2013; Leuchter et al., 2020; von Suchodoletz et al., 2014). For block play, Weber and colleagues (2020) have examined the effect of verbal and material scaffolds on 5- to 6-year-old children's stability knowledge. The study employed a pre-post-follow-up experimental design with three groups: a free play group, a guided play group with material scaffolds and a guided play group with material and additional verbal scaffolds. The results have shown that both guided play groups outperformed the free play group in their stability knowledge, however, there was no statistically significant difference between the guided play group with material scaffolds and the group with additional verbal scaffolds. Nevertheless, descriptive results underlined the effectiveness of verbal scaffolds as children receiving additional verbal support had the highest probability of considering the correct theory when assessing stability (Weber et al., 2020). The probability of the group with additional verbal scaffolds was even twice as high as the probability of the material group to argue with the correct theory (Hazard ratio = 1.99). However, the study conducted by Weber and colleagues (2020) has examined the effects of a researcher-led intervention on children's learning and did not consider preschool teachers' practice in this domain. The present dissertation addresses this research gap and investigates the effect of teachers' verbal support in block play on children's stability knowledge.

1.2.6 Spatial language

Another important aspect of teachers' learning support comprises the adequate use of content-specific language to enrich children's learning experiences and their vocabulary.

Spatial language refers to the use of words describing spatial dimensions, an object's shape, place, direction, or spatial properties (e.g., Ferrara et al., 2011). By describing the height or spatial orientation of the blocks, discussing the location of objects in relation to each other and exploring geometric properties like (a-)symmetry, teachers and children can collaboratively engage in spatial talk during block play (e.g., Borriello & Liben, 2018; Ferrara et al., 2011). There is evidence that spatial language serves as a basis for spatial skills, which, in turn, encompass the mental manipulation and transformation of spatial information (e.g., Casey et al., 2008; Ferrara et al., 2011).

However, the understanding of the contexts in which children are exposed to spatial language and the settings where they naturally employ spatial language remains limited, despite its significance in fostering spatial skill development (Ferrara et al., 2011). Numerous studies have shown that block play can be used to promote children's spatial and math skills by using spatial language (e.g., Borriello & Liben, 2018; Ferrara et al., 2011; Pruden et al., 2011; Verdine et al., 2019). For example, one study has found a positive association between preschool block performance and math achievement during transition to middle school, specifically in 7th grade and throughout high school, which highlights the long-term impact of children's early spatial and block-related skills on later achievement. (Wolfgang et al., 2001). Moreover, studies have shown that, during joint play, parents and children frequently engage in conversations about shapes (Pruden et al., 2011; Ramani et al., 2014). Further, preschool-aged children have the ability to learn shape categories, properties, and definitions when the play material represents defining features, as demonstrated in the study by Fisher and colleagues (2013). Borriello and Liben (2018) have shown that mother-child dyadic interactions in block play, which were instructed to use spatial language, produced more spatial language compared to non-instructed dyads. Besides, there is evidence that guided play is more effective than free play in promoting parent's spatial utterances in block play (Ferrara et al., 2011). Most importantly, children's spatial language also increased with their parent's use of spatial language, which might point at an immediate learning effect, which, in turn, might further impact children's spatial reasoning. Moreover, a study of Cohen and Emmons (2016) has shown that teachers applied verbal scaffolding of spatial utterances during guided play sessions, which also increased the frequency of 4- to 12-year-old children's spatial utterances.

Casey and colleagues (2008) have examined the relationship between block-building interventions and children's spatial skills in a quasi-experimental study with 5.6-to 6.7-years-old children and their preschool teachers. Teachers were assigned to three groups (EG1: block building intervention and storytelling intervention, EG2: block building intervention and CG: no intervention). They found a significant increase in children's spatial skills in both experimental groups. The first experimental group outperformed the two other groups in the post-test concerning the block building score (i.e., complexity of buildings), but the difference between EG2 and CG was not significant. Yet, children in both experimental groups exhibited a significant increase in their spatial visualization skills after the intervention (i.e., matching 2-dimensional block structures) compared to the control group. However, it is important to acknowledge a significant limitation of the study, namely the notable differences in pre-test scores between two of the three outcome measures. This threat to internal validity makes it difficult to establish a causal relationship between the experimental manipulation and the observed improvements Nevertheless, the findings indicate that teachers can benefit from a targeted intervention to promote the development of children's spatial skills in block play. The study findings also highlight the importance of providing teachers with strategies and support to effectively use block play as an educational tool for enhancing spatial abilities in children.

Summarizing, empirical evidence about children's exposure to spatial language in preschool settings is sparse (cf. Casey et al., 2008), although research has shown the beneficial effects of spatial language on children's spatial skills. The present dissertation aims to address this research gap by considering preschool teachers' use of spatial language in free and guided play as well as children's spatial language skills.

1.2.7 Math language

Another important aspect of content-specific language in block play refers to the use of math language. Math language comprises vocabulary employed in math, including terms like addition, subtraction, and geometric terminology (i.e., triangle, rectangle; see Klibanoff et al., 2006). Math language is thought to play a crucial role in children's numeracy development by helping children to understand quantity and numerical relationships (e.g., Miura & Okamoto, 2003) and several studies have provided evidence of a strong language component in early numeracy skills (e.g., Neumann et al., 2013). More specific, research has indicated that children's math language is a predictor of their early numeracy skill development (Toll & van Luit, 2014) and that early numeracy skills, in turn, are significant predictors of children's future achievement in math (Nguyen et al., 2016). Further, there is evidence that young children's understanding of math language serves as a more powerful predictor for their numeracy skills compared to general language abilities (Toll & Van Luit, 2014). Thus, the integration of math language in block play should be promoted to foster children's math skills.

During block play, children often engage in math language with their parents or preschool teachers by counting blocks or comparing the height of block buildings (e.g., Purpura et al., 2021). Further, preschool teachers might also employ math language when counting blocks, referring to quantities (e.g., half/third) or applying scale units for measurement (e.g., centimeter, meter). Research has shown that children's math language skills are malleable and that targeted interventions and instructional approaches can effectively improve children's proficiency in math language (e.g., Hassinger-Das et al., 2015; Purpura et al., 2017; Purpura et al., 2021). Further, recent studies have suggested that the amount of math language also improved number knowledge in preschool-aged children (Espinas & Fuchs, 2022; Gibson et al., 2020; Purpura et al., 2019; Purpura et al., 2021), while spatial language may not have the same impact (e.g., Purpura et al., 2019).

A current systematic literature review, which has investigated longitudinal effects between math language and math abilities, has found a positive relation between the amount of math language and children's math abilities (Turan & De Smedt, 2022). Moreover, King and Purpura (2021) have conducted a longitudinal study with children between 3 and 5 years of age over the duration of 6 months. They found that children’s math language significantly mediated the association between direct home numeracy environment (i.e., the amount or frequency children were exposed to math at home) and children’s numeracy skills. Their study corroborates the findings of Toll and van Luit (2014), who found that preschool teachers’ amount of math talk mediated the relationship between 4-to 5-year-old children’s basic language and their early numeracy skills. Thus, the deliberate use of math language seems to be particularly important for children’s development of numeracy skills.

However, preschool teachers may not necessarily possess the necessary skills or knowledge to effectively support children's numeracy development and math anxiety might hinder teachers’ engagement in teaching math to children (e.g., Maloney et al., 2015). To address these concerns and to promote children's numeracy skills, a potential approach is to offer structured activities in everyday settings that encourage preschool teachers to engage in math. Nonetheless, with few exceptions, research on the nature and frequency of math input in preschool classrooms is limited. To date, studies have either primarily focused on the amount of math language in parent-child-interactions (e.g., Gibson et al., 2020), or have concentrated on directly fostering children’s math language (e.g., Purpura et al., 2017; Purpura et al., 2019). This dissertation addresses this research gap and expands previous findings by investigating preschool teachers’ math language in free and guided play and its associations with children’s math knowledge. Further, this dissertation aims to untangle the association between the effects on spatial language and math language on children’s math learning.

2. Early science curricula

Curricular frameworks for ECEC differ in many countries with regard to their content, their pedagogic approaches as well as their predefined goals and objectives (ECEC/OECD, Anders, 2015). In general, curricula refer to specific learning goals in well-defined learning areas (ECEC/OECD, Anders, 2015). However, the quality of curricula implementation strongly depends on teachers' instructional quality in a specific domain (ECEC/OECD, Anders, 2015). In general, two types of curriculum approaches for preschools can be distinguished: on the one hand, an academic approach, which aims at promoting children's school readiness with clearly defined learning goals and on the other hand, a socio-pedagogic approach, which primarily aims at promoting children's social skills and providing attachment and autonomy (ECEC/OECD, Anders, 2015).

Academic approaches impose concrete learning goals and often apply standardized assessments to monitor children's proficiency in the prescribed domains (e.g., the ECEC system of the United States or France; ECEC/OECD, Anders, 2015). Socio-pedagogic approaches, which are predominant in Germany, advocate against children's knowledge assessment and prioritize children's socio-emotional development. However, in Germany, official curricular guidelines have been introduced between 2003 and 2007, which define basic principles of ECEC settings and provide examples for learning areas (ECEC/OECD, Anders, 2015). Yet, due to the federal organization of Germany, the curricular guidelines only provide non-obligatory principles and their implementation strongly differs between the federal states (ECEC/OECD, Anders, 2015). Further, the process quality of early childhood teaching is neither monitored, nor is the predefined content aligned with primary schooling. Nonetheless, research-based early science curricula have been developed, for example in the field of floating and sinking (Hardy et al., 2017) and magnetism (Steffensky & Hardy, 2013). These curricula are particularly aligned with primary schooling and establish cross-level connections in children's and students' competences. However, their implementation is voluntary and due to the extensive nature of these curricula, teachers need extensive training for their implementation.

As pointed out earlier, research on teachers' practice has shown that children's skill development is rarely targeted by teachers' instructional practice, even though children display cognitive skills (e.g., predicting, hypothesizing, asking questions) that allow the promotion of early science learning (e.g., Engel et al., 2013; Tu, 2006). Overall, it appears that children have limited chances to acquire science knowledge compared to their opportunities for learning literacy, social studies, and art (Early et al., 2010). This can partly be attributed to the scarcity of validated science curricula specifically designed for young children (Trundle & Saçkes, 2012). To date, there is still a scarcity of easily accessible and well-structured curricula, even though educational researchers have increasingly called for their development and implementation. Yet, to the best of my knowledge, three research-based and validated curricula have been introduced in the area of block play. For example, Giebitz (2018) designed a block play curriculum based on the principles of guided play to foster children's statistical literacy. The curriculum encompasses six lessons, each of which has a pre-defined learning goal with increasing complexity levels (e.g., lesson one: free form block play to find statistics and create data displays). During the lessons, a tutor offers guidance and assistance to foster children's understanding of counts or measurements with characteristics such as shape, spread, and center. However, this curriculum is designed for 6- to 8-years old children, thus, its implementation might be inappropriate for the early childhood years.

Another research-based block play curriculum, specifically designed for kindergarten-aged children, stems from Clements and Sarama (2007). The curriculum activities are specifically tailored to align with the experiences and interests of children and place a strong emphasis on fostering children's math (e.g., number recognition, adding and subtracting) and geometrical (e.g., shape identification, congruence) abilities through block play. This is accomplished through the integration of various resources such as computers, manipulatives (including everyday objects), and printed materials. The effectiveness of the curriculum was assessed in a pre-post experimental study. Results have shown that children’s math and geometrical skills in the experimental group with the curriculum significantly improved in comparison to the results of children in the control group, which received no curriculum (Clements & Sarama, 2008). Recently, a Korean study conducted by Lee and Kim (2018) has validated a play-based curriculum to foster children’s math and spatial abilities, based on a smart toy system that links technology-based learning with traditional block play. The effectiveness of the curriculum was tested in a pre-post experimental design with 26 5-year old children. They found a significant increase in the logical-mathematical ability of children, who had played with the curriculum materials.

Taken together, the empirical results underpin the effectiveness of block play curricula to foster children’s math and spatial learning. Consequently, educational researchers increasingly call for the development of curricula. Nevertheless, research-based science curricula for preschools remain sparse to date and international ECEC systems vary greatly in their educational approaches. This is particularly problematic, as teaching science in the early childhood years requires considering children’s individual knowledge, interest and motivation as well as developmental constraints (e.g., Trundle & Saçkes, 2015). In the following, the present dissertation highlights principles for designing science curricula for the early years and provides a critical analysis of the incorporation of play within these curricula.

2.1 Design of early science curricula

Effective science teaching for young children should include inquiry-based instructions to foster children's learning with hands-on activities (Anderson, 2007; Trundle & Saçkes, 2012). Inquiry-based learning is characterized by children's active engagement in constructing knowledge through processes such as questioning, observing, hypothesizing, experimentation, evaluation of evidence, and sharing of information with peers (e.g., Anderson, 2007; Trundle & Saçkes, 2012). Inquiry-based activities thus counteract traditional instructivist approaches, where the focal point of the learning process is an informed teacher who transmits knowledge to children (e.g., Leuchter et al., 2020; Saçkes et al., 2011). Current theories, which stress the learners' active role in knowledge construction, consider the instructivist approach to be incompatible with what is known as good science learning (e.g., Duit & Treatgust, 2003; Trundle & Saçkes, 2012). However, research has shown that instructivist views on teaching and learning are not necessarily associated with poorer outcomes. For example, Bonawitz and colleagues (2011) have shown that teachers' guidance constrained children's exploration with a novel-looking toy; yet, with free exploration, children were less likely to discover all functions and learn causal relationships of the toy.

In line with this, critics have also raised concerns about the effectiveness of inquiry-based approaches, arguing that they might impose a significant cognitive load on novices, potentially impeding their capacity to effectively process new information and consequently inhibiting learning processes (e.g., Kirschner et al., 2006). To this end, inquiry-based approaches advocate for preschool teachers' guidance during early science learning. This guidance involves structuring the learning content and offering support for children's learning, such as through the use of scaffolding techniques (e.g., Hmelo-Silver & Barrows, 2008; Hsu et al., 2015; van Uum et al., 2017). A vast amount of empirical studies underpins beneficial effects of guided inquiry-based approaches on preschoolers' science learning (e.g., Giebitz, 2018; Lin et al., 2020; Peterson & French, 2008; Weber et al., 2020; Weber & Leuchter, 2022; Zudaire et al., 2021). Results of a meta-analysis have also suggested that teachers' guidance facilitates children's science learning outcomes in inquiry-based learning (*d* = .50; Lazonder & Harmsen, 2016). Consequently, inquiry-based approaches can be seen as a gold standard for designing and implementing early science curricula in preschool (e.g., Trundle & Saçkes, 2012). The abovementioned aspects were considered in the design of the present block play curriculum (see study 3).

2.2 Integration of play into science curricula

Play-based learning is widely recommended in the early years' curricula for kindergarten-aged children (Hirsh-Pasek et al., 2009). A majority of educational researchers agrees that play and learning in early childhood are intertwined and regarded as inseparable components in the development of young children (e.g., Osborne & Brady, 2001). However, the provision of an all-encompassing definition seems to be difficult (Akman & Özgül, 2015). Modern theories about play all have in common that they focus on comprehending the impact of play on children from a developmental perspective (Akman & Ozgül, 2015). Key elements of play encompass children's freedom of choice (voluntariness), child-directedness, intrinsic motivation and process-orientation (e.g., Pellegrini, 2013; Trawick-Smith, 2012). Besides, literature about children's play contains multiple classifications of play corresponding to different child development stages. For example, Piaget (1962) categorized play into three types: a) sensorimotor play, primarily displayed by babies and toddlers, b) imaginary play, primarily shown by children aged 2 to 7 and c) games with rules, shown by 7- to 8-year old children.

For the present dissertation, Vygotskys' (1967) definition of play applies, which emphasizes the significance of play in enhancing children's cognitive development and higher mental functions, while they engage in play within the zone of proximal development. Research about the relationship between play and children's development have generally shown positive effects on children's cognitive skills (e.g., Gmitrová & Gmitrov, 2003). Nonetheless, as empirical studies provide more specific operationalizations of play, the associations with children's skills become more precise. This is shown in a study conducted by Levine and colleagues (2012), which revealed that early engagement in puzzle play served as a predictor for children's spatial transformation skills. The findings underscore the importance of examining the distinct aspects of play and their corresponding impacts on specific skill domains, offering valuable insights into the relationship between play and children's development. Even though the majority of educational researchers advocates for the integration of play in curricula for the early childhood years, the integration of play into preschool curricula has also been problematized. Kuschner (2012) highlights the inherent contradictions between play, which is considered a natural component of early childhood, and educational processes within schools. In schools, the primary objective is to promote children's skill development in specific domains such as reading and math (Kuschner, 2012). Educational processes in schools need to be efficient, which seemingly contradicts the notion of learning through play. Thus, a tension between structured learning in primary school and play-based approaches in preschool might arise, which represents a challenge for both, educators and children, in the early years. However, forms of playful instruction (i.e., guided play) might be a compromise between playful approaches and structured learning.

Current literature on play defines play as a continuous construct with two poles (e.g., Zosh et al., 2018): On one side of the spectrum, there is free play, characterized by voluntary and internally motivated behavior initiated by the child. On the other side, there are structured and adult-directed forms of play with specific goals, known as playful instruction. Guided play is a form of guided instruction integrated into play, in which adults (e.g., parents or teachers) offer deliberate guidance and support during children's play activities (e.g., Zosh et al., 2018). As pointed out earlier, some researchers have criticized free play for being ineffective in terms of children’s learning outcomes (e.g., Kuschner, 2012). Guided play, however, strikes a balance between independent exploration in free play and the direction provided in teacher-directed play, allowing children to explore autonomously while also offering preschool teachers the opportunity to scaffold and promote specific learning objectives (e.g., Zosh et al., 2018). The idea, that adults or teachers engage collaboratively in play is expanded on by Trawick-Smith and Waite (2009), who highlight the importance of conducting play within a classroom environment that is theory-grounded, planned, and assessment-based. As pointed out earlier, the inquiry-based approach can serve as a method to provide children with developmentally appropriate science learning opportunities through play (e.g., Anderson, 2007; Haber et al., 2021) and this play-based approach has shown to foster children's learning in block play (Clements & Sarama, 2007; Giebitz, 2018; Lee & Kim, 2018; Weber et al., 2020).

To implement inquiry-based learning, the provision of adequate materials is inevitable. Toys are considered an integral component of play as they enable children to bridge the gap between the real world and their imagination (e.g., Akman & Özgül, 2015). For block play, curricula should include building blocks varying in shape (e.g., rectangular, triangular), color and weight (e.g., Weber et al., 2020). Moreover, additional material in the form of photographs or construction toys can be used to enrich children's play and to expand children's learning opportunities (e.g., inclusion of an inclined plane or additional weights for (de)stabilization). The provision of adequate and well-structured materials not only enriches children's play, it also facilitates preschool teachers' teaching practice (e.g., Nilsen, 2021). Furthermore, research indicates that preschool teachers place significant value on the availability and accessibility of play materials (Nilsen, 2021). They express that the scarcity of suitable materials to facilitate early science education is one of the primary reasons for their infrequent engagement in teaching early science (Sandstrom, 2012; Yildirim, 2021). The lack of appropriate resources hinders their ability to effectively incorporate science education into children's play, highlighting the need for easily accessible materials. Nevertheless, there is also evidence that preschool teachers do not use the science materials already available in their classrooms (Tu, 2006). This suggests that the use of science materials is not solely determined by their availability but rather by their accessibility in early science education.

Consequently, it is crucial to develop research-based curricula that incorporate appropriately structured materials and promote developmentally suitable practices such as play-based and inquiry-based learning. Such curricula should also support teachers in their roles of planning, organizing, and delivering high-quality early science instruction. To foster teachers' implementation of early science education, curriculum designs should be aligned with teachers' needs and provide them with the necessary tools and resources. In the present dissertation, all these aspects have been considered and a play-based block play curriculum, which contains appropriately structured materials, has been implemented and tested for its impact on preschool teachers' practice and children's learning. Further, the curriculum was enriched with information about verbal support, which has the potential to facilitate the implementation of developmentally appropriate practice.

2.3 Teacher professional training with curricula

The continuous development of teacher knowledge and skills is a fundamental aspect of teacher professionalization (e.g., Howes et al., 2012). The need for professional development arises from the fact that many teachers are not prepared to implement high quality teaching practice (e.g., Howes et al., 2012, Spektor-Levy et al., 2013; Yildirim, 2021). Curricula are thought to support teachers' practice as they provide subject-specific contents and materials, that should be taught in a specific manner (Darling-Hammond & Bransford, 2005). However, a curriculum does not dictate teachers' decisions during teaching (e.g., adaption of the content or provision of verbal support, sequencing of the material). Moreover, teachers differ in their knowledge regarding different learning areas, which might also affect the implementation of the curriculum material (Darling-Hammond & Bransford, 2005; Yildirim, 2021). To this end, curricula are often accompanied by professional development trainings, which aim at increasing teachers' knowledge about the curriculum and their knowledge about how to provide age-appropriate learning support to children (Darling-Hammond & Bransford, 2005; Garet et al., 2001; Howes et al., 2012).

On the backdrop of this, several studies have investigated what makes teacher training effective. Garet and colleagues (2001) have identified three core and three structural features that cause changes in teachers' knowledge and their classroom practice. First, teacher trainings need to focus on specific subject matters (i.e., math, science) to foster teachers' profound understanding of the content (CK). Most importantly, teacher trainings should also focus on teachers' understanding of how children learn to foster teachers' content-specific teaching skills (PCK). Second, teacher trainings should promote active learning by giving teachers the opportunity to observe experts and being observed, engaging in planning a classroom intervention, or leading a group discussion (Garet et al., 2001). Third, professional development should be coherent with other learning activities. This means that teacher training should build upon teachers' prior knowledge, align with national standards and include communication with other teachers, who are also willing to develop their competences (Garet et al., 2001).

Further, structural features also influence the effectiveness of teacher professional development. For example, the type of activity (e.g., workshops on the weekend or after work, outside or inside the classroom) has shown to be an important aspect for teachers' change in practice (Garet et al., 2001). Teacher trainings should be carried out during the day in teachers' classrooms to foster teachers' sense of coherence and the generalization of the training content for their daily work (Garet et al., 2001). Moreover, the duration of the training has shown to be an important factor, as longer trainings provide more opportunities for teachers to discuss the contents and to familiarize themselves with the new teaching practices (Garet et al., 2001). Also, collective participation (i.e., the participation of teachers from the same institution) is an important structural feature, as joint professional development has many advantages (e.g., discussing problems together, sharing experiences, providing feedback), which make it easier for teachers to engage in new teaching practices (Garet et al., 2001).

A similar framework for the effectiveness of teacher training can be found in Darling-Hammond and Bransford (2005), who propose that teacher trainings should include (a) connection and coherence (i.e., with real-life practice), (b) organized and well-sequenced content about the subject itself, children's learning process and the context, in which learning takes place and (c) a situation-based learning approach (i.e., practical application of the learning contents, learning in professional communities, construction of experiences). Further, Darling-Hammond and Bransford (2005) have proposed to integrate a meta-cognitive approach in professional teacher trainings, to help teachers to reflect their own learning.

In many teacher trainings, curricula are used to develop teacher's professional competences in a specified area. However, the curricula do not determine how teachers' implement the intended curriculum (e.g., Darling-Hammond & Bransford, 2005). For example, teachers might differ in their extent of learning support, their sequencing of the learning content or the appropriateness of their assignments (e.g., Darling-Hammond & Bransford, 2005). Further, preschool teachers differ in their CK and PCK and thus vary in their curricular planning, their understanding of educational goals, children's learning or of the curriculum itself (e.g., Darling-Hammond & Bransford, 2005). In line with this, empirical evidence points towards a discrepancy between the intended and the enacted curricula (e.g., Krajcik & Delen, 2017) and the implementation of the curriculum seems to be strongly influenced by the features of the curriculum's material rather than by the curriculum's learning objectives (e.g., Choppin et al., 2020). Moreover, professional trainings have been shown to differ in their effectiveness in changing teachers' knowledge or their practice (e.g., Diamond et al., 2014; Piasta et al., 2015; Studhalter, 2017). Thus, it is important to consider both, teachers' CK, PCK and teaching practice, as improvements in teachers' knowledge do not necessarily transfer into practice and vice versa.

In line with this, research has shown that high quality curricula alone are insufficient in changing teachers' practice and to ensure the promotion of high-quality early science (for an overview see Howes et al., 2012). Thus, in line with Garet and colleagues (2001), experts have advocated that science and math curricula should be implemented with teacher training, with a special focus on (a) math and science knowledge, (b) knowledge about age-appropriate learning approaches and (c) an understanding how children's learning can be supported (Howes et al., 2012). Trainings for preschool teachers should particularly focus on children's developmental trajectories in math and science learning and how to foster their learning in an age-appropriate way (Howes et al., 2012). Approaches, which have included age-appropriate learning support have shown to be successful in promoting effective teaching strategies which had, in turn, a positive effect on children's learning (e.g., Clements & Sarama, 2008; Lee & Kim, 2018).

Another important aspect, which is considered a critical component in teacher professional training with curricula, is promoting teachers' implementation fidelity (e.g., Howes et al., 2012). Research has shown that teachers' implementation fidelity was positively associated with children's outcomes (Hamre et al., 2010). Promoting teachers' implementation fidelity can be done by integrating within-activity curricular supports (e.g., recommending the use of specific language, making suggestions for altering or extending the activities in the curriculum; Howes et al., 2012) and by encouraging the transfer of teaching practices by providing examples within professional development trainings (Howes et al., 2012). Moreover, curriculum materials should not need extensive preparation and be easy to use so that teachers can focus on their practice (Howes et al., 2012). The present dissertation builds on the empirical findings about the effectiveness of teacher trainings with curriculum material in early science. In study 3, a teacher training was combined with parsimonious curriculum material in block play and effects on teachers' knowledge and practice as well as on children's learning were examined.

3. Children's knowledge in block play

3.1 Children's knowledge about stability in block play

The present dissertation examines children's knowledge of stability in block play as an important outcome. Studies have shown that young children have an intuitive understanding of stability in block play (e.g., Baillargeon et al., 1992; Bonawitz et al., 2012; Weber et al., 2020). For example, 6.5-month-old children looked longer at unstable trials compared to stable trials when a box was pushed over the edge of its supporting surface (Baillargeon et al., 1992). However, young children primarily hold misconceptions about stability (e.g., Weber et al., 2020). To assess the stability of a symmetrical object, it is sufficient to consider an object's geometrical center, which corresponds to a symmetrical object's center of mass (as depicted in figure 2). If the geometrical center is supported by a surface, the symmetrical object will remain stable. However, when assessing the stability of an asymmetrical object, it is necessary to consider the object's center of mass, which does not correspond to its geometrical center (see figure 2). If the center of mass is not supported by a surface, the asymmetrical object will tumble, regardless of the support for its geometrical center. In a study with 95 6-to 7-year-old children, Bonawitz and colleagues (2012) have examined children's balancing and identified three approaches to assessing stability: (1) evaluating stability based on the geometrical center, (2) using the object's center of gravity (mass) as an indicator of stability, and (3) a guessing pattern without a consistent theoretical basis.

Studies with infants commonly use habituation paradigms to examine their stability knowledge. Visual habituation paradigms hypothesize that infants will pay more attention to an unexpected event compared to an expected event. The average time infants spend looking at the unexpected stimuli is referred to as the dependent variable. Studies with infants aged 4.5- to 9.5-months old have shown that infants spent more time looking at (seemingly) unstable trials compared to stable trials and on impossible compared to possible events, respectively (e.g., Baillargeon et al., 1992; Baillargeon & Hanko-Summers, 1990; Needham and Baillargeon, 1993). It appears that infants rely on intuitive understanding of statics, however, their knowledge of stability is still developing. This is evident from their preference for symmetrical items and their equally long looking times for stable and unstable asymmetrical items (Baillargeon & Hanko-Summers, 1990).

Further, research has shown that 3-year-old children have a basic understanding of stability principles, such as the importance of a supporting surface and the role of gravity in keeping structures upright (Krist, 2010). 3-to 4-year-old children may initially understand balance in a simple sense, such as knowing that a structure will tumble if too much weight is placed on one side of the object. Children at that age were able to assess the stability of symmetrical items, however, they had difficulties in assessing the stability of asymmetrical items. Further, children’s performance significantly increased with age. The author states that children continue to play with blocks over time and thus develop more complex concepts related to stability. Children may also begin to consider the properties of individual blocks, such as size and weight, and how these properties can affect the stability of a structure and consequently, children build on their increasing understanding, (e.g., Bonawitz et al., 2012; Krist, 2010). Further, there is evidence that children's understanding of the concepts of geometrical center and center of mass in block play develops over time as they engage in hands-on experiences with blocks and other objects (Baillargeon et al., 1992, Krist et al., 2005; Krist et al., 2018).

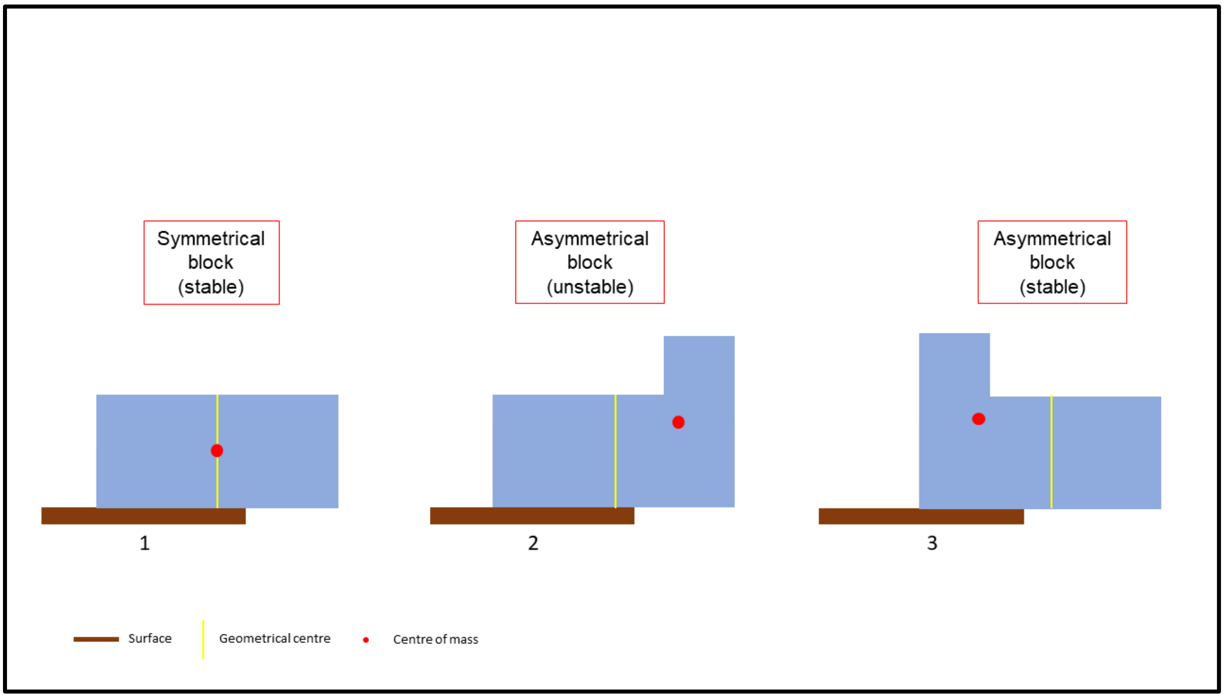

Figure 2. *Stability of symmetrical and asymmetrical blocks*

By around age 6 or 7, children's understanding of the difference between the geometrical center and the center of mass improves (Pine et al., 2007). Children at this age successively use this knowledge to predict and explain the stability of structures. For example, 6- to 7-year old children may understand that a tall, narrow tower will be less stable than a shorter, wider tower, even if both towers have the same geometrical center. Further, they can also understand that an object's center of mass can be manipulated by adding or removing blocks on one side of a structure, and that this affects the object's stability. Nevertheless, the results of Pine and colleagues (2007) revealed that children's speech predominantly revealed an undifferentiated pattern of guessing. This is also backed up by the results of a more recent study, which has indicated that half of the 5- to 6-years old children seem to have no consistent theory when assessing the stability of asymmetrical structures and that less than 10% of the children used a mass theory to explain stability (Weber & Leuchter, 2020). However, evidence suggests that children's acquisition of a center- or a mass theory can be fostered through play (5- to 6-year olds: Weber et al., 2020; 4- to 7-year-olds: Bonawitz et al., 2012). For example, in a longitudinal design, Weber and colleagues (2020) have shown that 5- to 6-year-old children’s acquisition of a mass theory can be supported by the experimenter through the means of guided play and material and verbal scaffolds. The percentage of children explaining their theory with mass increased from 16% at the pretest to 45% at the post-test and 49% in the follow-up in the experimental group receiving verbal and material scaffolds.

In conclusion, research has shown that block play provides an important opportunity for children to develop an understanding of stability. Inquiry-based and hands-on learning experiences can help children to internalize and remember stability knowledge and might build a foundation for future learning and achievement. Thus, the examination of children’s block building skills and particularly their stability knowledge is valuable in educational research. Study 3 focuses on preschool teachers support during block play and the effect on children’s acquisition of a mass theory.

3.2 Spatial language and math knowledge

Several studies suggest that block play can be used to enhance children's math (e.g., Clements & Sarama, 2007; Fisher et al., 2013; Lee & Kim, 2018; Schmitt et al., 2018; Verdine et al., 2014) and spatial skills (e.g., Borriello & Liben, 2018; Ferrara et al., 2011; Jirout & Newcombe, 2015). Spatial skills serve as a basis for math skills and children’s proficiency in math is a gatekeeper for later achievement and the acquisition of essential skills (e.g., Wolfgang et al., 2001). To this end, block play has successfully been integrated into early science curricula to promote children’s math learning (e.g., Clements & Sarama, 2007; Lee & Kim, 2018; Giebitz, 2018).

As pointed out earlier, block play presents opportunities for preschool teachers to engage in discussions related to numbers, such as counting blocks, geometric shapes (i.e., triangles and rectangles), measurements such as height (in centimeters), and performing basic math operations like addition and subtraction or to foster children’s math thinking by employing math language (e.g., Hornburg et al., 2018; Klibanoff et al., 2006; von Spreckelsen et al., 2019). Further evidence for the effectiveness of block play on children’s math proficiency stems from

Bower and colleagues (2020). In a cross-lagged-panel-design, their study showed that 3-year old children's structural complexity in block play (i.e., partial overlap and perpendicular arrangement) significantly predicted their spatial skills at the ages 3, 4 and 5 and their math skills at age 3. Besides, children's block building behaviors (i.e., reattachment, gaze time per trial and total time per trial) were associated with their spatial skills at age 3 and 5. Further, children's spatial and math skills were positively intercorrelated across time. This suggests that children a) benefit from block building activities not only in the stability domain and b) that the development of spatial and math skills can be predicted by structural complexity and behavior during block play.

Further, block play provides a valuable opportunity to promote early spatial learning in an age-appropriate manner (e.g., Borriello & Liben, 2018). Empirical studies have shown that both, spatial abilities and math knowledge are intertwined, as early spatial skills can serve as predictors of future math achievement (e.g., Moehring et al., 2021; Uttal & Cohen, 2012; Zhang & Lin, 2015). However, the present dissertation primarily focuses on children's spatial language development. There is evidence that the use of spatial language supports children's spatial reasoning and the development of spatial skills (e.g., Ferrara et al., 2011). This is backed up by other studies, which have demonstrated beneficial effects of math language and spatial language during block building activities on children's math and spatial skills (e.g., Ferrara et al., 2011; Fisher et al., 2013; Verdine et al., 2019; for an overview, see chapter 1.2.5 and 1.2.6). However, little is known about the use of spatial and math language in teacher-child interactions and about children's spatial language development in block play. The present dissertation addresses this research gap.

3.3 Cognitive prerequisites

The cognitive perspective on learning seeks to reveal the underlying mechanisms of knowledge acquisition and acknowledges the significance of children's prior knowledge for their learning (Schneider & Stern, 2010). Research suggests that prior knowledge influences learning outcomes, especially in STEM subjects (e.g., Betts et al., 2020). Thus, when examining children's knowledge, it is essential to consider children's prior knowledge and individual cognitive prerequisites, such as intelligence and working memory (Trundle & Saçkes, 2015). In the following, I will discuss three cognitive sub-aspects that play an important role in children's learning: fluid intelligence, crystallized intelligence and working memory.

3.3.1 Fluid Intelligence

Intelligence is considered one of the most important predictors for learning and future academic success (Fergusson et al., 2005; Schneider & Preckel, 2017). According to Cattell (1963) intelligence can be divided into two subfacets: fluid and crystallized intelligence. Fluid intelligence refers to an individuum's ability to solve problems in different contexts and to reason abstractly (Cattell, 1963). Thus, fluid intelligence involves the ability to adapt to problems in unknown contexts and is largely determined by biological factors (e.g., Kent, 2017). Fluid intelligence has been shown to gradually decline with age (e.g., Bugg et al., 2006; Wang & Kaufman, 1993) and is closely related to working memory capacity (e.g., de Abreu et al., 2010; Hornung et al., 2011; Kent, 2017; Yuan et al., 2006).

Cattell's theory identified more specific factors, which can be subsumed under fluid intelligence and which might be related to children's STEM learning (e.g., Newcombe et al., 2013). Subfactors strongly related to fluid intelligence encompass visual-spatial processing (i.e., the ability to perceive, analyze, and manipulate visual information and understand spatial relationships) and processing speed (i.e., the ability to quickly and accurately process cognitive tasks). When analyzing children's theories about stability, higher abilities to process visuo-spatial information and a higher processing speed might facilitate children's learning and theory acquisition about stability. Furthermore, children with higher cognitive abilities are likely to demonstrate greater improvements in areas such as math and language skills. Consequently, they might benefit more when participating in early science learning with their preschool teachers. Thus, in the present dissertation, children’s fluid intelligence was considered as a background variable.

3.3.2 Crystallized Intelligence

According to Cattell (1963), crystallized intelligence represents the accumulation of knowledge, skills, and expertise acquired through learning and experience. It includes vocabulary knowledge, general knowledge, and specialized knowledge in specific domains. Crystallized intelligence continues to develop and increase throughout a person's lifetime as they acquire more knowledge and expertise (e.g., Wang & Kaufman, 1993). Good indicators for crystallized intelligence are language capacity or general knowledge tests (Cattell, 1987). In the context of stability learning, children with higher crystallized intelligence might previously have acquired more knowledge about stability and thus might be able to faster adjust their theories by integrating new information more effectively (Thorsen et al., 2014).

3.3.3 Working Memory

Working memory, even when controlling for intelligence, is recognized as a significant factor in predicting children's academic achievement (Andersson, 2008). Evidence suggests that 5- to 7-year old children engage in similar cognitive working memory processes as adults, however, their attention span is still limited, which constraints a long recall in span tasks (Hornung et al., 2011). Research findings indicate that young children’s working memory is positively associated with their performance in math (Emslander & Scherer, 2022; van den Bos et al., 2013), language (St Clair-Thompson & Gathercole, 2006), and reading (Swanson, 2008; Titz & Karbach, 2014). Moreover, studies have demonstrated the relationship between children’s working memory and visuospatial and analytical problem-solving abilities (Fleck, 2008; Passolunghi & Mammarella, 2012). Children with a high working memory capacity may be better at understanding stability in block play due to their higher ability to store and manipulate information over short periods. These children might be able to retain and manipulate spatial information (i.e., positions and orientations of different blocks) more effectively, resulting in a better understanding and a faster adjustment of stability theories.

3.4 Academic self-concept

Children's academic self-concept plays an important role in children's learning, either as a moderating factor between children's abilities and their learning success or as an important outcome itself (e.g., Chapman, 1988; Shavelson et al., 1976). Self-concept refers to an individual's perception of themselves in specific domains, which is shaped by their interactions and experiences with their environment (Shavelson et al., 1976). Important characteristics of a person's self-concept comprise (a) its multidimensional structure (i.e., the distinction between academic and non-academic self-concept), (b) its hierarchical organization (i.e., one factor with several subdomains like math self-concept, science self-concept) and /c) its age-related development and stableness across life (e.g., Marsh & Shavelson, 1985; Shavelson et al., 1976). A person's academic self-concept is expressed through specific behaviors and is thus related to task performance (e.g., task choice, perseverance and time devoted to a task; Patrick & Mantzicopoulos, 2015). The reciprocal effects model postulates that achievement influences academic self-concept (skill-development model) and that academic self-concept influences achievement (self-enhancement model; Guay et al., 2003). Studies have shown that self-concept has an impact on academic achievement in language, math and science (e.g., Guay et al., 2003; Marsh & Martin, 2011; Wu et al., 2021).

Nevertheless, studies examining the association between self-concept and measures of achievement report rather moderate correlations between academic self-concept and general achievement. However, when subject-specific academic self-concepts (e.g., math self-concept) and outcomes are considered, the associations tend to be stronger (Valentine & DuBois, 2005). For example, the association between children's language self-concept and their science achievement is less strong compared to the association between children's science self-concept and their science achievement, due to distinctive reference processes, children use to evaluate their ability in different domains (Marsh, 1986).

Besides, research has shown that children’s academic self-concept tends to be overly positive (Harter, 2015; Weber & Leuchter, 2022). This seems to be predominantly caused by the mainly positive feedback children receive from their parents or preschool teachers and by children’s all-or-none thinking (e.g., Harter, 2015; Helmke, 1999; Weber & Leuchter, 2022). Further, studies suggest that young children’s self-concept can be divided into a motivational (e.g., how much do I like science?) and a competence component (e.g., how well do I perform in science?; Arens et al., 2016). Motivational beliefs are closely associated with children's intrinsic interest in a particular topic. Children, who exhibit interest in a specific subject, are more inclined to actively engage with the content and strive for a deeper understanding compared to those who lack interest (Renninger & Hidi, 2016).

Engaging in playful interventions using familiar materials, such as building blocks, might bear the potential to enhance children’s understanding of science concepts while simultaneously fostering their self-concept (Bonawitz et al., 2011; Zosh et al., 2018). Yet, the association between academic self-concept and achievement seems to be less clear for young children. For example, in block building, Weber and Leuchter (2022) investigated how various types of block play (i.e., free block play, guided block play with material scaffolds, guided block play with material and verbal scaffolds) influence the development of 5- to 6-year old children’s block-building self-concept and the acquisition of stability knowledge in a pre-post-follow-up design. They found a) overly positive self- concepts at begin of the study, b) a decline in children’s self-concept over time in the free play group and c) no associations between competence and motivational beliefs in the free and guided play groups. The decline of children’s self-concept is explained by failures children might have experienced in stabilizing their building blocks. However, the absence of reciprocal effects between academic self-concept and achievement was surprising. The authors state that reciprocal effects may develop as children grow older (e.g., Arens et al., 2016) and that their operationalization of self-concept might have missed out context-specific aspects, children focused on when engaging in block building (Weber& Leuchter, 2022).

Further evidence for the assumption of the emergence of reciprocal effects with increasing age stems from a study of Guay and colleagues (2003). The authors applied a multicohort-multioccasion-design with 385 children in grades 2, 3 and 4. Children’s academic self-concept as well as their achievement was measured three times in a 1-year interval. The findings of the study indicated that a) children's academic self-concept becomes more stable with age and b) that the correlation between children's academic self-concept and their academic achievement becomes stronger as children grow older. These findings highlight developmental trends in children's academic self-concept referred to by Arens and colleagues (2016) and Weber and Leuchter (2022) indicating an increase in the stability of children’s self-concept, and its alignment with academic achievement as children progress through age.

4. Research Questions

Based on the abovementioned findings, three main research questions arise, which contribute to both theoretical and practical implications while addressing existing research gaps. Fostering children's early science has been shown to be a significant predictor for later achievement (Kaderavek et al., 2020). Thus, preschool teachers need to have adequate knowledge about science concepts and on how to promote early science learning by considering children's cognitive prerequisites, their self-concept as well as developmental constraints (Trundle & Saçkes, 2015). Nevertheless, empirical evidence concerning the interplay between teachers' knowledge, beliefs and their teaching practice remains sparse (e.g., Akerson et al., 2010; Liu, 2011; Wilcox-Herzog, 2002). Thus, the first research question is concerned with the association between teachers' dispositions and their practice. To investigate these associations, the model of professional competence for preschool teachers proposed by Fröhlich-Gildhoff and colleagues (2011) was employed in study 1.

The second research question arises from the contradictory findings concerning the associations between preschool teachers' instructional quality and children's knowledge (e.g., Burchinal et al., 2008; Weiland et al., 2013). Study 2 provides initial insights into this relationship in block play and considers generic and domain-specific conceptualizations of preschool teachers' instructional quality. Domain-specific elements of instructional quality encompassed preschool teachers' verbal support during play (i.e., their use of scaffolding, spatial language and math language). As outcomes, children's, self-related aspects, as well as stability knowledge, spatial language and math knowledge were investigated. Further, children's intelligence was considered as a background variable.

The third research question arises from the finding. that curricula for the early years do not necessarily change teacher practice and indicate that teachers struggle with the implementation of the intended curricula (Krajcik & Delen, 2017). Moreover, science curricula specifically tailored for the early childhood years remain scarce to date. Existing curricula have typically focused on either enhancing children's learning outcomes or supporting teachers in their instructional practices, but rarely on both (e.g., Trundle & Saçkes, 2012). Thus, the third study is concerned with the effectiveness of a teacher training with a block play curriculum in changing teachers' knowledge and practice and whether the implementation of the curriculum has an effect on children's learning. Further, the effect of different teacher trainings on teachers' knowledge and their practice was investigated. Therefore, preschool teachers were assigned to three experimental groups, receiving either basic and additional training, basic training or no training. An overview of the three studies and their main findings is given in table 1.

4.1 Research Question I

As pointed out earlier, empirical evidence revealed contradictory associations between teachers' knowledge, their beliefs and their practice. Thus, the first research aim of the present dissertation is:

(1) How are preschool teachers' dispositions and their teaching practice interrelated?

In order to address research question 1, a multifaceted approach on teachers' disposition was adopted. This involved considering preschool teachers' beliefs, knowledge, and their willingness to participate in early science learning. In study 1, the structural validity of the instrument to assess willingness was examined with a confirmatory factor analysis. In a next step, bivariate correlations between teachers' dispositions and their practice were analyzed. Variables, that exhibited significant associations with willingness, were further investigated on their incremental validity via multiple regression analyzes.

4.2 Research Question II

The second research objective of the dissertation is to examine the associations between preschool teachers' instructional quality with children's knowledge and self-related aspects. The second research question is as following:

(2) Is preschool teachers' instructional quality related to

(a) children's domain-specific knowledge (i.e., stability in block play), their spatial language and math knowledge?

(b) Further, is preschool teachers' instructional quality related to children's academic self-concept?

Study 2 expands findings of the current literature on the interplay of teacher practice and children's knowledge. Further, study 2 makes a significant contribution to research on children's cognitive and self-related aspects and their associations with knowledge. The study takes a correlational approach and provides first insights into the manifold relations on an intraindividual level (i.e., associations between dimensions of instructional quality within teachers, and children's learning and its associations with cognitive and self-related aspects) and on an interindividual level (i.e., the associations between children's learning and teachers' instructional quality).

4.3 Research Question III

The third research question is concerned with the effects of a teacher training with a block play curriculum on teachers' knowledge and practice as well as on children's learning (i.e., stability knowledge, spatial language and math.) The third research question holds relevance in the context of early science teaching and learning, as there remains a notable gap in terms of validated curricula specifically designed for preschools. The third research question is as following:

(3) Is the implementation of a block play curriculum effective with regard to

(a) a change in preschool teachers' CK, PCK and practice (in free vs. guided play)?

(b) children's learning in stability, spatial language and math knowledge?

(c) Further, how do different teacher trainings affect teachers' practice in block play?

To address the third research question, in study 3, a longitudinal design was applied and methods of univariate and multivariate data analyzes were combined. Study 3 sheds light on important aspects of curriculum designs and teacher trainings, and how young children's learning can be enhanced.

	Article 1	Article 2	Article 3
Title	**Preschool teachers' pedagogical content knowledge predicts their willingness to engage in early science learning**	**First Insights into Preschool Teachers' Instructional Quality in Block Play and its Associations with Children's Knowledge, Interest, Academic Self-Concept and Cognitive Aspects**	**Preschool Teacher Training of a Block Play Curriculum in Kindergarten Enhances Preschool Teachers' Scaffolding Activities and its Implementation Promotes Mathematical Learning in Children**
Design/ Instruments	-Only pre-test -Questionnaire -Free play sessions (*N* = 73)	-Only pre-test -Free play sessions (*N* = 73) -children: COM, WVT, spatial language	-Pre/post/follow-up design -teachers assigned to three groups (EG1: training + modelling, EG2: training without modelling, CG: no training) -free and guided play sessions before and after training
Research Questions	(1) Can teachers' willingness be validly measured? (2) How are preschool teachers' dispositions and their practice interrelated? (3) Which variables have incremental validity concerning the prediction of willingness?	(1) Are there associations between children's learning and their cognitive and self-related aspects? (2) Are the different aspects of instructional quality intercorrelated? (3) Is there an association between teachers' instructional quality and children's learning?	(1) Is there a pre-post change in teachers' knowledge and their practice? (2) Are there differences in teachers' use of spatial language, math language and scaffolding between the groups and between guided and free play? (3) Are there differences in children's learning between the groups across time?
Methods	*N* = 151 preschool teachers RQ1: Confirmatory factor analysis RQ2: Correlational analysis RQ3: Multiple regression analyses	*N* = 73 preschool teachers *N* = 431 children RQ1: Correlational analysis RQ2: Correlational analysis RQ3: Multiple regression analysis	*N* = 74 preschool teachers *N* = 288 (t_1) children RQ1: one-way ANOVAs RQ2+3: Chi-square-tests, MANOVAs and multiple regression analysis
Results	(1) Willingness can be validly measured (2) No relations between teachers' dispositions and their practice (3) Co-construction and PCK predict willingness to engage in diagnosis/ PCK predicts willingness to engage in scaffolding	(1) Consistent interrelations between children's learning and cognitive/ self-related aspects (2) Different aspects of instructional quality are intercorrelated (3) Overall instructional quality predicts children's stability knowledge	(1) no change in teachers' knowledge, but: scaffolding in free play (post) > free play (pre) (2a) Free play: EGs > CG (scaffolding, spatial, math Language) & EG1 > EG2 (scaffolding) (2b) Guided play: more scaffolding, spatial and math language compared to free play & EG1 > EG2 (scaffolding) (3) significant increase in children's math knowledge in EG1&2 pre-and post-test

Table 1. Overview of the three studies

5. Article 1

Preschool teachers' pedagogical content knowledge predicts their willingness to engage in early science learning

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Abstract

Background

The importance of diagnostic and scaffolding activities for early science learning has been shown consistently. However, preschool teachers scarcely engage in them. We developed an instrument to assess preschool teachers' willingness to engage in diagnostic and scaffolding activities in science learning situations and examined its relation with teachers' knowledge, beliefs and practice.

Aims

We validate an instrument to assess willingness to engage in scaffolding and diagnostic activities and study the interplay between willingness, learning beliefs, content knowledge (CK) and pedagogical content knowledge (PCK) in the context of science learning, particularly block play.

Sample(s)

A total of N =151 preschool teachers from 41 kindergartens in Germany participated in our study.

Methods

Preschool teachers completed a questionnaire, which took approximately one hour of time. We drew a subsample of N = 73 teachers and observed their practice during a 30 min. block play episode.

Results

With our instrument, we were able to distinguish between preschool teachers' willingness to diagnose and to scaffold. Preschool teachers' co-constructivist beliefs and PCK predicted willingness to engage in diagnosing, PCK also predicted willingness to engage in scaffolding. Associations between learning beliefs and practice were inconsistent.

Conclusions

Our study highlights aspects of the association between preschool teachers' PCK and their willingness to engage in diagnosing and scaffolding. However, we found inconsistencies between preschool teachers' beliefs and practice, which call for further clarification.

Keywords: Scaffolding, Willingness, Preschool Teachers, Teacher Beliefs, Teacher Knowledge, Science Teaching, Block Play

5.1 Theory

Interest in early science learning has increased during the last years because preschool children's knowledge is predictive for later achievement and school success (e.g., Morgan et al., 2016; Trundle & Saçkes, 2015). There is growing consensus that science education should start early (e.g., Anders & Rossbach, 2015; Dunekacke et al., 2021, Möhring et al., 2021) and that early science should include inquiry-based and child-centred activities (Gropen et al., 2017). Appropriately structured learning situations are needed to support children's learning (Hadzigeorgiou, 2002). Thus, curricular guidelines call for promoting children's pre-academic skills (ECEC/ OECD, Anders, 2015). To foster children's learning, preschool teachers need to have content knowledge (CK), which refers to teachers' understanding of the subject matters' concepts, principles and theories, and pedagogical content knowledge (PCK, cf. Shulman, 1987), which refers to knowledge of effective teaching strategies such as scaffolding as well as techniques for assessing children's learning; Shulman, 1987). However, preschool teachers face problems supporting young children's learning, especially in the STEM fields, as they often feel ill-prepared for the task (Spektor-Levy et al., 2013).

Despite multiple empirical findings confirming the importance of science education (e.g., McCray & Chen, 2012; Möhring et al., 2021; Zhang & Lin, 2017), some preschool teachers still view science learning as inappropriate for the early childhood years (Park et al., 2017). The promotion of process skills (e.g., hypothesising) is usually neglected in early childhood education (LaParo et al., 2004). Traditional approaches focus on children's spontaneous activities that should be the root of kindergarten teaching and favour socio-pedagogic approaches (ECEC/OECD, Anders, 2015).

However, it remains unclear whether teachers' beliefs about early science learning transfer into a willingness to engage in science teaching (e.g., Buehl & Beck, 2015) and how their interplay affects preschool teachers' practice. Thus, we investigated beliefs, willingness to engage in early science, CK and PCK in a sample of $N = 151$ German preschool teachers and analyzed their practice $N = 73$ interactions. In Germany, children typically attend kindergarten from three to six years of age. With our study we focus on a clarification of the relationship between teachers' dispositions and practice.

5.1.1 *Willingness to Engage in Learning Situations*

Models of teachers’ professional competence (e.g., Baumert & Kunter, 2006; Blömeke et al., 2015; Gess-Newsome, 2015) assume that teachers’ performance in learning situations is determined by motivational-affective states (e.g., self-efficacy), knowledge facets (e.g., CK and PCK) and attitudes (e.g., learning beliefs). However, various studies have shown that these dispositions do not always influence teachers’ practice (e.g., Akerson et al. 2010; Blömeke, 2012; Liu, 2011; Wilcox-Herzog, 2002). A promising approach to explain the lack of correlation between teachers’ dispositions and their practice may be the theory of planned behaviour, which identifies willingness to bridge the gap between beliefs and practice (e.g., Fishbein & Ajzen, 2011, 2010; Fröhlich-Gildhoff et al., 2011). In our case, willingness represents the inner readiness to teach science although it is not mandatory (Heuckmann, 2020).

The explanatory power of willingness has been widely demonstrated in different contexts such as alcohol and drug use (e.g., Armitage et al., 2014), healthy nutrition (e.g., Zoellner et al., 2013), physical activity (e.g., Darker et al. 2010) or workplace health (e.g., Sheeran & Silverman, 2003). However, according to Cooper and colleagues (2016), the predictive power of willingness for teacher behaviour is less apparent than in other contexts because in teaching, there are many influencing factors (beliefs, CK and PCK) to consider (Chan & Lay, 2021; Lee, Cerreto, & Lee, 2010; van Aalderen et al., 2012). In the context of early science learning, empirical research and instruments to assess willingness are still sparse. Thus, we developed an instrument to assess willingness in the context of early science learning and to analyze its relationships with preschool teachers’ knowledge about early science and their learning beliefs.

5.1.2 *Preschool Teachers’ Knowledge About Science Teaching*

Studies suggest that preschool teachers' knowledge has an impact on the quality and frequency of science teaching and children's learning (Kallery and Psillos, 2001; McCray & Chen, 2012). Therefore, knowledge is considered an integral part of professional competence models and thus instructional quality (Fröhlich-Gildhoff et al., 2011; Baumert & Kunter, 2006). Studies demonstrate a considerable variance in preschool teachers' science-specific CK, PCK and their teaching (e.g., Barenthien et al., 2020; Pianta et al., 2008).

Research indicates that preschool teachers have low science CK (Garbett, 2003; Kallery and Psillos, 2001; Yildirim, 2021). CK has shown to be important for recognising learning opportunities in preschool, which are usually embedded in play situations (Dunekacke et al., 2015; Oppermann et al., 2016; Samuelsson & Carlsson, 2008). Hence, preschool teachers need to recognize these learning situations by carefully observing the situations and applying diagnostic strategies.

PCK is conceptualised as the subject-specific learning support provided by the teacher (e.g., Gess-Newsome et al., 2015; Leuchter et al., 2020), and is an important predictor for instructional quality and student's learning gains (Kunter, 2013; McCray and Chen, 2012). Diagnostic activities are regarded as a basis for fostering children's development and for the application of adequate scaffolding-techniques (e.g., Leuchter et al., 2020; van de Pol et al., 2010), and thus are important for preschool educational programs (e.g., Schmidt & Liebers, 2017). However, preschool teachers often lack PCK (Barenthien et al., 2020) to promote the development of science-specific procedural skills in kindergarten children and to foster their understanding (Piasta et al., 2014; Roth, 2014).

The benefits of scaffolding for children's learning have been shown consistently (Hong & Diamond, 2012; Leuchter & Saalbach, 2014; Weisberg et al., 2016). Studies report that children supported by scaffolding are more likely to develop science competences (French, 2004; Klahr et al., 2011; Samarapungavan et al., 2008). However, preschool teachers seem to face difficulties in supporting children's knowledge as a part of STEM even during everyday activities (Spektor-Levy et al., 2013). Moreover, scaffolding-techniques requiring high PCK were observed less than none-challenging teacher support (Leuchter & Saalbach, 2014).

In sum, studies suggest that preschool teachers' use of diagnostic and scaffolding activities in everyday situations and in science teaching are rare (Cabell et al., 2013; Leuchter & Saalbach, 2014; von Suchodoletz et al., 2014). Studies demonstrate that preschool teachers are in favour of organising play over supporting learning through diagnosing and scaffolding (Leuchter & Saalbach, 2014; Sylva et al., 2007). Drawing on the abovementioned findings, we can assume that a considerable amount of variance in the use of diagnostic and scaffolding techniques might be ascribed to preschool teachers' differences in CK (e.g., Barenthien et al., 2020) and PCK (e.g., Pianta et al., 2008).

5.1.3 *Teachers' Beliefs About Science Teaching*

Beliefs about learning and teaching are an integral part of teachers' competences (e.g., Leuchter et al., 2020) and influence professional practice (Richardson, 2003; Wilkins, 2008). Some authors have argued that teacher beliefs act as amplifiers and filters for teachers' professional practice (e.g., Buehl & Beck, 2015). Co-constructivist beliefs stress the importance of a dialogic and interactive process between teacher and child, in which knowledge is mutually constructed (Chi & Menekse, 2015). These beliefs encompass the view that children restructure their prior knowledge to generate coherent explanations, when supported by the teacher (Schmidt & Smidt, 2021).

However, hands-on activities are frequently mistaken as a form of co-constructivist learning (Haefner & Zembal-Saul, 2004). Constructivist beliefs are often contrasted with instructivist beliefs, which stress a teacher-centred view and conceptualise teaching as a unidirectional process (Schmidt & Smidt, 2021). Teachers who hold instructivist beliefs think that an informed adult transmits knowledge to children (Leuchter et al., 2020). Research indicates that this view is incompatible with science education that fosters children's understanding of science phenomena (Saçkes et al., 2011). Autonomy beliefs stem from a situation-oriented approach, which is particularly prominent in Germany (ECEC/OECD, Anders, 2015). These beliefs emphasise children's socio-emotional development whereas the development of early academic skills is less valued (Merkel, 2013).

Leuchter and colleagues (2020) have examined a Swiss sample of preschool teachers and differentiated between highly co-constructivist, low co-constructivist and instructivist beliefs, with the latter being the largest group. They found that teachers with high constructivist beliefs ranked highest in PCK. Rank (2009) has shown that most German preschool teachers engage in instructivist forms of learning. An international study has provided evidence that teachers with low CK and PCK tend to view learning from a transmissive point of view (Blömeke, 2012). However, a recent German study suggests that instructivist beliefs are less pronounced than previously thought, when being compared to co-constructivist or autonomy beliefs (Schmidt & Smidt, 2021). A Greek study implies that preschool teachers' beliefs towards teaching science are generally positive (Bourotzogluo et al. 2016), however, teachers were unwilling to spend time creating science learning materials and did not consider children's experimenting as an adequate way of learning.

The expectation that teacher beliefs directly transfer into practice is not met by empirical studies (Buehl & Beck, 2015). Some studies have shown weak associations between teachers' beliefs and self-reported teaching practice (Mohamed & Al-Qaryuoti, 2016; Stipek & Byler, 1997; Waters-Adams, 2006). Moreover, contextual conditions have shown to play a major role. Although preschool teachers can hold co-constructivist beliefs, they might not act accordingly, if their colleagues do not support co-constructivist beliefs or if the classroom requires a lot of organising and structuring (Hur et al., 2016; Kaufman & Moss, 2010; Stofflett & Stoddart, 1994).

Despite the small correlations reported in other studies, some authors advocate for the importance of teachers' beliefs for teaching practice (e.g., Maxwell et al., 2001). Studies with preschool and elementary school teachers have reported medium to high correlations between beliefs and observed instructional practice (Perren et al., 2017; Quance et al., 2008; Slot et al., 2015). In a Taiwanese study, Tsai (2006) found that teachers holding instructivist beliefs focused predominantly on student's test scores and viewed student's role as more passive. Moreover, classroom quality was higher for preschool teachers, who held child-centred beliefs (Pianta et al., 2005). Furthermore, preschool teachers who held developmentally appropriate beliefs, such as co-constructivist beliefs, engaged more in problem-based learning than teachers with instructivist beliefs (McMullen et al., 2006). Yet, when considering teachers from all grade levels, the association between practice and beliefs seems to be weaker for co-constructivist than for instructivist approaches (Mansour, 2013).

Empirical evidence points towards a complex association between beliefs and practice. Yet, teachers' willingness to engage in a specific practice could bridge the gap between their beliefs and enacted practice. As research has shown that preschool teachers tend to prioritize play-based activities (e.g., Leuchter & Saalbach, 2014; Sylva et al., 2007) we focus on the context of block play as an important aspect of science education (Weber et al., 2020).

5.1.4 *Block Play*

Studies on supporting knowledge through block play have focused on parent-child (Ferrara et al., 2011) or researcher-child interactions (Weber et al., 2020), while studies on teacher-child interactions during block play remain sparse. In block play, one of the central aspects is stability. To estimate stability of an asymmetrical block construction, knowledge about mass must be applied (CK). In this context, PCK can be understood as identifying the potential of block play for learning (e.g., mathematics, statics, language). We chose block play as an everyday kindergarten activity to assess preschool teachers' CK and PCK as well as their practice.

Drawing from the abovementioned findings, we aim to measure and test factorial validity of a newly designed test instrument to assess willingness to engage in scaffolding and diagnostic activities and study the interplay between willingness, learning beliefs, CK and PCK.

5.1.5 *Research Questions*

1. Does the instrument for assessing willingness differentiate validly between Diagnosis, Scaffolding and Inactivity?

2. How are preschool teachers' CK, PCK, learning beliefs, willingness and their practice (scaffolding) related?

3. Which variables showing significant bivariate correlations bear incremental validity in the prediction of willingness to engage in scaffolding, diagnosis and inactivity?

5.2 Methods

The research was conducted from January to July 2022 in *N* = 41 German kindergartens. The sample consisted of *N* = 151 preschool teachers. *N* = 85 preschool teachers provided demographical data (M_{age} = 35.76; SD_{age} = 13.18; 87% female; with a professional experience of M_{exp} = 12.85; SD_{exp} = 11.59 years). 83% had passed a vocational training programme, 5% held a university degree and 12% had any other professional qualification. All participants were informed about the goal of the study and consented to participation. The study was approved by the local Ethics Committee.

5.2.1 *Instruments*

Preschool teachers completed the 1-hour questionnaire on a tablet computer. The questionnaire was administered in German and the items were translated for this article. All reported scales were part of the questionnaire but were administered within different sections.

Willingness. We designed vignettes (VIG) that each displayed a playful science learning opportunity, which offered the chance to apply diagnostic and scaffolding techniques. In expert discussions, five science learning opportunities in preschool were identified which could be presented textually and graphically (VIG 1: stability and weight, VIG 2: magnetism, VIG 3: materials and their characteristics, VIG 4: stability in block play, VIG 5: marble run (inclined plane)). Research has shown that German preschool teachers favour autonomy beliefs (ECEC/OECD, Anders, 2015) and that diagnosing and scaffolding to support learning is not in the focus of preschool teachers (Leuchter & Saalbach, 2024; Sylva et al., 2007). On this basis, we distinguished three willingness dimensions: willingness to engage in diagnostic (DIA), scaffolding (SCAF) and inactivity (INA).

We conducted two pilot studies to test factorial validity of our self-developed instruments (PCK, willingness). In a first pilot study with 35 preschool teachers, a maximum-likelihood exploratory factor analysis tested for one-dimensionality of PCK. The one-factor-solution yielded a good fit ($\chi2$ (35) = 33.69, p = .531). However, our vignette-based approach had to be adapted considering the mediocre reliability of the items. After repeated expert discussion, we changed the item's wording to clarify their meaning. In a second pilot study with 40 preschool teachers (M_{age} = 40.10, SD_{age} = 12.10) we again tested reliability and dimensionality of willingness. Reliability for willingness was good (α_{DIA} = .93, α_{SCAF} = .82, α_{INA} = .82). The empirical BIC reached a minimum with three factors.

Before presenting this part of the questionnaire, we gave a brief introductory text which informed teachers that we wanted to explore their willingness to provide learning support in five typical preschool science activities. Each of the five vignettes consisted of a drawing, a short introductory text describing the situation and six items which the participants had to rate on 4-point-Likert-scales (1 = *don't agree at all*, 4 = *totally agree*; see Figure 1). Two items served as indicators for the diagnostic component (DIA) (e.g., *I would observe attentively what the children are doing*, α = .97, ($CI_{95\%}$ = [.96; .97])). Two items per vignette served as indicators for the scaffolding-component (SCAF, e.g., *I would have a conversation with the children about what they are doing right now*, α = .85, ($CI_{95\%}$ = [.82; .89])). Two items served as indicators for inactivity (INA) (e.g., *I would leave the children on their own*, α = .93, ($CI_{95\%}$ = [.91; .94])). The items across all five vignettes were aggregated to a sum score.

Imagine it is a quiet morning in your daycare center and the children are busy playing quietly with different materials in different places.
Below you see a situation of two (three) children and possible reactions of pedagogical professionals.
Now it is about your personal beliefs. Since this is about your very personal statements or opinions, there are no "right" or "wrong" answers. Simply give the answer to each question that most closely applies to you personally.

Caro, Kim and Luca are playing with building blocks. Kim says to Caro, "If you build it like this, it will fall down."

A: I would go and have a conversation with the kids about what they are doing right now.

B: I would leave the children alone.

C: I would encourage the kids to try next steps in what they do.

D: I would watch the kids silently and write down what they were doing.

E: I would keep the kids to themselves.

F: I would pay close attention to what the children were doing.

Figure 1. Example of a vignette. Answers A and C served as indicators for SCAF, D and F as indicators for DIA and B and E as indicators for INA. The participants had to rate their agreement with the statements on a 4-point-scale.

Pedagogical content knowledge. PCK items (Table 1) were designed with experts by focusing on content-related and process-oriented aspects that can be applied in block play with children aged three to six, such as mathematics or hypothesizing. PCK in block play was assessed by 10 items rated on a 4-point-Likert-scale (1 = *don't agree at all* and 4 = *totally agree*). The participants rated the appropriateness of different possibilities to support children's block play (see Table 1). We computed a sum score, ranging from 0 to 40. Internal consistency was α = .85, ($CI_{95\%}$ = [.80; .88]).

Table 1.

Items measuring preschool teachers' PCK.

Introductory Text	*Aspects*
A colleague has come up with a concept for block play with a group of children. Below is a list of aspects that your colleague wants to consider. How much do you agree with the ideas of the colleague?	-Physics
	-Systematizing and ordering
	-Spatial thinking
	-Comparing
	-Making assumptions
	-Fostering children's reasoning
	-Promotion of location and direction
	-Geometrical bodies and forms
	-Quantities, orders of magnitude, units of measurement
	-Language

Note. Preschool teachers' PCK was measured on a four-point-Likert-Scale (1 = don't agree at all and 4 = totally agree).

Teachers' beliefs. Teachers' beliefs were measured via 12 items adapted from Schmidt and Smidt (2021) on 5-point-Likert-Scales (1 = *don't agree at all*, 5 = *totally agree*). Three beliefs are distinguished: *co-constructivist beliefs* (e.g., *When supporting children, it is important that teachers and children find out something together*; α = .77, ($CI_{95\%}$ = [.69; .81])), *autonomy beliefs* (e.g., *When supporting children, it is important that teachers interfere as little as possible*; α = .57, ($CI_{95\%}$ = [.44; .67])) and *instructivist beliefs* (e.g., *When supporting children, it is important that the children are taught a lot by the teacher*; α = .78, ($CI_{95\%}$ = [.72; .83])). Despite of the low α for *autonomy beliefs*, we decided to maintain the three factors according to the developed instrument and the underlying theory.

Content knowledge. CK in block play was measured for block play with the Centre-of-Mass-Test (Weber & Leuchter, 2020, see Figure 2). The participants were asked to judge whether an asymmetrical block construction would fall or remain stable, if a black block was removed. The 16 items could only be correctly solved if knowledge about mass was applied. For every correct answer, participants were awarded one point. The resulting test score, ranging from 0 to 16, served as an indicator for preschool teacher's CK in block play. Internal consistency was α = .83, ($CI_{95\%}$ = [.82; .87]).

Figure 2. Example items of the COM-Test (A: unstable, B: stable).

Scaffolding practice. Furthermore, we drew a subsample of N = 73 preschool teachers who consented to be filmed and videotaped their interaction with a group of two to six children for 30 minutes. The subsample did not differ from the total sample in the relevant characteristics (age, willingness, beliefs, CK, PCK). Group sizes varied due to different kindergarten sizes, presence of the children at the day of data collection and parents who denied videotaping. Preschool teachers were instructed to play freely with building blocks. We applied a global rating of teachers' scaffolding activities to analyze whether they encouraged children to undertake further steps on a four-point-scale (1 = *very low*, 4 = *very high*, see Table 2). Interrater agreement was 95,7% (ICC = 0.99, F (22, 23) = 148.0, $p \leq .001$).

Table 2.

Rating of preschool teachers' scaffolding activity.

Rating of scaffolding activity	*Explanation*
1	Preschool teacher does not talk to the children about contexts, concepts are not or inappropriately taught.
2	Preschool teacher occasionally talks about logical relationships or concepts, some concepts are taught age and ability appropriate.
3	Preschool teacher talks about logical connections, children are encouraged to express their thoughts and supported by the preschool teacher when solving a problem.
4	Preschool teacher supports children's thinking throughout the play, concepts are introduced with reference to the children's situation and interests or to concrete problems that the children have to solve.

Note. Preschool teachers' scaffolding was rated independently by two raters on a four-point-scale (1 = very low, 4 = very high).

5.2.2 *Statistical Procedure*

The statistic program R, Version 4.2.1 (R Core Team, 2022) was used for data analysis. Missing values were imputed using the package "missForest" (Stekhoven, 2022). We decided to use non-parametric missing value imputation for mixed-type data as we had to deal with continuous as well as categorial variables. In a next step we recoded the items and estimated reliability by using the R-package "car" (Fox & Weisberg, 2019). For data processing and -preparation we used the packages "psych" (Revelle, 2022), "tidyverse" (Wickham et al., 2019) and "dplyr" (Wickham et al., 2022). To validate the instrument for willingness, confirmatory factor analyzes were carried out using the package "lavaan" (Rosseel, 2012). The model was evaluated by inspecting model fit indices (CFI, TLI, RMSEA, SRMR) additionally to the result of the χ^2-Test, as proposed by Hu & Bentler (1999). For data visualization, we used the package "ggplot2" (Wickham, 2016). To examine correlations, we used the package "apaTables"

(Stanley, 2021). To analyze incremental validity, we computed multiple regression. We checked bivariate correlations of predictors with the criteria to exclude suppression.

5.3 Results

5.3.1 *Descriptive Results*

The descriptive statistics are presented in Tables 3 and 4. First, we analyzed preschool teachers' learning beliefs. Preschool teachers' approval was highest for the co-constructivist belief and lowest for instructivist belief. Preschool teachers' willingness to engage in scaffolding activities was lower than their willingness to engage in diagnostic activities. Preschool teachers' CK in block play was rather low with $M = 10.03$ ($SD = 3.66$) dichotomous items solved out of 16. Participants performed slightly above chance level ($M = 0.63 > \mu = 0.5$; $t(150) = 6.81$, $p \leq .001$). PCK in block play was rather high ($M = 33.78$; $SD = 3.41$; $Max = 40$). Preschool teachers' scaffolding activity was moderate ($M = 2.15$, $SD = 1.06$, $Min = 1$, $Max = 4$).

Table 3.

Descriptive Results for Learning Beliefs.

	M	*SD*	*Min*	*Max*
Learning Beliefs				
To support children's learning and development it is important that…				
Co-constructivist beliefs				
- the children are encouraged by the teacher to find their own solutions	4.62	0.45	3	5
- teachers and children exchange information on an equal footing	4.48	0.52	3	5
- the children are made to think through the conversation	4.66	0.52	2	5
- teachers and children find out something together	4.21	0.72	2	5
Autonomy beliefs				
-the initiative comes from children	4.24	0.62	2	5
-teachers interfere as little as possible	3.69	0.68	1	5
-each child chooses his or her own tasks	3.74	0.61	2	5
-the children educate themselves from themselves	3.98	0.65	1	5
Instructivist beliefs				
-the teacher dictates what the children should do	1.92	0.72	1	4
-the children are taught a lot by the teacher	2.92	0.72	1	5
-the initiative comes from the teacher	2.49	0.64	1	4
-children carry out the instructions of the teacher	2.37	0.79	1	5
Co-constructivist beliefs	4.48	0.43	-	-
Autonomy beliefs	3.91	0.43	-	-
Instructivist beliefs	2.43	0.56	-	-

Note. Learning beliefs were measured on a five-point-Likert-Scale (1 = don’t agree at all, 5 = totally agree).

5.3.2 *Analyzes*

1. Does the instrument for assessing willingness differentiate validly between Diagnosis, Scaffolding and Inactivity?

We tested the instrument for assessing willingness for the suggested 3-dimensional model comprising Diagnosis (DIA), Scaffolding (SCAF) and Inactivity (INA). On account of the small number of observations (N = 151), the specified item-based model did not converge. Thus, 6 item parcels consisting of 5 items with two items per vignette per parcel were built. The first parcel consisted of the dimensions' first items and the second parcel of the dimensions' second items, aggregated over all 5 vignettes. The resulting 3-dimensional model yielded an acceptable fit (χ^2 (6) = 15.68, p = .016; CFI = .987; TLI = .967; RMSEA = .10; SRMR = .04). CFI, TLI and SRMR fell above the cut-offs proposed by Hu and Bentler (1999) and thus indicate a good fit. However, chi-square/df-ratio exceeds the factor 2. The RMSEA as a badness-of-fit-index was slightly above the recommended cut-off (.10). These deviations might be due to small degrees of freedom and sample size and do not necessarily indicate a bad fit (e.g., Kyriazos, 2018; Kenny et al., 2015). Thus, goodness-of-fit-indices and intercorrelations (Figure 3) suggest factorial validity of the 3-dimensional model, which is in accordance with the results of the exploratory factor analysis in our pilot study.

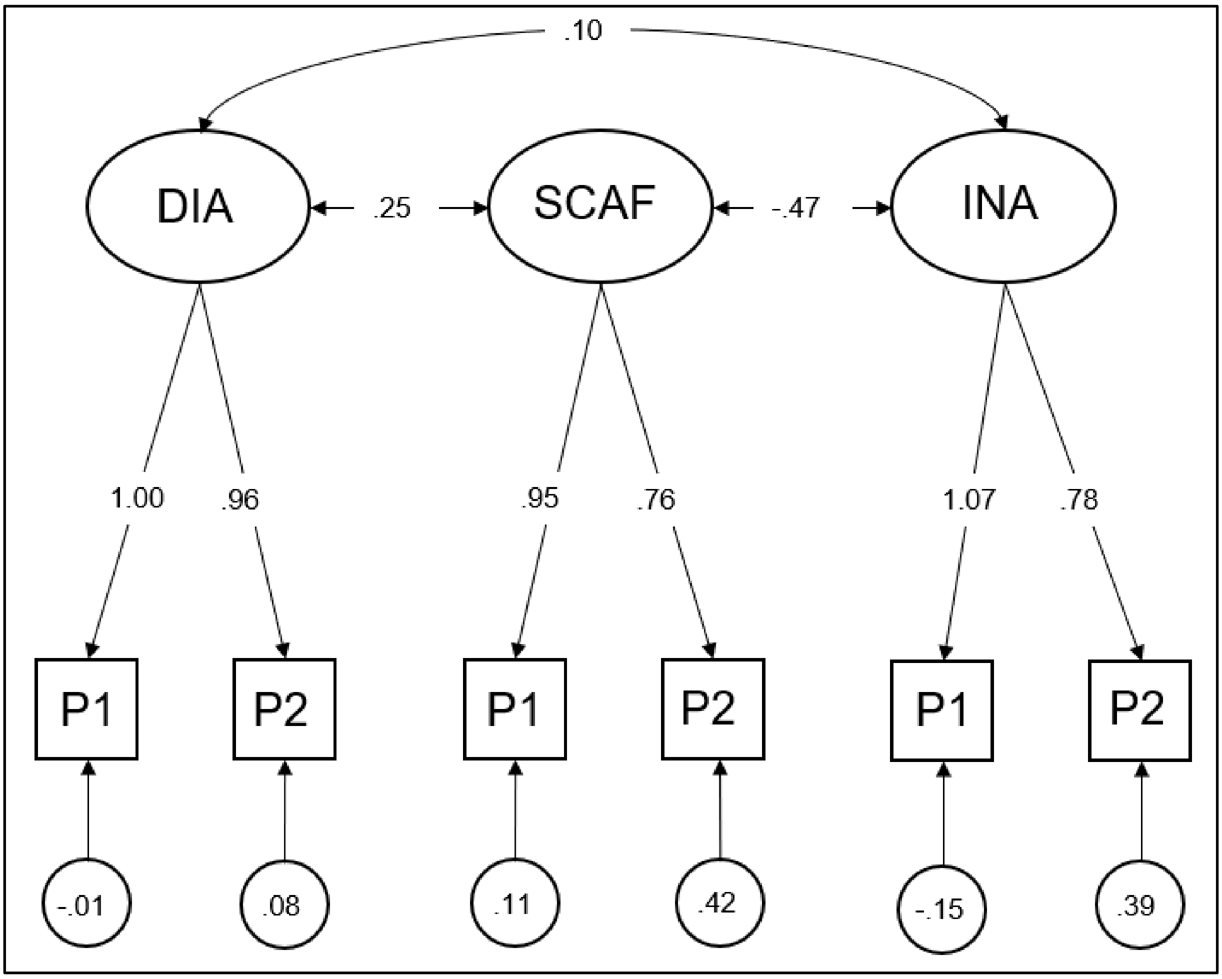

Figure 3. Factor loadings and residual variances of the tested 3-dimensional model.

2. How are preschool teachers' CK, PCK, learning beliefs, willingness and their practice related?

To answer the second research question, correlations between the investigated variables were examined based on *N* = 151 observations (Table 5). Co-constructivist beliefs were negatively correlated with age; however, co-constructivist and autonomy beliefs were positively related. The correlation between autonomy beliefs and instructivist beliefs was negative. Willingness to engage in DIA was positively correlated with co-constructivist beliefs, autonomy beliefs and PCK. Furthermore, willingness to engage in SCAF was positively associated with co-constructivist beliefs and PCK. PCK showed a negative association with INA and CK. Moreover, we examined the correlations between scaffolding performance measured via video analyzes (video) and all other variables based on *N* = 73 observations. Age correlated with scaffolding performance: the older the preschool teachers, the more they were involved in children's play by asking them questions and encouraging them to undertake further steps. However, the other variables were not significantly correlated. As group sizes varied substantially between preschool teachers, we examined the correlation between group size and preschool teachers' scaffolding practice, which was not significant (r = .04, p = .743).

Table 5.

Results of the correlation analysis.

	Variable	1	2	3	4	5	6	7	8	9	10
	1. age										
	2. diploma	-.10									
Willingness	3. DIA	.07	.07								
	4. SCAF	.11	.18	**.28**							
	5. INA	-.04	-.23	.12	**-.33**						
Learning Beliefs	6. instr.	.01	-.01	-.13	.04	.08					
	7. co-constr.	**-.27**	.07	**.40**	**.29**	-.10	-.18				
	8. autonomy	-.14	-.24	**.25**	-.14	.01	**-.38**	**.30**			
Knowledge	9. CK	.04	.16	-.15	-.11	-.22	-.11	.05	-.18		
	10. PCK	-.07	-.09	**.30**	**.32**	**-.26**	.12	.21	.05	**-.25**	
	11. video	**.46**	.05	.08	.08	-.05	.20	-.17	-.17	.04	-.03

Note. Significant correlations are printed in bold.

3. Which variables showing significant bivariate correlations bear incremental validity in the prediction of willingness to engage in scaffolding, diagnosis and inactivity?

Multiple regression analyzes were performed for the dependent variables with more than one significant correlation based on N = 151 observations (Table 3). Autonomy beliefs were not related to willingness when accounting for co-constructivist beliefs and PCK, which, in turn, were related to willingness to engage in DIA (Table 6). The model accounted for 25% of variance ($R^2_{adj.}$ = .25, F (3, 147) = 17.37, $p \leq$ .001).

Results suggested that co-constructivist beliefs were not related with willingness when accounting for PCK, which, in turn, was related to willingness to engage in SCAF (Table 7). The model accounted for 10% of variance ($R^2_{adj.} = .10$, F (2, 148) = 9.15, $p \leq .001$).

Table 6.

Results of the Multiple Regression Analyzes on DIA.

Variable	*B*	*SE(B)*	*t*	*p*
autonomy	0.17	0.20	0.85	.394
co-construction	0.89	0.22	4.11	≤.001***
PCK	0.34	0.10	3.37	≤.001***

Note. * $p < .005$, ** $p < .01$, *** $p < .001$.

Table 7.

Results of the Multiple Regression Analyzes on SCAF.

Variable	*B*	*SE(B)*	*t*	*p*
co-construction	0.17	0.20	0.86	.389
PCK	0.36	0.10	3.62	≤.001***

Note. * $p < .005$, ** $p < .01$, *** $p < .001$.

5.4 Discussion

Research on preschool teachers' willingness to engage in science learning situations has been sparse. Thus, the purpose of this study was to assess preschool teachers' willingness to engage in diagnostic and scaffolding activities through developing an instrument and to examine its relations to learning beliefs, CK, PCK and practice.

Our results show that our proposed 3-dimensional factor structure of willingness was valid. Teachers, who were willing to engage in diagnosis, were also willing to engage in scaffolding activities. However, when willing to engage in scaffolding activities, they were not willing to stay inactive. Moreover, our analyzes demonstrated that preschool teachers favoured to engage in diagnostic activities rather than to engage in scaffolding. We assume that preschool teachers' high willingness to engage in diagnosing is an indicator of the socio-pedagogic tradition in Germany (e.g., ECEC/OECD, Anders, 2015). From this tradition, leaving the children on their own and intervening as little as possible is an appropriate situation for diagnosing. Besides, willingness to stay inactive was slightly higher than willingness to engage in scaffolding, which further underpins this assumption. We cannot rule out that other pedagogic traditions might interfere with preschool teachers' willingness to engage in diagnosing or scaffolding differently and thus produce alternative results.

Moreover, we found consistencies within teachers' beliefs. The correlations between learning beliefs were coherent as we found teachers with co-constructivist beliefs to score higher in autonomy beliefs and to score lower in instructivist beliefs. Furthermore, our analyzes suggest that co-constructivist beliefs were more common than autonomy beliefs in contrast to the socio-pedagogic tradition in Germany (e.g., ECEC/OECD, Anders, 2015). This finding is in line with Perren and colleagues (2017) and Schmidt & Smidt (2021), who found that preschool teachers held mostly co-constructivist beliefs. Contrary to other studies, we cannot find empirical evidence that preschool teachers held instructivist beliefs (e.g., Leuchter et al., 2020; Rank, 2009; Yin et al., 2020).

The interplay between beliefs, willingness and practice was consistent as teachers with co-constructivist beliefs seemed to be more willing to engage in scaffolding. Besides, analogous to teachers' willingness to stay inactive, video analyzes uncovered that teachers' scaffolding activities were rather infrequent, which corresponds to current literature about preschool teachers' low instructional quality (e.g., Piasta et al., 2014; Roth, 2014). However, we also found inconsistencies when taking a closer look at the correlations between age, beliefs and practice. The older preschool teachers were, the less they valued co-constructivist beliefs. At the same time our video analyzes suggested that the use of scaffolding-techniques significantly increased with age. Moreover, co-constructivist beliefs did not predict preschool teachers' classroom practice. However, co-constructivist beliefs were positively associated with teachers' willingness to engage in diagnosis and scaffolding. Additionally, we found a positive association between preschool teachers' co-constructivist beliefs and their PCK which failed to meet the significance criterion. This finding is in line with the study of Leuchter and colleagues (2020) who found that teachers who held highly co-constructivist beliefs ranked higher in PCK. Nevertheless, when considering teachers' PCK, their co-constructivist beliefs did not predict their willingness to engage in scaffolding. However, both, co-constructivist beliefs and teachers' PCK related to their willingness to engage in diagnosis. This implies that teachers' PCK might be more important for their willingness to engage in diagnosis and scaffolding than their learning beliefs. A reason for this might be that teachers holding co-constructivist beliefs show lower associations between beliefs and practice than teachers holding instructivist beliefs (Mansour, 2013). In our study, the relation between instructivist beliefs and practice was positive but failed to meet the significance criterion. These results might reflect the high demands of putting co-constructivist beliefs into action. An additional issue may be that we analyzed our data across five science contexts while some authors have argued that beliefs represent context-specific assumptions (e.g., Leuchter et al., 2020). Besides, teachers' educational quality might differ in different situations (e.g., lunch time vs. block play; Reyhing

& Perren, 2023): Thus, the associations between teachers' dispositions (knowledge, beliefs) and their practice might be strongly dependent on the context.

Summarising, this study showed that PCK is related to preschool teachers' willingness to engage in diagnostic activities across science contexts as well as in block play. However, age was more important than PCK for teachers' use of scaffolding-techniques in block play. One explanation for the missing relation between preschool teachers' PCK and their practice might be that preschool teachers have difficulties in recognising science learning opportunities, which is a prerequisite to engage in learning support (Samuelsson & Carlsson, 2008). PCK is not only related to the implementation of scaffolding techniques but also to the sensitivity towards science contents and learning opportunities and exerts a cross-context influence on practice (e.g., Cabell et al., 2013; Hamre et al., 2014; von Suchodoletz et al., 2014). Interestingly, when we moved away from preschool teachers' self-reported dimensions, the associations between scaffolding practice and willingness to engage in scaffolding remained rather small. Hence, we corroborate research which has found small associations between teacher dispositions and practice (e.g., Mohamed & Al-Qaryuoti, 2016; Stipek & Byler, 1997; Waters-Adams, 2006).

5.4.1 *Limitations*

We employed five vignettes to measure willingness to engage in diagnosis and scaffolding. Hence, only a small number of science learning opportunities was examined. More vignettes with varying content and open-ended questions would increase the predictive power and validity of our study (e.g., including literacy and reading skills).

PCK was measured via statements of appropriateness, thus, preschool teacher answers might have been affected by social desirability. The same problem accounted for the self-report of willingness to engage in scaffolding. However, the detrimental effect of social desirability on validity seems to be smaller than previously thought (Paunonen & LeBel, 2012). As we decided to put willingness in the focus of our study, we applied a global rating of frequency and quality of scaffolding in our video analyzes. Future studies should examine scaffolding activities more precisely by considering appropriateness and sensitivity of timing. We might have missed context-specific characteristics, which could contribute to a clarification of the interplay between beliefs and practice. As data acquisition took place during the COVID-19-pandemic we had to deal with missing data which led to a reduction in sample size and to a loss of power for our statistical analyzes. To account for this circumstance, items for the CFA were parcelled and missing data were imputed. Nevertheless, the results of CFA were backed up by our pilot study. Future studies should examine more pathways, which mediate the association between dispositions and practice (e.g., self-efficacy; Reyhing & Perren, 2023).

5.4.2 *Conclusion*

Our findings contribute to the literature on early science education and preschool teachers' professional competences as the introduced instrument might be a promising and low-effort approach to measure preschool teacher's willingness to engage in early science learning. Our study addresses the gap between preschool teachers' dispositions (i.e., knowledge, beliefs, willingness) and their practice, which contributes to the literature on early science learning. We have shown that preschool teachers with higher PCK were more willing to engage in diagnosis and scaffolding. However, we found inconsistencies between preschool teachers' age, beliefs and practice, which calls for further clarification.

5.5 Literature

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6. Article 2

First Insights into Preschool Teachers' Instructional Quality in Block Play and its Associations with Children's Stability Knowledge, Motivation, Spatial Language and Math Achievement

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Abstract

Research findings: Promoting children's science knowledge by adequate measures such as guided or free play is a cardinal goal of preschool. However, there is considerable variability in preschool teachers' instructional quality in block play, which might be associated with children's domain-specific science skills but also their mathematic and language achievement. To examine preschool teachers' instructional quality in a free block play episode we used a video-based assessment. We assessed children's knowledge in block play along with mathematics, language capacity, self-concept and cognitive skills. In order to obtain first insights into the association between teachers' practice and children's knowledge, we took a correlational approach. The sample consisted of N = 73 preschool teachers and N = 431 children. The results revealed considerable differences between preschool teachers' instructional quality. Overall instructional quality during block play as well as specific dimensions such as the use of spatial language, math language and cognitive activating scaffolding were positively associated with children’s stability knowledge in block play. Moreover, preschool teachers’ general language use and stimulation of communication as well as their sensitivity were positively associated with children’s self-concept in block play.

Practice and policy: Our study emphasizes the importance of preschool teachers’ support for children’s knowledge and self-concept and expands prior findings on early science learning.

6.1 Theory

Promoting children's school readiness by age-adequate means is a fundamental goal of preschool. Teacher-child-interactions are considered a foundation for promoting children’s development in e.g., cognitive and motivational facets (e.g., Weisberg et al., 2016). Children develop their own intuitive theories to explain the world around them and continuously adjust these theories as they gain new knowledge (Gopnik and Wellman, 2012). To support children's science learning, it is important to consider developmental constraints and to incorporate everyday activities, such as play (Zosh et al., 2018). One way to implement early science learning with young children is through block play, which offers the opportunity to foster children’s concepts about stability, spatial knowledge as well as mathematical knowledge (e.g., Borriello & Liben, 2018, Casey et al., 2008; Levine et al., 2012; Gunderson et al., 2012; Park et al., 2008; Verdine et al, 2014; Weber et al., 2020). Spatial abilities are important prerequisites for children’s science, technology, engineering and math (STEM) learning (Uttal et al., 2013). Besides, children’s concepts about stability in block play are used in early science classrooms for example when integrating engineering play (e.g., Gold et al., 2020). Yet, research has shown that kindergarten-aged children predominantly hold misconceptions about stability (e.g., Weber et al., 2020). To further enhance children's learning, teachers can provide scaffolding during play, either through providing materials (e.g., building blocks) or through verbal support or through combining both (e.g., van de Pol et al., 2010; Weisberg et al., 2016). Most important, providing children with high quality learning support has been identified as a core aspect of preschool teachers' professional competence (e.g., Anders et al., 2013). However, preschool teachers face problems supporting children’s learning, especially in early science, as they often feel ill-prepared for the task (Spektor-Levy et al., 2013). Studies how a considerable variance in preschool teachers’ instructional quality in early science (Pianta et al., 2008) and in block play (e.g., Trawick-Smith et al., 2017).

To the best of our knowledge, there has been no study which has simultaneously investigated the association between preschool teachers' instructional quality in block play and children's learning of stability, mathematics and language. To date, most of the research on block play has focused either on its relationship to spatial skills (e.g., Casey et al., 2008; Ferrara et al., 2011; Yang & Pan, 2021) or to mathematics (e.g., Verdine et al., 2014). In our study, we considered $N = 73$ preschool teachers' instructional quality, and $N = 431$ children's knowledge, interest and self-concept in block play as well as mathematical skills, spatial language and cognitive abilities (fluid and crystallized intelligence and working memory).

Block play in kindergarten

Block play is considered to be an everyday situation in German kindergartens that teachers can use to interact with children and integrate early learning opportunities (e.g., spatial learning, mathematical learning). However, research on the frequency of block play in kindergartens remains sparse to date. There are studies advocating that preschool teachers use block play to foster children's mathematical and spatial learning, and particularly the development of social skills (for an overview, see Henschen, 2020). Socio-emotional approaches, which have been particularly prominent in Germany, prioritize the development of children's socio-emotional skills (ECEC/OECD, Anders, 2015). Nevertheless, preschool teachers' professionalization in the recent years has focused more on teaching early mathematics and science (Mischo & Froehlich-Gildhoff, 2011), albeit the transmission of pedagogical knowledge is still an overarching goal.

Instructional quality and child outcomes.

Preschool teachers' instructional quality has been of major interest in educational research and is discussed as one of the key determinants of children's learning gains (e.g., Schlesinger & Jentsch, 2016; Goble et al., 2019; Guo et al., 2011). However, there is little consensus about the conceptualization and measurement of instructional quality regarding context-specificity (i.e., subject-dependency), dimensionality (i.e., whether it is multifaceted and which dimensions should be considered) and observed practice (see the review by Senden et al., 2022). Research has shown that instructional quality is no one-way street and is determined by both, teacher and child behavior. For example, children's motivation has shown to have a positive impact on instructional quality (Scherer & Nilsen, 2016). Nevertheless, challenging learner's cognition by age-appropriate measures has been identified consistently as a core aspect of high instructional quality across classes and ages (Senden et al., 2022).

One way to provide challenging learning support may be through cognitive activating scaffolding (for an overview, see van de Pol et al., 2010). Based on van de Pols theoretical framework, there are studies, which have conceptualized scaffolding for early science learning (e.g., Leuchter et al., 2020; Monteira et al., 2020; Weber et al., 2020). Studies suggest that children benefit from verbal scaffolds during guided play more than when playing freely without verbal scaffolding (e.g., Fisher et al., 2011; Weber & Leuchter, 2020). In the context of block play, Weber and colleagues (2020) showed that children's learning can be fostered by verbal scaffolding techniques. For example, preschool teachers might activate prior knowledge or focus children's attention to facilitate their learning (e.g., Weber et al., 2020). Applying cognitive activating scaffolding encompasses the deliberate use of language to stimulate children's thinking (e.g., the use of spatial and mathematical language in block play). Spatial language refers to the use of words and phrases that describe the spatial relationships between objects, e.g., referring to height or spatial orientation of the blocks (e.g., Ferrara et al., 2011). Math language refers to the specific terminology used in mathematics, such as addition, subtraction, or geometric terms, e.g., when counting blocks or foster children's geometric understanding when comparing shapes (e.g., Ferrara et al., 2011; Klibanoff et al., 2006). Thus, spatial and math language can be used in block play to foster children's learning. In sum, teacher-led activities, which include cognitive activating scaffolding, enhanced teacher-child instructional quality (Smidt & Embacher, 2020). However, studies have shown that preschool teachers' use of cognitive activating scaffolds varies considerably (Hamre et al., 2014; Pianta et al., 2008).

Recent studies have focused on the association between teachers' general instructional quality and children's learning outcomes (Senden et al., 2022). However, research on a causal link between instructional quality and children's achievement is ambiguous. A study of Weiland and colleagues (2013) with 414 children attending Boston public preschools could not find any associations between preschool classroom quality and children's language, literacy or mathematical skills. Further, Duncan and colleagues (2015) examined whether the fading-out of rather short-term learning gains in preschool could be reduced by higher instructional quality and found no effect. However, research has shown that the quality of language and literacy instruction in preschool was commonly low, with only few teachers delivering high-quality instruction (Burchinal et al., 2008; Justice et al., 2008). This finding might account for the lack of significant associations between high quality teaching and children's learning gains. By contrast, Hall Kenyon and colleagues (2009) provide an alternative explanation for the lack of association between instructional quality and learning outcomes: They have shown that the impact of instructional quality on children's achievements is rather subject-specific than generic and related to the impact of other confounding variables (e.g., presence of children, full vs. half day classrooms and children's attentiveness and social background).

However, some studies have indicated that high-quality instructional interactions targeting children's higher order thinking, language and conceptual understanding were associated with positive outcomes for preschoolers (e.g., Kook & Greenfield, 2021). With the focus on language acquisition, preschool teachers' language and literacy instructional quality was positively associated with children's vocabulary gains (Guo et al., 2011). This finding is in line with the results of Mashburn and colleagues (2008) who have reported that preschool teachers' instructional interactions predicted preschoolers' language achievement and thus facilitated school readiness. Additionally, studies have revealed that sensitive and stimulating interactions fostered children’s language acquisition and pre-academic skills (Burchinal et al., 2008).

With the focus on math learning, several studies have shown positive associations between instructional quality and math achievement (e.g., Anders et al., 2013; Lehrl et al., 2016). Nonetheless, the quality of preschool teachers’ mathematical instructions has shown to be rather low (e.g., Cerezci, 2020). Two longitudinal studies have examined the effect of early mathematical instructional quality on children’s mathematical achievement in Germany. Lehrl and colleagues (2016) have found that instructional quality in preschool predicted children’s increase in mathematical knowledge in grade 1 to 3. Anders and colleagues (2013) could show that beneficial effects of high mathematical instructional quality in preschool lasted from age 3 at least until the end of the first class of elementary school. Moreover, this effect was independent of the instructional quality in mathematics in primary school and thus underlines the importance of fostering children’s early mathematical learning. These results are supported by Stipek and Chiatovich (2017) who have shown that high instructional quality in preschool predicts reading and mathematical achievement in class 3.

Preschool teachers need to apply a combination of verbal support, contingent feedback and sensitivity to provide effective teaching and to foster children’s self-concept and interest in science learning (Lepper et al., 2005; Stipek et al., 1995). Besides, research has shown that teachers’ general language use is associated with children’s academic outcomes, such as reading and general language skills (e.g., Dickinson, 2011; Dickinson & Porche, 2011). Furthermore, researchers in the field of early science learning argue that preschool teachers need to establish a joyful atmosphere, integrating early science learning into children’s play (e.g., Lepper et al., 2005; Samuelsson & Johansson, 2006). Additionally, findings suggest that teachers’ sensitivity in providing responsive feedback and warm interactions is an integral part of effective preschool teaching (e.g., Birch & Ladd, 1997; Downer et al., 2010). When teachers are sensitive to children's needs, they can create a safe and supportive learning environment that fosters children's self-concept and engagement in learning. A study by Pianta and Stuhlman (2004) found that preschool children who had sensitive teachers were more likely to be enthusiastic and engaged in learning activities, and less likely to display negative social behaviors in grade one. To account for these perspectives on instructional quality, there are instruments available to rate preschool teachers' use of language, teachers' stimulation of communication and their joy during teacher-child-interactions (e.g., Early Child Environment Rating Scale Revised Edition (ECERS-R), Harms et al., 1998; in German: Kindergarten-Skala. Revidierte Fassung mit Zusatzmerkmalen (KES-RZ), Roßbach et al., 2017), as well as sensitivity (Erickson-Scales, Egeland et al., 1990).

In sum, empirical evidence points towards an effect of instructional quality on children's domain-specific learning gains and self-concept. The combination of different conceptualizations may allow for a detailed and broad picture of teachers' instructional quality. Thus, we decided to take a multifaceted view on teachers' instructional quality by considering their use of language to stimulate children's thinking as well as their general language use, expressed joy and sensitivity to foster children's self-concept and learning. Nevertheless, the impact of teacher professionalization on children's learning gains is still a desideratum in educational research (e.g., Wullschleger et al., 2022). In our case, it remains unclear whether instructional quality in block play is associated with children's achievement of stability knowledge, mathematics and language skills.

Aspects of children's learning in the context of block play

Knowledge of stability. In our study, we focus on children's knowledge about stability. According to Bonawitz and colleagues (2012), three theories about stability can be differentiated: (1) the consideration of the geometrical center for assessing stability, (2) the use of an object's center of gravity (mass) for assessing stability and (3) an undifferentiated pattern of guessing with no consistent theoretical explanation. For the correct estimation of a symmetrical object's stability, it is sufficient to consider the object's geometrical center (see

Figure 1). If the geometrical center is supported by an underlying surface, the symmetric object will remain stable. However, for the correct estimation of an asymmetrical objects' stability, the objects' mass distribution must be considered, because their geometrical center does not correspond to their center of mass. If the center of mass is not supported by an underlying surface, the asymmetrical object will tumble, regardless of the support of its geometrical center (see figure 1).

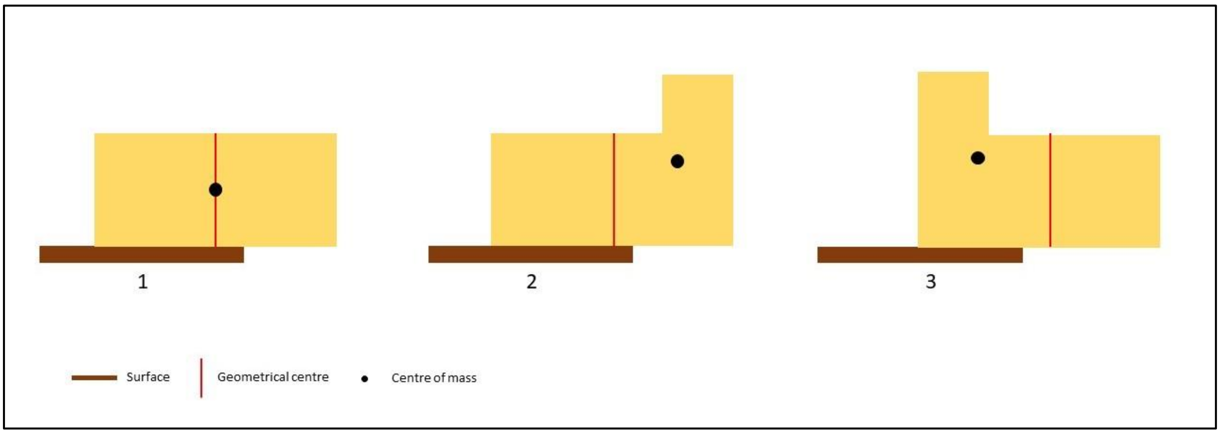

Figure 1. Stability of symmetrical (1 on the left, stable) and asymmetrical objects (2 in the middle, unstable, 3 on the right, stable).

Weber and colleagues (2020) have shown that more than half of 5- to 6-years-old children did not use a consistent theory to predict stability and less than 20% of the children could be classified as mass theorists. 43% were identified as center theorists (Weber et al., 2020). The finding that most pre-school children do not use mass theory to predict stability is supported by other studies (e.g., Bonawitz et al., 2012; Krist et al., 2018; Krist, 2013; Krist, 2010; Krist et al., 2005). Moreover, research has shown that children perform better on symmetrical objects than for asymmetrical ones (Krist, 2010; Krist et al., 2005). Although the studies used different paradigms to assess children's knowledge about mass such as pictures (Weber and Leuchter, 2020), real stimuli (Krist, 2010, 2013), physical action (Bonawitz et al., 2012; Krist et al., 2005) or eye-tracking (Krist et al., 2018), they all reflect young children's limited capability to consider an object's mass when assessing stability. There is evidence that children's use of mass theory increases with age (Bonawitz et al., 2012; Krist et al., 2018; Krist et al., 2005) and can be fostered by playful interventions (Pine & Messer, 2003). However, these studies neglect ecological validity and thus do not integrate preschool teachers' instructional quality in block play when analyzing children's stability knowledge. Yet, the substantial variability of preschool teachers' instructional quality in block play (e.g., Trawick-Smith et al., 2017) might be associated with children's theories about stability.

Spatial language. Block play bears the opportunity to foster spatial learning with a low-threshold and age-appropriate approach (Borriello & Liben, 2018; Ferrara et al., 2011; Jirout & Newcombe, 2015). For example, preschool teachers can use spatial terms referring to height or spatial orientation of the blocks (e.g., Ferrara et al., 2011) or apply cognitive activating scaffolding measures that encourage children to give explanations or evoke their prior knowledge about spatial principles (e.g., Weber and colleagues, 2020). Language in block play can include positions of objects in relation to each other, geometric properties, distances, units of measurements and prepositions (Cohen & Emmons, 2016; Ferrara et al., 2011). There is evidence that the use of spatial language supports children's spatial reasoning and the development of spatial skills (e.g., Ferrara et al., 2011). Moreover, spatial skills are an integral predictor of young children's later science and mathematics achievement (Uttal & Cohen, 2012). However, studies on supporting spatial knowledge through block play have focused on parent-child (Borriello & Liben, 2018; Ferrara et al., 2011) or researcher-child interactions (Weber and colleagues, 2020), while studies on teacher-child interactions during block play remain sparse (Casey et al., 2008). However, the variance of preschool teachers' use of spatial language might be associated with children's language development and their spatial skills (e.g., Casey et al., 2008).

Mathematical knowledge. Studies have demonstrated that a semi-structured block play intervention can foster children's mathematical knowledge (Schmitt et al., 2018). Further evidence for the effectiveness of interventions in the context of block play for math achievement stems from studies which have employed building blocks and geometric shapes (e.g., Fisher et al., 2013; Verdine et al., 2014). Additionally, studies suggest that children's early spatial skills are predictive for later math achievement (e.g., Moehring & Ribner, 2021; Zhang & Lin, 2017). Quantitative and spatial words related to mathematical skills are typically labelled as "Math Talk" (e.g., Klibanoff et al., 2006). Block Play bears the opportunity to talk about numbers (e.g., counting blocks), geometric shapes (e.g., triangles, rectangles), measures (e.g., height in cm) or to carry out basic mathematical operations (e.g., addition, subtraction). On this basis, we assume that children's achievement not only in stability knowledge but also in math language and corresponding spatial knowledge might be fostered through block play. Research has shown that the amount of Math Talk predicts children's growth in mathematical knowledge (e.g., Hornburg et al., 2018; Klibanoff et al., 2006; Moffett & Eaton, 2017; von Spreckelsen et al., 2019). However, the amount of mathematical language seems to vary considerably between preschool teachers (Johnston & Degotardi, 2022; Klibanoff et al., 2006; Rudd et al., 2008).

Interest. Children show a natural interest in science phenomena such as block play which is a good starting point for the promotion of their science knowledge (e.g., Trundle & Saçkes, 2015). Children who are interested in a particular topic are more likely to engage with the content and seek deeper understanding than children who are uninterested (Renninger & Hidi, 2016). Therefore, it is probable that children with higher levels of interest in the stability of blocks perform better than uninterested children in stability knowledge, in spatial language and corresponding math knowledge. For block play, research has shown a greater interest for boys to play with blocks (Saracho, 1994; Weber & Leuchter, 2020).

Self-concept. Research has shown that block play is a motivating context for children's learning (Weisberg et al., 2016). According to Marsh and colleagues (2002), the academic self-concept is made up of competence and motivational beliefs and regarded as an important component of children's development which are associated with performance (e.g., Marsh et al., 2012). There is evidence that girls' self-concept in block play is less pronounced than those of boys (Weber & Leuchter, 2020). Science-self-concept is closely related to motivation as children favor activities, in which they are convinced of their capability to be successful (e.g., Marsh et al., 2012; Weber & Leuchter, 2020). This association seems to strengthen over time, especially in elementary school (Wigfield et al., 1997). However, preschool children in general tend overestimate their skills, leading to rather high self-concepts in early science (e.g., Harter, 2015).

Intelligence and working memory. A considerable variance in children's achievements is explained by cognitive variables (e.g., intelligence), which is one of the most important predictors for learning and later academic achievement (e.g., Fergusson et al., 2005; Schneider & Preckel, 2017). According to Cattell (1987), fluid intelligence consists of the ability to think logically and to solve problems independently of previously acquired knowledge. Fluid intelligence comprises figural reasoning and perception and might thus be associated with children's stability knowledge and math knowledge. Besides, we expect substantial correlations between children's crystalline intelligence and their use of spatial language, as language-related subtests are usually used as indicators for crystallized intelligence (e.g., Petermann & Daseking, 2018). Moreover, higher crystallized intelligence should facilitate children's learning not only in a specific domain, but also in other pre-academic fields (e.g., mathematics). Crystallized intelligence increases with age and depends, compared to fluid intelligence, more on external factors (Rindermann et al., 2010), and might thus be associated with teachers' support. Accordingly, research has shown that crystallized intelligence is less associated with working memory than fluid intelligence (Swanson et al., 2008).

Working memory is considered to be an important factor as well when predicting children's achievement even if studies control for intelligence (e.g., Andersson, 2008). Findings suggest that young children's working memory exerts an influence school achievement in mathematics (e.g., Emslander & Scherer, 2022; van den Bos et al., 2013), language (e.g., St Clair-Thompson & Gathercole, 2006) and reading (Swanson, 2008; Titz & Karbach, 2014), respectively. Furthermore, research has shown that working memory is related to visuospatial and analytic problem-solving (e.g., Fleck, 2008; Passolunghi & Mammarella, 2012). Therefore, we examined the association between children's working memory and their stability knowledge in the context of block play.

Rationale of the study. In our study, we have focused on children's cognitive and self-related aspects in the context of block play as gatekeepers to STEM-learning. The importance of self-concept, interest and motivation for STEM learning has been shown consistently (cf. Guo et al., 2015; Marsh et al., 2012). Based on the reciprocal effects model proposed by Marsh and Craven (2006), there is a mutual relationship between academic self-concept and knowledge acquisition in a specific area, such as block play. Consequently, children's academic self-concept affects subsequent knowledge acquisition, and vice versa (Marsh et al., 2012). Children with a strong self-concept and interest in block play might tend to engage in block building activities more frequently and may challenge themselves with more difficult tasks (e.g., Weber et al., 2022). These children may display a greater willingness to take risks, experiment with different approaches, and persist in problem-solving, as they are motivated by their own internal drive and enjoyment of the activity. Their confidence in their abilities may contribute to a more intensive engagement with block play, fostering opportunities for skill development. However, despite the growing body of research on the potential impact of block play in fostering spatial learning, spatial language, math knowledge, and stability knowledge (e.g., Borriello & Liben, 2018; Fisher et al., 2013; Park et al., 2008; Weber et al., 2022; Wolfgang et al., 2001), there is still a lack of studies exploring the connection between young children's self-concept and their skill development. Thus, we examined whether children's self-concept was associated with their skill development, i.e., knowledge about stability, spatial language and math knowledge. Besides, by incorporating spatial and mathematical vocabulary associated with the height or orientation of blocks (Ferrara et al., 2011) or basic mathematical operations (e.g., Klibanoff et al., 2006) and employing cognitive scaffolding strategies that prompt children to articulate and utilize their existing spatial knowledge (Weber et al., 2020), preschool teachers have the potential to enrich spatial learning experiences. Studies indicate that the integration of spatial language facilitates the advancement of children's spatial reasoning abilities and skill development (Ferrara et al., 2011). From that, we assume that children’s spatial language ability might be associated with their stability knowledge too. Children’s spatial skills, in turn, have shown to be associated with interindividual differences in math knowledge (e.g., Bull et al., 2008; Rittle-Johnson et al., 2019). Hence, we examined the interplay between children’s math knowledge, spatial language and stability knowledge. Moreover, cognitive components (i.e., intelligence and working memory) were considered as background variables, which may influence children’s knowledge acquisition (Thorsen et al., 2014). Ultimately, research has shown that teachers’ instructional quality and the use of cognitive activating scaffolding (Hamre et al., 2014; Pianta et al., 2008), spatial language (cf. Casey et al., 2008) and math language (Johnston & Degotardi, 2022; Rudd et al., 2008) varies considerably. However, it remains unclear whether teachers’ overall instructional quality or specific dimensions of instructional quality are associated with children’s cognitive or self-related aspects. Nevertheless, studies have indicated that structured interventions with building blocks and geometric shapes can enhance children's stability knowledge (e.g., Pine & Messer, 2003; Weber et al., 2020), spatial knowledge (Ferrara et al., 2011) and math knowledge (Fisher et al., 2013; Schmitt et al., 2018).

Given these theoretical assumptions, we aim to provide first insights into the associations between children’s cognitive and self-related aspects (research question 1) as well as the associations between preschool teachers’ instructional quality in block play and children’s self-concept, stability knowledge, their spatial language, and their math knowledge (research questions 2 and 3).

Research questions.

1. Are there associations between children's stability knowledge, their spatial language, their math knowledge, interest and self-concept in block play, fluid and crystallized intelligence and working memory?
2. How frequently do preschool teachers use instructional strategies (i.e., use of language to stimulate communication, sensitivity) in block play are there associations between their aspects of instructional quality and the use of spatial language, math language and scaffolding?
3. Are there associations between preschool teachers' instructional quality (overall and specific) and children's stability knowledge, interest, self-concept, spatial language, and math knowledge?

6.2 Methods

The research was conducted from January to July 2022. The sample consisted of N = 431 children (207 boys and 224 girls; M = 71.31 months, SD = 7.67, Min = 52, Max = 91) and N = 73 preschool teachers. Prior to the start of the study, 80 kindergartens in the surrounding area (+-50km) were contacted and informed about the project. A total of 40 kindergartens consented to participating in the research and assisted in establishing contact with the children and their parents. In Germany, data on ethnicity is typically assessed by asking children what language they speak at home. N = 353 children reported German as their mother tongue and N = 78 children as their second language. The preschools were situated either in small villages (< 5.000 habitants, n = 9), a medium-sized city (< 50.000 habitants, n = 13) or a large city (> 100.000 habitants, n = 18). Some children had missing values on some of the items e.g., since they expressed dissatisfaction during testing or fell ill. Therefore, the number of participants varies depending on the analyses. All children participated voluntarily in the study and with their parent's written consent. In advance, the study was approved by the local Ethics Committee.

Instruments

The assessment took about 60 minutes per child and was conducted as single interviews on a tablet computer. The assessment of children's knowledge took place before the video was taken. First, the experimenter established a good relationship with the child by asking about his or her interests in general. Breaks were taken frequently during the assessment, either when the child was tired or if loosing attention.

Knowledge of stability. We assessed children's stability knowledge with the 16 items Center-of-Mass-Test (COM-Test; Weber & Leuchter, 2020). Children had to decide whether an asymmetrical construction of building blocks would remain stable (8 items) or fall over (8 items) when a black block was removed (see Figure 2). To reply the items correctly, children had to consider an object's center of mass. Please note that the probability to solve an item by chance is 50%, which might impair internal consistencies. Internal consistency was for stable items α_{stable} = .65; and for unstable items $\alpha_{unstable}$ = .60.

Figure 2. Example items of the COM-Test (A: unstable, B: stable).

Interest in block play. We assessed children's interest in block play via seven picture-based items (Webeer & Leuchter, 2020). The children were asked whether they preferred playing with blocks or playing with any other material (e.g., playing with dolls or reading a book). Internal consistency was α = .64.

Self-concept. Self-concept in block play comprised competence beliefs (12 items, e.g., "how much do you already know about building with blocks") and motivation in block play (9 items, e.g., "show me how much you would like to learn more about building with blocks"; Weber & Leuchter, 2020). Children were shown two identical looking dolls. The interview was framed within a fictional story (e.g., "Kiki already knows a lot about building with blocks. Kora doesn't know so much about building with blocks yet. What about you? Do you already know a lot about building with blocks or do you not know so much about building with blocks?"). In order to reply children had to point on a triangle, which ranged from 1 ("not at all") to 4 ("very much"). Internal consistency was α = .90.

Spatial language. We assessed children's spatial language with a self-developed test. Based on the categorization system of Cannon and colleagues (2007). The first task was concerned with "shapes and bodies" and the children were asked to identify a certain shape by pointing (8 items, e.g., "show me the square"). The second task was concerned with "locations and directions”. The children had to place a toy figure in a certain way on a game board by considering various aspects of the environment (10 items, e.g., “can you put the figure to the left of the horse?”). The third task was concerned with “spatial properties and dimensions”. The children were asked to state the correct response by pointing (8 items, e.g., “can you show me which of these lines are parallel?”). Internal consistency was α = .80.

Mathematical knowledge. Mathematical knowledge was assessed with the Würzburger Vorschultest (WVT, Endlich et al., 2015). We applied four tasks: *counting* (14 items, e.g., “can you count the candles on the cake?”), *comparison of quantities* (8 items, e.g., “on which side are more biscuits”), *addition and subtraction* (14 items, e.g., “how much is 7 plus 2?”) and *word problems in mathematics* (7 items, e.g., “Stefan has 8 biscuits. He has 3 more biscuits than Lisa. How many biscuits does Lisa have?”). Internal consistency was α = .91.

Intelligence and working memory. Intelligence was assessed with the German version of the Wechsler Preschool and Primary Scale of Intelligence, Fourth Edition (WPPSI IV; Petermann & Daseking, 2018). We applied three subscales (*matrices* (26 items), α = .88; *vocabulary* (31 items), α = .89; *working memory* (35 items), α = .89). The matrices test served as an indicator for children’s fluid intelligence (Cattell, 1987). The vocabulary subscale comprised crystallized intelligence (Cattell, 1987). The working memory subscale was a delayed retrieval test, which asked children to store as many elements as possible. For all three subscales the assessment was ended once the child replied to three consecutive items incorrectly.

Videotaping. To examine preschool teachers’ instructional quality in block play we videotaped N = 73 interactions between preschool teachers and groups of two to six children each. Every interaction was limited to 30 minutes (M = 28.48, SD = 0.14). The groups assessed varied in size due to different preschool group sizes, number of children present on the day of data collection or number of filming permissions granted by parents. Preschool teachers were instructed to play with the children with a standardized set of 140 provided building blocks. We applied four subscales of the German version of the *ECERS-R* (Kindergarten Einschätzskala (KES-RZ), Roßbach et al., 2017) and the *Sensitivity and Timing for Instruction Scale*, which was derived from the Erickson Scales (Egeland et al., 1990) as a global rating over the whole videotaped sequence. Moreover, splitting the videos into 10-second-sections, we examine the amount of spatial language following the coding system of Cannon and colleagues (2007) and mathematical language following Klibanoff and colleagues (2006) and of cognitive activating scaffolding techniques following Weber and colleagues (2020). Table 1 shows an overview of the scales examined. Three raters were trained in the category system in a training session lasting several hours. First, 5 videos that were not part of the later analysis were coded independently and then problems and contradictions in the category system were identified, discussed and eliminated. In a next step, all three raters independently coded 20 of the 73 videos analyzed (27.40%). Interrater reliability was measured via Krippendorff's Alpha coefficient and was good with $\alpha_{Krippendorff}$ = .80 (Krippendorff, 2004).

Table 1.

Examined variables of preschool teachers' instructional quality in block play.

Category	Scale	Derived from	Range	Explanation
Aspects of Interaction Quality (KES-RZ)	*Stimulate Communication*	*KES-R* (Roßbach et al., 2017)	1 = *inadequate* 3 = *minimal* 5 = *good* 7 = *excellent*	e.g., the teacher rarely/frequently encourages children to communicate. Suggestions for communication are appropriate to the age and abilities of the children.
	General Language Use	*KES-R* (Roßbach et al., 2017)	1 = *inadequate* 3 = *minimal* 5 = *good* 7 = *excellent*	e.g., the teacher talks little/much with the children, asks questions that require longer answers and also has individual conversations.

	Interaction Between Teacher and Child	*KES-R* (Roßbach et al., 2017)	1 = *inadequate* 3 = *minimal* 5 = *good* 7 = *excellent*	e.g., the teacher is inattentive/ attentive in contact with the children, verbal and non-verbal messages are contingent. The teacher enjoys interacting with the children.
	Sensitivity and Timing in Instruction	*Erickson Scales* (Egeland et al., 1990)	1 = *inadequate* 3 = *minimal* 5 = *good* 7 = *excellent*	e.g., teacher consistently provides hints which are well-timed and well-suited to the efforts of the child with appropriate content at appropriate times.
Spatial Language	*Spatial Dimensions*	Cannon and colleagues (2007)	0-†	e.g., big, small, wide, size, length, height, volume
	Shapes and Bodies	Cannon and colleagues (2007)	0-†	e.g., circle, square, sphere, cube, pyramid
	Place and Direction	Cannon and colleagues (2007)	0-†	e.g., towards/away, inside/outside, below, space, distance
	Spatial properties	Cannon and colleagues (2007)	0-†	e.g., round, curved, even, odd, smooth, circular
Math Language	*Quantities*	Klibanoff and colleagues (2006)	0-†	e.g., whole/all, part, piece, section, half/ third
	Scale units	Klibanoff and colleagues (2006)	0-†	e.g., centimeter/meter/ millimeter
	Mathematical operations	Klibanoff and colleagues (2006)	0-†	e.g., more/ plus, less/ minus

	Reflecting back children's statements	Weber and colleagues (2020)	0-†	e.g., you just said that you think the building will not stay/fall
	Encouraging children's further thinking	Weber and colleagues (2020)	0-†	e.g., that was a good idea of yours. Now think even further. What else could happen?
	Activating prior knowledge	Weber and colleagues (2020)	0-†	e.g., have you seen this before?
Cognitive activating Scaffolding	*Fostering assumptions*	Weber and colleagues (2020)	0-†	e.g., what do you think, will it hold or fall?
	Encouraging comparisons	Weber and colleagues (2020)	0-†	e.g., look! What is the difference between X and Y?
	Asking for precise explanations	Weber and colleagues (2020)	0-†	e.g., what have you found out? Why is it stable/ unstable?
	Modelling	Weber and colleagues (2020)	0-†	e.g., the building blocks don't always have to lay with the middle on the surface to stay stable. If the heavier side hangs in the air, it is unstable.
	Directing children's attention towards relevant aspects	Weber and colleagues (2020)	0-†	e.g., look at the stone that lies above the red stone. (Accompany the child's gestures).

Note. 0-† = indicates the scale range, which is limited to the number of 10-second-blocks per video.

Statistical procedure

For data analysis, we employed the statistical software R, Version 4.2.1 (R Core Team, 2022). We recoded reverse-framed items and estimated reliability by using the R-package *car* (Fox & Weisberg, 2019). For data processing and -preparation we used the packages *psych* (Revelle, 2022) and *dplyr* (Wickham et al., 2022). Effect sizes were determined with the package *lsr* (Navarro, 2015). To address our research questions, we computed correlations using the package *apaTables* (Stanley, 2021). Moreover, we computed a global sum score of preschool teachers' instructional quality by subsuming all subscales from the KES-RZ, sensitivity and use of spatial language, math language and cognitive activating scaffolding.

6.3 Results

Descriptive results

Children's test scores. The descriptive statistics of children's test scores are provided in Table 2. Children's knowledge in block play exceeded the mean slightly, however, the difference from the scale mean (μ = 8) was significant (8.36 > 8; t (367) = 4.29, $p \leq .001$). According to Cohen (1988) we found a small effect of $d = 0.22$. Interest in block play was rather low, however, self-concept in block play was high. A slight ceiling effect occurred in the spatial language test, nevertheless, there was considerable variance in children's spatial language. The remaining variables were within a medium range.

Table 2.

Descriptive statistics for children's test scores.

Test	*M*	*SD*	*Min*	*Max*	*Scale Range*
Knowledge $_{\text{Block Play}}$	8.36	1.60	3	14	0-16
Spatial Language	19.47	3.58	4	26	0-26
Mathematics	15.66	8.07	3	41	0-43
Interest $_{\text{Block Play}}$	2.48	1.77	0	7	0-7
Self-Concept $_{\text{Block Play}}$	69.85	11.77	21	84	21-84
Fluid Intelligence	13.01	4.94	0	23	0-26
Crystal. Intelligence	17.09	6.10	0	27	0-31
Working Memory	15.52	5.45	1	29	0-35

Note. *M* = Mean, *SD* = Standard Deviation, *Min* = Minimum, *Max* = Maximum. *Scale Range* indicates the minimum and maximum number of points to be achieved.

Intercorrelations of children's test scores. To address the first research question, we computed the correlations of children's test scores (Table 3). Children's stability knowledge, their spatial language mathematical skills and the WPPSI-IV-subscales (fluid, crystallized intelligence and working memory) significantly increased with age. The intercorrelations between fluid intelligence, crystallized intelligence and working memory were positive and thus indicated intelligence-related convergent validity. All three subscales of the WPPSI-IV were associated with children's spatial language and their mathematical achievement. Children's knowledge in block play was associated with their mathematical test score and age, respectively. Boys were more interested in block play than girls and tended to perform better in mathematics than girls. Children who spoke German as their mother tongue tended to be better in the spatial language test, mathematics and crystallized intelligence, respectively, with the latter relying heavily on language skills too.

Table 3.

Correlations of children's test results and demographical data.

Variable	1	2	3	4	5	6	7	8	9	10
1.Stability Knowledge										
2.Spatial Language	.02									
3. Mathematics	**.14***	**.50****								
4. Interest Block Play	.10	.08	**.20****							
5. Self-Concept Block Play	-.02	.04	-.04	.02						
6.Fluid Intelligence	-.02	**.32****	**.44****	-.01	-.00					
7.Crystal. Intelligence	.02	**.60****	**.45****	.05	-.08	**.43****				
8.Working Memory	.01	**.23****	**.24****	-.01	-.05	**.37****	**.25****			
9. Age	**.12***	**.22****	**.40****	-.02	-.05	**.32****	**.34****	**.21****		
10. Language	.03	**.48****	**.16****	.11	.05	.07	**.38****	.08	-.04	
11. Sex	-.05	.04	**-.17****	**-.56****	-.03	.07	.05	.03	.02	.02

Note. *Sex* = male (0) and female (1), *Language* = indicates whether the child speaks German as a mother tongue (1) or as a second language (0). * indicates p <.05. ** indicates $p < .01$.

Preschool teachers' instructional quality. The descriptive statistics for preschool teachers' instructional quality in block play are provided in Table 4. Preschool teachers frequently stimulated children's communication, were rather sensitive in their timing and instruction and made use of age-appropriate and child-centered language (Table 4). There was a considerable amount of variance in preschool teachers' spatial language, math language and cognitive activating scaffolding use, on an interindividual (between teachers) and on an intraindividual (between categories) level, respectively (Table 4). Overall, preschool teachers employed spatial language within 19.29 % of the 10-second-sections. Math Language (3.03 %) and cognitive activating scaffolding (4.65 %) were employed quite seldomly.

Table 4.

Descriptive Statistics of Preschool Teachers' Instructional Quality in Block Play.

Scale	*M*	*SD*	*Min*	*Max*	*Scale Range*
Stimulate Communication	6.36	1.01	3	7	1-7
General Language	5.85	1.28	0	7	1-7
Interaction	6.22	1.49	1	7	1-7
Sensitivity	4.32	1.22	1	6	1-7
Spatial Language	33.37	23.08	2	125	0-†
Math Language	5.25	4.92	0	21	0-†
Scaffolding	8.04	7.26	0	45	0-†

Note. General Language = general language use, *Interaction* = interaction between teacher and child. *M* = Mean, *SD* = Standard Deviation, *Min* = Minimum, *Max* = Maximum. *Scale Range* indicates the minimum and maximum number of points to be achieved, *0-†* = indicates the scale range, which is limited to the number of 10-second-blocks per video.

Intercorrelations of preschool teachers' instructional quality dimensions. To address the second research question, we computed preschool teachers' correlations between dimensions of instructional quality (Table 5). Preschool teachers' cognitive activating scaffolding in block play was significantly associated with the use of spatial and mathematical language and sensitivity and timing in instruction. The latter association can be interpreted as an aspect of convergent validity too. Furthermore, the more teachers stimulated communication, the better scored was their general language use and their sensitivity and timing in instruction. Sensitivity and timing in Instruction, in turn, was associated with all variables.

Table 5.

Correlations of preschool teachers' instructional quality in block play.

Variable	1	2	3	4	5	6
1. Stimulate Communication						
2. General Language	**.43****					
3. Interaction	.18	.20				
4. Sensitivity	**.51****	**.38****	**.51****			
5. Spatial Language	.22	.18	**.33****	**.43****		
6. Mathematical Language	.01	.21	**.33****	**.25***	**.63****	
7. Scaffolding	.21	.21	.11	**.31****	**.65****	**.32****

Note. General Language = general language use, *Interaction* = interaction between teacher and child. * indicates $p < .05$. ** indicates $p < .01$.

Associations between instructional quality and children's outcomes. To address the third research question, we first examined the relationship between preschool teachers' overall instructional quality in block play and children's stability knowledge in block play, language and math as well as their interest, motivation and self-concept in block play. Since the number of participating teachers per preschool differed, the sum scores were standardized by dividing them through the number of participating teachers per preschool. The results are provided in Table 6. Preschool teachers' global instructional quality in block play has shown to be positively correlated with children's stability knowledge.

Table 6.

Correlations between children's test scores and preschool teachers' overall instructional quality.

Variable	1	2	3	4	5
Overall Quality	**.18****	.03	-.08	-.04	.07

Note. 1 = Stability Knowledge, *2* = Spatial Language, *3* = Mathematics, *4* = Interest in Block Play, *5* = Self-Concept (Block Play). * indicates $p < .05$. ** indicates $p < .01$.

In order to obtain an in-depth insight into the association between teachers' instructional quality and children's achievement, we determined correlations between particular dimensions of preschool teachers' quality and children's test scores (Table 7). All dimensions of preschool teachers' specific dimensions of instructional quality in block play were associated with the following children's block-play-associated outcomes: knowledge in block play (1), spatial language (2), mathematics (3) and self-concept (5). Spatial and Math Language as well as cognitive activating scaffolding were positively associated with children's knowledge in block play (1). The use of math language and cognitive activating scaffolding had the largest shared variance with children's stability knowledge ($R^2_{MathLanguage} = .03$; $R^2_{Scaffolding} = .03$). To examine the interplay between the significantly correlated variables spatial language, math language and cognitive activating scaffolding and their association with children's stability knowledge, a multiple regression analysis was carried out. The results revealed that only cognitive activating scaffolding remained a significant predictor of children's knowledge when considering all three variables simultaneously (β = .13, *t* (352) = 2.28, *p* = .023). The multiple regression model accounted for 3% of the variance (R^2 = .03, *F* (3, 352) = 3.89, *p* = .009).

Furthermore, preschool teachers' stimulation of communication was positively associated with children's spatial language skills (2). Additionally, preschool teacher's general language use, interaction, sensitivity and timing in instruction as well as math language were positively associated with children's self-concept (5). Since these four preschool teachers' variables were intercorrelated, we checked for unique effects in a multiple regression on children's motivation. However, the unique effect of none of the predictors contributed significant. The combination of all four preschool teacher variables accounted significantly for 2% of the variance, which was not significant (R^2 = .02, *F* (4, 333) = 1.60, *p* = .175).

Table 7.

Correlations between specific dimensions of preschool teachers' instructional quality and children's test scores.

Variable	1	2	3	4	5
Stimulate Communication	.08	**.19****	.07	-.08	.10
General Language	-.03	.02	<.01	.02	**.14***
Interaction	.07	.02	-.01	-.10	**.13***
Sensitivity	.07	.09	-.02	-.10	**.14***
Spatial Language	**.13***	.06	-.03	-.08	.01
Math Language	**.17****	-.09	**-.15***	.05	**.12***
Scaffolding	**.16****	-.02	-.07	.05	.02

Note. General Language = general language use, *Interaction* = interaction between teacher and child. *1* = Stability Knowledge, *2* = Spatial Language, *3* = Mathematics, *4* = Interest in

Block Play, *5* = Self-Concept (Block Play). * indicates p < .05. ** indicates p < .01.

6.4 Discussion

Instructional quality has been of major interest in educational research and is critical for children's learning achievement (e.g., Schlesinger & Jentsch, 2016; Guo et al., 2011). However, considerable variance in preschool teachers' instructional quality in early science has been shown in a range of studies (e.g., Pianta et al., 2008). Moreover, research has shown that instructional quality is depends on the interplay of teacher and child behaviors (e.g., Scherer & Nilsen, 2016). We examined preschool teachers' instructional quality in block play as an aspect of science teaching and learning on children's achievement by considering children's cognitive and motivational variables. On the backdrop of three research questions, we found that (a) there are positive associations between children's stability knowledge with math knowledge and age, (b) specific aspects of preschool teachers' instructional quality are positively intercorrelated, whereas the association between teachers' cognitive activating scaffolding and spatial language was the strongest and (c) preschool teachers' cognitive activating scaffolding was positively associated with children's stability knowledge when controlling for spatial and math language in a multiple regression model. Furthermore, our results suggest that several aspects of preschool teachers' instructional quality are associated with children's self-concept. Our findings are in line with previous research and provide a deeper insight into a widespread early science learning opportunity such as block play. Our study sheds light on how to support preschool children by examining the association between specific aspects of instructional quality and their association with children's stability knowledge and self-concept.

Children's achievement and associated variables

Firstly, our research indicates that children's stability knowledge is limited as they performed only slightly above the scale mean on the test employed. Therefore, we conclude that most preschool-aged children either show no concept of mass or that they use an object's geometrical center to assess stability. This is in line with previous research on children's stability knowledge which suggests that the majority of children at this age do not yet understand this concept (e.g., Bonawitz et al., 2012; Krist et al., 2018; Weber et al., 2020). Moreover, research has shown that children adjust their theories about stability when they are faced with counterevidence to their concept in everyday life, progressively integrating them into their theories, which leads to improved predictions (Bonawitz et al., 2012). In our study, we replicated the evidence of increasing performance with age (Bonawitz et al., 2012; Krist et al., 2018). From this, we may conclude that children in our study might have had the opportunity to engage in block play prior to our examination.

In our research, stability knowledge was positively associated with math knowledge, and age. One math task (*comparison of quantities)* was to estimate the amount of cookies on two images shown at the same time on the left and right side of a separator bar. This task i required the same set of abilities as our stability test, where the children were asked to determine which side of a symmetrical or asymmetrical structure had more blocks, which may have contributed to this correlation.

Spatial language and math knowledge both correlate positively with fluid and crystallized intelligence, working memory and age. The positive correlation of all variables with age can be explained with a maturation effect. Moreover, children's logical reasoning (i.e., fluid intelligence), their vocabulary (i.e., crystallized intelligence) and working memory have shown to be integral parts of mathematical understanding and language capacity in previous studies (e.g., Schneider & Preckel, 2017; Liao et al., 2015). Besides, boys tended to outperform girls in the math test and showed significantly more interest in block play. Interest in block play was positively associated with math knowledge, which, in turn, was positively associated with stability knowledge. This indicates that boys higher math achievement might result from mediation effects between interest on stability knowledge and math knowledge, which, in our correlational design, cannot be tested for. One might hypothesize that boy's higher math achievement is mediated by interest, consequently, they might seek deeper understanding compared to girls (e.g., Renninger & Hidi, 2016).

As expected, children's self-concept in block play was considerably high, which emphasizes children's tendency to overestimate their skills and to engage in all-or-none thinking (e.g., Harter, 2015). Their overly positive self-concept might be explained by the absence of objective feedback until the entrance of primary school (e.g., due to the absence of grades).

Preschool teachers' instructional quality

Preschool teachers' variability of the frequency of spatial and math language and cognitive activating scaffolding use was considerable. They rarely applied spatial language, math language and cognitive activating scaffolding. Few preschool teachers did scaffold children's cognition up to 45 times in the 30 minutes block play episode. However, most of them used cognitive activating scaffolding rarely or hardly at all. With this, we were able to corroborate previous research, which has shown that instructional quality between preschool teachers varies considerably and reflects preschool teachers' difficulty to provide challenging learning support (e.g., Hamre et al., 2014; Klibanoff et al., 2006; Pianta et al., 2008; Spektor-Levy et al., 2013). Spatial and math language were also used rarely. However, spatial language was applied more often than math language. Both, spatial and math language correlate with cognitive activating scaffolding supporting the assumption that they represent an essential aspect of preschool teachers' cognitive activating scaffolding. Thus, in line with other research, cognitive activating scaffolding can be understood as encompassing the use of adequate language to foster children's thinking (e.g., Ferrara et al., 2011; Weber et al., 2020).

Overall, preschool teachers' general use of language could be classified as age-appropriate according to the KES-RZ-scale (Roßbach et al., 2017). Further, preschool teachers' stimulation of communication and their verbal and nonverbal contingency to children's reactions were classified as high (sensitivity and timing in instruction scale, Egeland et al., 1990). Preschool teachers' suggestions were well-timed and well-suited to children's efforts and predominantly delivered at appropriate times (e.g., Egeland et al., 1990). Cognitive activating scaffolding was positively associated with sensitivity and timing in instruction, which underpins the educational research hypothesis, that adequate cognitive activating scaffolding is context-specific and at its best contingent to the child's efforts (e.g., van de Pol et al., 2010). Research has shown that preschool teachers' adaptive support is crucial to foster children's learning, albeit teachers seem to have difficulties in the adaption to learning situations (e.g., Siraj-Blatchford, 2002).

Interplay between teachers' instructional quality and children's achievement

There is evidence that children's achievement in stability knowledge is associated with playful interactions embracing cognitive activating scaffolding (Casey et al., 2008). To examine the association between preschool teachers' instructional quality on children's stability knowledge, interest, and self-concept in block play as well as spatial language and math knowledge, a general score of instructional quality was computed. We revealed a rather small but significant association between overall instructional quality and children's stability knowledge. This is in line with Weiland and colleagues (2013), who found small to zero or curvilinear associations between instructional quality and children's outcomes. A possible reason for this might be that preschool teachers' daily routine in kindergarten seldomly allows them to engage in high-quality interactions with a small group of children (Cabell et al., 2013; von Suchodoletz et al., 2014). Thus, one explanation for the small but significant association of overall instructional quality on children's stability knowledge might be explained through the study design which relied on small group interactions of teacher and children. However, the small association might be also explained through former findings which have shown that preschool teachers' knowledge in early science education is limited (Garbett, 2003; Kallery and Psillos, 2001; Yildirim, 2021). Therefore, we might conclude that children's early science knowledge in block play is not fostered exhaustively. Moreover, children's knowledge was assessed prior to the block-play-interaction. Even though a small number of teachers' instructional quality might have been high, children's knowledge in block play could have been limited due to a restricted block-play experience in kindergarten before the stability test. Another reason for the small association between instructional quality and children's knowledge might be that stability knowledge was a dichotomous variable, which led to a major loss of information and variance. Hence, a dependent variable going into more detail about children's theories (e.g., asking children about their thinking when assessing stability) might reveal more about the relationship between children's knowledge and preschool teachers' instructional quality. Nevertheless, the positive association between preschool teachers' instructional quality and children's stability knowledge was significant and indicates that teacher behavior is linked to child-related outcomes.

However, the overall quality score might have been too general due to the multifaceted and inconsistent nature of instructional quality (e.g., Senden et al., 2022). Thus, we explored the dimensions of instructional quality in block play in more detail. We found significant associations between spatial language, math language as well as cognitive activating scaffolding and children's stability knowledge. However, cognitive activating scaffolding has shown to be the only significant predictor when simultaneously controlling for spatial and math language. Thus, our results expand on the findings of Ferrara and colleagues (2011) and Casey and colleagues (2008) and show that cognitive activating scaffolding is a more powerful predictor for children's stability knowledge than spatial and math language. Yet, indicated by our findings, spatial and math language might be understood as aspects of cognitive activating scaffolding. Nonetheless, regarding other early science domains, such as floating and sinking, no effect of cognitive activating scaffolding could be shown on preschool children's achievement, whereas domain-specific language had shown to be the only predictor (e.g., Leuchter & Saalbach, 2014). Still, floating and sinking is a multifaceted science concept encompassing an object's buoyancy, density and displacement, while stability knowledge can be seen as one specific and focused aspect of block play. Thus, the analysis of the interplay of teachers' cognitive activating scaffolding and children's achievement in a focused context might be more informative than in a broad, multifaceted context. In a broad context, less knowledge might be gained about the association between preschool teachers' specific learning support and children's knowledge. Thus, it might be valuable to examine the influence of cognitive activating scaffolding on carefully selected and narrowly defined contents, due to its high adaptive and context-specific demands in teaching and learning.

We found initial evidence of a substantial role of teachers' sensitivity for children's self-concept. This is in line with evidence of providing responsive and child-contingent feedback as an essential part of effective preschool teaching (e.g., Birch & Ladd, 1997; Downer et al., 2010) and its contribution to fostering children's joy and motivation (e.g., Lepper et al., 2005). We assume two reasons for this finding: First, the sensitivity scale assessed whether teachers' support was contingent in time to the child's effort. We suppose that teachers' well-timed verbal support was more motivating for children than their stimulation of communication and general language use. Teachers' well-timed support might be understood as an aspect of cognitive activating scaffolding too. Second, the sensitivity rating also assessed whether preschool teachers supported appropriately. Thus, the interplay between well-timed and appropriate verbal support might explain the positive association between teachers' sensitivity and children's self-concept, including motivation.

Moreover, our research shows preschool teachers' use of communication to be positively associated with children's spatial language skills and further, the amount of math talk seems to be negatively associated with children's mathematical knowledge. The first result underpins the finding that reciprocal communication between teachers and children is positively associated with children's vocabulary (e.g., Guo et al., 2011). Future research might investigate the negative association between math talk and mathematical skills in more detail. In contrast to Klibanoff and colleagues (2006) we assessed math talk quite narrowly and separate from spatial language (i.e., shape names were not considered as math talk, which was the case in the work of Klibanoff and colleagues (2006) and might have contributed to this result). This assumption is underpinned by the finding that children's spatial language was positively associated with their math knowledge. Further, preschool teachers did not use *scale units* (e.g., centimeter, meter) at all, which, might have led to an underestimation of the association between teachers' math talk and children's math knowledge in our study.

Nevertheless, one might keep in mind that instructional quality is not only determined by preschool teachers' behavior. Studies have shown that instructional quality is strongly influenced by teachers' motivational aspects and learning beliefs (e.g., Buehl & Beck, 2015; Scherer & Nilsen, 2016). Thus, teachers' motivation should be assessed in a further study. In our study, we found significant correlations between children's knowledge and teachers' scaffolding and between children's self-concept and teachers' sensitivity. Embedding instructional quality in a reciprocal conjunction of teacher and child behaviors, high instructional quality can be understood as determined by teachers as well as children. Two complementary explanations can be put forward for this: On the one hand, if children were eager to engage in block building activities, teachers were more cognitively activating and more sensitive in their teaching, resulting in higher adaptivity of their support towards children's efforts. On the other hand, more adaptive teacher behaviors may in turn have led to higher self-concepts and cognitive achievement among children. Thus, our study implies the bidirectional aspect of instructional quality in preschool.

Limitations and conclusion

It should be mentioned that our study, regarding the design, only allows for correlative inferences. We chose this design in order to provide an initial step for a better understanding of preschool teachers' instructional behavior in block play and its possible associations with children's outcomes. Besides, our correlational approach allowed us to observe bidirectional relations between teacher and child behaviors. This is particularly important as research has shown that instructional quality arises from the interplay between teachers and children (Scherer & Nilsen, 2016). We provide an overview of variables involved in block play which might serve as a starting point for future research aiming to detect causal links between preschool teachers' instructional quality and child-related outcomes.

Moreover, some variables that have not been considered in our study might have affected children's learning outcomes (e.g., cognitive capacity, socioeconomic background, presence at preschool) and preschool teachers' instructional quality (e.g., staffing, pedagogical content knowledge, pedagogical beliefs) resulting in a potential underestimation of the actual associations. We primarily concentrated on the cognitive development of children. Equally important aspects in block play, such as social and emotional development (e.g., Rogers, 1985), might be integrated in future research with a broader range of variables to obtain more information on their particular effects.

In conclusion, our study bears two important findings: First, we showed that there is a domain-specific association between preschool teachers' cognitive activating scaffolding and children's stability knowledge. Second, we revealed an association between preschool teachers' sensitivity and timing in instruction and children's self-concept. Moreover, our study shows that it is valuable to examine particular topics in early science, as associations between teacher knowledge and children outcomes might become evident not on a global but on a small-scale level. Based on our study, we have shown the importance of preschool teachers' early science teaching skills to provide children with high quality learning opportunities.

6.5 Literature

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7. Article 3

Preschool Teacher Training of a Block Play Curriculum in Kindergarten Enhances Preschool Teachers' Scaffolding Activities and its Implementation Promotes Mathematical Learning in Children

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Abstract

Preschool teachers play a crucial role in fostering children's STEM knowledge by building upon children's intuitive early understandings. However, preschool teachers' practice often does not correspond to these affordances. High-quality STEM curricula are one method to change teacher practice, however, their effect is not given. Moreover, research has shown that there often is a gap between intended an enacted curricula and that teachers value the features in the curriculum materials higher than the curriculum aims and objectives. In this study, we examined whether a preschool teacher training with a curriculum for guided block play had an effect on preschool teachers' content knowledge, pedagogical content knowledge and their practice (i.e., use of scaffolding, spatial and math language) and whether the implementation of the curriculum promoted children's stability knowledge, language and mathematical skills. A total of N = 74 preschool teachers and N = 288 children participated in the study. Teachers were assigned to three experimental conditions (two Experimental Groups with different trainings, one Control Group with no training). We analysed teachers' knowledge and practice before and after the training and videotaped them in episodes of free and guided block play. We found no change in teachers' knowledge, however; in the free play episode after the training, both Experimental Groups used more scaffolding than the Control Group. During guided play, both Experimental Groups applied more scaffolding, spatial and math language than during free play and Experimental Group 1 used more scaffolding than Experimental Group 2. Children in the Experimental Groups showed an increase in math knowledge from pre- to post-test. These results show that a curriculum based on guided block play may help teachers to close the gap between intended and enacted curriculum and may support children's learning.

7.1 Theory

Research suggests that through play, children develop intuitive mathematical and scientific understandings and demonstrate the ability to engage in complex and abstract thinking (Otsuka & Jay, 2017). The early acquisition of these skills lays the foundation for later STEM learning (Science, Technology, Engineering, and Mathematics; Moehring et al., 2021). Preschool teachers can foster children's STEM-knowledge by building on children's prior knowledge, their intuitive understandings and experiences (Wan et al., 2021). Hence, providing children with high-quality science and mathematics learning opportunities in preschool has been defined as one core aspect of early education (e.g., Anders et al., 2013). Block play is a valuable approach for introducing early STEM learning to young children, fostering their understanding of stability, spatial language, and mathematical concepts (e.g., Casey et al., 2008; Levine et al., 2012; Weber et al., 2020).

To support preschool teachers' practice and to enhance children's early learning STEM-curricula have been developed (e.g., Clements & Sarama, 2007; Hassan et al., 2019). These curricula are designed to foster children's knowledge and skills and provide valuable resources for teachers to teach science (e.g., Clements & Sarama, 2007) or mathematics (e.g., Hassan et al., 2019; Sarama et al., 2012). However, research has shown that the provision of curricula does not necessarily change teacher practice and that its implementation seems to be difficult for teachers (Krajcik & Delen, 2017; Pianta et al., 2005), highlighting a gap between intended and enacted curriculum (Krajcik & Delen, 2017; Pianta et al., 2005). One reason has shown to be teachers' lack of knowledge (e.g., Pianta et al., 2005). For the successful implementation of curricula, teachers need content knowledge (CK, i.e., knowledge about the content that is shaped by the curriculum) and pedagogical content knowledge (PCK, i.e., knowledge about ways how to teach the curriculum) and apply appropriate strategies to foster children's learning (Howes et al., 2012; Garet et al., 2001).

In our pre-post-follow-up-study, we examined whether a curriculum for block play fostered preschool teachers' CK and PCK, and teaching practice and if this was associated with children's learning. Therefore, N = 74 preschool teachers were assigned to two Experimental Groups with different trainings in a curriculum on guided block play and one Control Group with no training, but free block play.Teachers' scaffolding-techniques, spatial and math language as well as children's knowledge in block stability, their mathematical and spatial language were assessed.

Development of professional competences with curriculum material

Developing preschool teachers' professional competences is a main objective in the field of early education. Research has shown that professional development is more effective when it concentrates on clear, specific objectives and when it prioritizes teaching practice (Zaslow et al., 2010). In science education, the use of curriculum material has shown to play a supporting role in changing teachers' professional competences (Donna & Hick, 2017). However, unfamiliar curriculum material that is complex to handle might be too demanding to develop teachers' practice (e.g., Arias et al., 2016; Fogleman, et al., 2011; Krajcik & Delen, 2017). Furthermore, a discrepancy between intended and implemented curricula indicates that teachers often prioritize the features of instructional materials over the curriculum's intended goals (Choppin et al., 2020). Besides, curriculum material can cause teachers strive to implement the material as accurately as possible, losing sight of supporting children's learning (Roehrig & Kruse, 2005). These difficulties might be owed to teachers' lack of CK and PCK which may be difficult to compensate for in professional development, even when curriculum material is implemented (Granger et al., 2019).

According to a cross-sectional study conducted by Garet et al. (2001) the following key features should be included in teacher professional development to ensure that teacher trainings have positive effects on teachers' knowledge and practice: (a) emphasis on content knowledge; (b) incorporation of opportunities for teachers to learn actively; and (c) alignment with teachers' other learning activities. However, it is important to note that the impact of these features on teacher learning is further amplified by structural features, such as (a) the applied method of the activity (e.g., workshop vs. study group); (b) involvement of a group of teachers from the same institution; and (c) the length of the training (Garet et al., 2001).

Nonetheless, research with preschool teachers has revealed that even after undergoing training with curriculum materials, they show only minimal changes in their professional competences, particularly in their support of children's learning (e.g., Diamond et al., 2014; Piasta et al., 2015; Studhalter, 2017). However, research indicates that preschool teachers highly value play materials (Nilsen, 2021) and express that the scarcity of suitable materials is one of the main reasons for their limited engagement in teaching science (Sandstrom, 2012; Yildirim, 2021). Yet, this is contradicted by the finding that preschool teachers do not make use of the science materials already available in their classrooms (Tu, 2006).

Considering these constraints, we developed curriculum material based on block play, assuming that block play is already familiar to preschool teachers and children. Moreover, preschool teachers might have some knowledge about the implicit potential of block play for fostering children's stability knowledge, spatial and math skills. Thus, preschool teacher training based on block play might reduce the complexity of the required CK and PCK, allowing to focus on preschool teachers' learning support. Therefore, in our study, preschool teachers were provided with a parsimonious curriculum material and information about verbal support during block play to stimulate children's learning.

Verbal support in the context of block play

Verbal support plays a crucial role in facilitating children's learning and in promoting sustained shared thinking (Siraj-Blatchford & Manni, 2008). The focus on fostering children's learning through temporary verbal support is closely linked to Vygotsky's socio-cultural theory (Vygotsky, 1967). Verbal support integrates broad-spectrum scaffolding techniques and content focused language (e.g., van de Pol et al., 2010).

Scaffolding

In the context of science education, scaffolding is a key aspect of teachers' learning support (e.g., van de Pol et al., 2010). Recent research has indicated that the amount of verbal scaffolds preschool teachers apply was positively associated with children's learning (Fisher et al., 2011; Weisberg et al., 2016). Scaffolding in science typically involves various strategies employed by teachers to facilitate learning. For example, in block play, preschool teachers can ask children if they have experience with building blocks or if they recognize certain structures. By asking these questions, teachers can tap into children's prior knowledge, which helps children to incorporate new information (Weber et al., 2020). Besides, teachers can provide explanations (e.g., Renkl, 2002) regarding the concept of stability in an age-appropriate way to foster children's knowledge. Moreover, teachers can encourage comparisons between different building blocks to highlight relevant similarities and differences between stable and unstable constructions and thus draw children's attention to relevant aspects (Hsin & Wu, 2011). Teachers can also foster children's learning by encouraging them to explain their own theories (Hsin & Wu, 2011). Besides, teacher modelling has shown to be effective in fostering children's learning (e.g., stabilizing a block structure by adding a block), and helps children develop consistent explanations for a phenomenon (Chinn & Hung, 2007).

Studies indicate significant variability in the quality of learning support between preschool teachers and suggest that preschool teachers' use of scaffolding not only in science teaching is rare (Cabell et al., 2013; Leuchter & Saalbach, 2014; Pianta et al., 2008; Siraj-Blatchford & Manni, 2008; von Suchodoletz et al., 2014). Differences in preschool teachers' use of scaffolding techniques might be attributed to significant variations in their CK (e.g., Barenthien et al., 2020) and PCK (e.g., Pianta et al., 2008). At the same time, preschool teachers' CK and PCK, have shown to be low in the science domain (e.g., Barenthien et al., 2020; Yildirim, 2021). Nevertheless, it remains unclear whether the variations in preschool teachers' use of scaffolding arise from differences in their knowledge or from their lack of familiarity with the curriculum material. Thus, in our study, preschool teachers in the experimental conditions were familiarized with scaffolding-techniques and encouraged to use them during block play.

Spatial language

Preschool teachers can enhance spatial learning by using spatial terms related to height or orientation of the blocks and words that describe spatial relationship between objects, shapes and sizes, locations and directions or spatial properties (Ferrara et al., 2011). Moreover, they may scaffold children to draw upon their prior spatial knowledge (Weber et al., 2020). Studies have shown that the use of spatial language in block play facilitates children’s spatial learning (Casey et al., 2008; Ferrara et al., 2011; Verdine et al., 2019). Moreover, there is evidence that teachers can purposefully use spatial language after a targeted training, which, in turn, promoted the development of children's spatial skills (Casey et al., 2008).

Math language

Math language includes words related to math topics like addition, subtraction, or geometry. During block building activities, math language can be employed while counting blocks or comparing shapes to facilitate children's geometric understanding (Ferrara et al., 2011; Klibanoff et al., 2006). Research suggests that children's mathematical language skills can be effectively modified through targeted interventions and instructional approaches (Hassinger-Das et al., 2015; Purpura et al., 2021). However, preschool teachers may not always possess the required competences to effectively support children's mathematical development (Maloney et al., 2015) and research on the nature and frequency of mathematical language in preschool remains limited.

Integration of guided play in the curriculum

Play-based learning is the ideal teaching approach in early years' curricula in many countries and is considered as developmentally appropriate for kindergarten-aged children (Hirsh-Pasek et al., 2009). According to Zosh et al. (2018), play can be understood as a spectrum encompassing various forms. Free play is characterized by voluntary and intrinsically motivated behaviour initiated by the child. Playful instruction is understood as structured and adult-directed, encompassing specific goals. Guided play, however, refers to a form of play-based learning during which adults provide intentional guidance and support based on children's needs (e.g., Zosh et al., 2018). In guided play, teachers take an active role in shaping the play environment, structuring the activities, and providing meaningful interactions to enhance children's learning. They allow children to explore independently, while also offering scaffolds and promoting specific learning goals (e.g., Zosh et al., 2018). Studies have shown that material-based guided play, supplemented by verbal scaffolding, enhances children's science learning more effectively compared to free play (Hadzigeorgiou, 2002, Fisher et al., 2011; Leuchter & Naber, 2019; Weber et al., 2020). Thus, our curriculum is based on material-based guided play, providing children with purposefully designed and structured materials aiming at a specific learning objective. Additionally, we encourage the preschool teachers to support children's learning verbally, through scaffolding, spatial and math language.

Aspects of children's learning in block play

Block play comprises several aspects of children's learning and can be used to foster children's (a) stability knowledge (e.g., Bonawitz et al., 2012), (b) spatial language (e.g., Borriello & Liben, 2018; Ferrara et al., 2011) and (c) mathematical knowledge (e.g., Clements & Sarama, 2008; Lee & Kim, 2018). According to Bonawitz et al. (2012), children's theories to assess stability can be classified as follows: (a) using the geometrical center, (b) using the object's center of gravity, and (c) showing an undifferentiated pattern of guessing. For symmetrical objects, the geometrical center is sufficient to assess stability. If the geometrical center is supported by a surface, the object remains stable. However, for asymmetrical objects, their mass distribution must be considered because the geometrical center does not correspond to the center of mass. If the center of mass lacks support from a surface, the asymmetrical object will tumble, regardless of the support of its geometrical center. Research has shown that less than 20% of 5- to 6-year-old children could be classified as mass theorists (Weber et al., 2020). However, children's use of mass theory to explain stability can be fostered by playful interventions (e.g., Bonawitz et al., 2012; Weber et al., 2020).

Besides, block play presents an accessible and age-appropriate possibility to promote spatial learning (Borriello & Liben, 2018; Ferrara et al., 2011). Research suggests that integrating spatial language in children's play supports children's use if spatial language (Ferrara et al., 2011). Children's spatial skills, in turn, have shown to be associated with interindividual differences in math knowledge (e.g., Verdine et al., 2017).

Studies have indicated that structured interventions with building blocks can enhance children's mathematical knowledge (Fisher et al., 2013; Schmitt et al., 2018). In block play, preschool teachers and children might discuss numbers (e.g., counting blocks), geometric shapes (e.g., triangles, rectangles), measurements (e.g., height in cm), and basic mathematical operations (e.g., addition, subtraction). Thus, block play can foster children's knowledge not only in stability or in spatial language, but also in mathematics (e.g., Clements & Sarama, 2008; Lee & Kim, 2018).

Intelligence is one of the most important predictors for learning and later achievement (e.g., Schneider & Preckel, 2017). Thus, we considered children's fluid and crystallized intelligence as well as their working memory capacity as background variables, which might interfere with their learning. For example, when examining children's theories about stability, higher visuo-spatial processing abilities (i.e., fluid intelligence) might facilitate the acquisition of mass theory. Moreover, these children might demonstrate greater improvements in math knowledge or spatial language. Children with higher levels of crystallized intelligence may have previously acquired more knowledge and language skills related to stability, which allows them to draw upon this knowledge to integrate new knowledge effectively. Besides, children with a larger working memory capacity may demonstrate enhanced abilities in comprehending stability in block play, as they have a greater capacity to store and manipulate information over short periods.

Based on these considerations, we examined whether preschool teachers' knowledge and practice can be changed through an in-service training and compared teachers' practice in block play during a free play and a guided play episode. Additionally, the effects of implementing the block play curriculum on children's learning outcomes were examined.

Research questions.

1. Is there a pre-post-change in preschool teachers' CK and PCK and teachers' practice in free play before and after the training?

2. Are there differences between the groups after the training regarding preschool teachers' use of scaffolding, spatial language and math language

(a) in a free block play episode and

(b) in a guided block play episode and

(c) in a free play episode compared to a guided block play episode?

3. Is there an association between preschool teachers' practice and children's stability knowledge, their spatial language and mathematical skills?

7.2 Methods

The study consisted of a pre-post-follow-up control-group design based on an opportunity sample in Germany. Preschool teachers were randomly assigned to three experimental conditions (experimental group 1 (EG1): curriculum with basic and additional training; experimental group 2 (EG2): curriculum with basic training; control group (CG): no training). The sample[1] consisted of $N_{(t1)}$ = 74 preschool teachers and $N_{(t1)}$ = 288 (153 boys and 135 girls, M_{age} = 6.01, SD_{age} = 0.63, *Min* = 4.50, *Max* = 7.58) children. The demographic characteristics of the three subsamples are shown in tables 1 and 2. Between the groups, preschool teachers did not differ significantly in age ($F(1, 68) = 1.05$, $p = .309$) or in years of experience ($F(1, 70) = 0.04$, $p = .835$). Children's age did not differ significantly between the groups either ($F(1, 286) = 1.35$, $p = .246$). In Germany, data on ethnicity is typically assessed by asking children what language they speak at home. 82% of the children reported German as their mother tongue. All children participated voluntarily, with their parents written consent, and the study received prior approval from the local Ethics Committee [number 2021-001]. It was possible to refuse participation at any time without giving further reasons.

Table 1.

Descriptive statistics for preschool teachers.

	M_{age}	SD_{age}	Min_{age}	Max_{age}	$M_{Experience}$ (*SD*)
CG (*n* = 25)	37.09	10.70	24	59	13.62 (12.27)
EG_2 (*n* = 30)	40.74	12.65	23	69	14.39 (12.85)
EG_1 (*n* = 22)	40.70	12.17	20	61	14.35 (10.34)

Note. M_{age} = Mean, SD_{age} = Standard Deviation, Min_{age} = Minimum, Max_{age} = Maximum,

[1]The study is based on a sample of the "Pädagogische Fachkräfte und Kinder in Naturwissenschaften und Technik" (PFKiNaT) project, which was was supported by the German Research Foundation (DFG) grant number: 446745359)

$M_{Experience}$ = mean of professional experience (in years).

Table 2.

Descriptive statistics for children at t1.

	M_{age}	SD_{age}	Min_{age}	Max_{age}
CG (*n* = 108)	5.91	0.55	4.58	7.00
EG_2 (*n* = 106)	6.13	0.61	4.58	7.50
EG_1 (*n* = 74)	5.99	0.74	4.50	7.58

Note. M_{age} = Mean, SD_{age} = Standard Deviation, Min_{age} = Minimum, Max_{age} = Maximum.

Procedure

The pre-test (t1) took place approximately three weeks before the training, the post-test (t2) was administered three weeks after the training and the follow-up (t3) took place approximately four to five weeks after the post-test. Teachers' data (CK, PC, scaffolding, spatial and math language) was assessed at pre- and post-test, children's data (stability knowledge, their spatial language, and mathematical skills) at pre-, post- and follow-up-test, their intelligence at pre-test only. Between all points of measurement, teachers were provided with protocols and asked to document the frequency of curriculum material implementation as well as the frequency of children's play with the building blocks. However, protocols showed that teachers hardly ever made use of the curriculum material themselves.

For pre-testing teachers' practice, all three groups were advised to play with the children in whatever manner they wanted for 15 minutes with provided blocks (free play). In the post-test, both EGs were asked to play with the blocks in whatever manner they wanted to for 15 minutes (free play), and to administer one specific part of the provided curriculum immediately afterwards (guided play). The CG was advised to play with the blocks in whatever manner they wanted to for 30 minutes, however, only the first 15 minutes of free play in the CG were coded. Preschool teachers' practice was videotaped.

Curriculum material

At the begin of the study, all kindergartens were provided with a standardized number of blocks (140) in different shapes and sizes. After the pre-test, EG1 and EG2 were provided with curriculum material (Weber et al., 2020). The curriculum material consisted of five activities (for a detailed description of the activities see Appendix D). The 5 activities were picture-based and provided in small boxes. The boxes were foldable, and the play instructions were presented on the lid. Furthermore, during training, preschool teachers were provided with handouts with relevant information about the use of scaffolding, spatial and math language. (see Appendix E).

Training

The teacher trainings were held by a PhD student. For manipulation check, the trainings were monitored by an assistant with a checklist, intervening by deviations from the standardized procedure. A basic training (30 minutes) in the EGs aimed at teachers' CK, PCK and scaffolding in block play and was conducted individually in their own classroom, lasting approximately half an hour. An additional training (20 minutes) was administered only for the EG1.

The basic training for EG 1 and EG2.

Both, curriculum material and verbal scaffolds, served as a basis for the guided play activity and were introduced using one predetermined photograph of three games (see Appendix D) with three predetermined verbal scaffolds as well as 3 predetermined utterances of spatial and mathematical language from the handouts with each game. One game (Add-a-block) was not introduced to preschool teachers. They were told to familiarize with the instruction, but not to play it with the children, as it would be used for the guided play activity in the post-test. A handout on cards summed up all relevant information on the required CK and PCK and contained examples of scaffolding, spatial and math language, which were specifically tailored to the play-based activities and was intended for teachers' use while engaging in play with children (see Appendix E).

Additional training for EG1

In addition to the basic training, three games were demonstrated in EG1 by the trainer for 7 minutes with a group of three to four children, who were not part of the study. One game (*Stable/Tumble*) was played by the preschool teachers and monitored by the experimenter for 7 minutes. During the following 5 minutes, suggestions for improvement of preschool teachers' performance (i.e., their use of spatial and math language and scaffolding) were made.

Instruments

Preschool teachers

(1) Teachers' CK in block play was assessed pre- and post-test with the 16 items of the *Center-of-Mass-Test* (Weber & Leuchter, 2020). Teachers' had to rate whether an asymmetrical block construction would tumble or remain stable after the removal of a black block ($\alpha_{t1} = .84$, $\alpha_{t2} = .81$).

(2) Teachers' PCK in block play was assessed pre- and post-test by asking teachers to rate various approaches to promote children's learning through block play (for example, using block play to enhance children's stability knowledge, for validation and explanation see Schmitt et al., 2023; $\alpha_{t1} = .86$, $\alpha_{t2} = .73$).

Videotaping. We videotaped $N = 73$ play sessions (t1) of preschool teachers before and after the training (t2, CGs were videotaped during the same time-span as the EGs). First, we examined whether preschool teachers' use of verbal support differed at the pre-test. Preschool teachers neither differed in their use of scaffolding ($p = .174$), spatial language ($p = .599$) or math language ($p = .644$). Next, we examined whether teachers' use verbal support was independent from the number of children participating in the play session (group size), which showed to be the case for scaffolding ($r = -.09$), spatial language ($r = -.10$) and math language ($r = .03$).

We partitioned the videos into segments of 10 seconds each and assessed the occurrence of scaffolding, spatial and math language with the coding systems (table 3). For the videos before the training, 15 minutes of free play were coded for all groups. For the videos of the EGs after the training, 15 minutes of block play without curriculum material and 15 minutes of play with the curriculum material were coded (only EGs). For the CG, the first 15 minutes of block play without curriculum material were coded. Two raters independently evaluated 27% of the videos. Interrater reliability was good with r = .85.

Table 3.

Examined variables of preschool teachers' instructional quality in block play.

Category	Scale	Derived from	Range	Explanation
Scaffolding	*Reflecting back children's statements*	Weber and colleagues (2020)	0-†	e.g., you just said that you think the building will not stay/fall
	Encouraging children's further thinking	Weber and colleagues (2020)	0-†	e.g., that was a good idea of yours. Now think even further. What else could happen?
	Activating prior knowledge	Weber and colleagues (2020)	0-†	e.g., have you seen this before?
	Fostering assumptions	Weber and colleagues (2020)	0-†	e.g., what do you think, will it hold or fall?
	Encouraging comparisons	Weber and colleagues (2020)	0-†	e.g., look! What is the difference between X and Y?
	Asking for precise explanations	Weber and colleagues (2020)	0-†	e.g., what have you found out? Why is it stable/ unstable?
	Modelling	Weber and colleagues (2020)	0-†	e.g., exactly! The building blocks don't always have to rest on their

				center to stay upright
	Directing children's attention towards relevant aspects	Weber and colleagues (2020)	0-†	e.g., look at the black block (accompany the child's gestures).
Spatial Language	*Spatial Dimensions*	Cannon and colleagues (2007)	0-†	e.g., big, small, wide, size, length, height, volume
	Shapes and Bodies	Cannon and colleagues (2007)	0-†	e.g., circle, square, sphere, cube, pyramid
	Place and Direction	Cannon and colleagues (2007)	0-†	e.g., towards/away, inside/outside, below, space, distance
	Spatial properties	Cannon and colleagues (2007)	0-†	e.g., round, curved, even, odd, smooth, circular
Math Language	*Quantities*	Klibanoff and colleagues (2006)	0-†	e.g., whole/all, part, piece, section, half/ third
	Scale units	Klibanoff and colleagues (2006)	0-†	e.g., centimeter/ meter/ millimeter
	Mathematical operations	Klibanoff and colleagues (2006)	0-†	e.g., more/ plus, less/ minus

Note. 0-† = indicates the scale range, which is limited to the number of 10-second-blocks per video.

Children

Children's theories about stability. Children's theories about stability were evaluated using a standardized interview (duration around 5 minutes) that involved showing pictures of six asymmetrical block constructions (figure 1). Each block construction was supported by a black block. The children were then asked to predict whether the block construction would stay stable or not if the black block was removed. After giving their answer, the interviewer asked the children to explain their knowledge by asking questions such as "*Can you tell me why you* *think this will stay/tumble when I take away the black block?*" The interview was conducted at all measurement points (t1, t2, and t3), with the same test items. The responses of the children were evaluated using the speech coding scheme developed by Pine et al. (2007) and Weber et al. (2020; see table 4) and categorized into No Theory, Center Theory, or Mass Theory. If a child was unable to communicate their answer verbally but, for instance, pointed correctly at the vertical block, the response was still categorized as Mass Theory. Children were classified as center or mass theorists if four out of six items were consistently justified with the respective theory. Two raters independently coded the explanations given by the children. Interrater agreement was substantial with $\kappa = .64$.

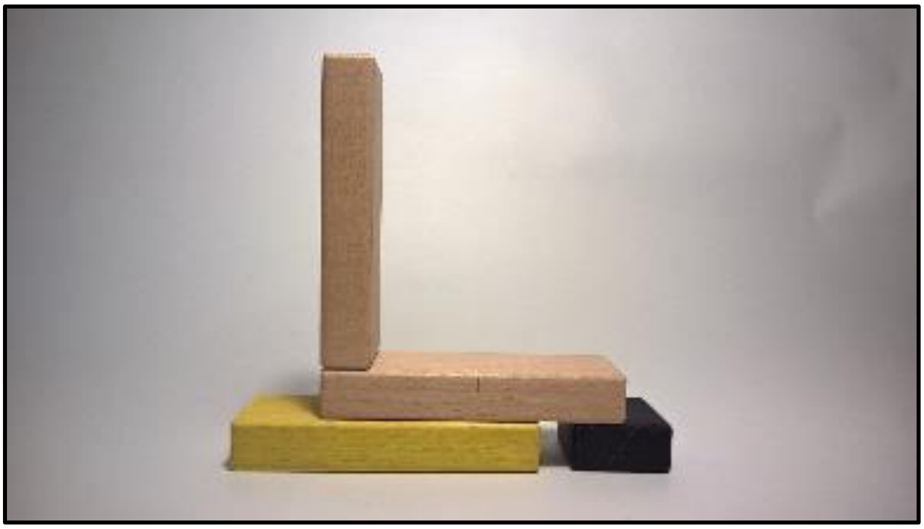

Figure 1. Asymmetrical item (stable) to assess children's stability knowledge

Table 4.

Coding Scheme.

Coding	**Speech**	**Example**
No Theory (0)	The child mentions a topic that is not related to stability, e.g., colour.	"It tumbles, because it is green."
Center Theory (1)	The child talks about either the center of the block or a larger portion of the block that is resting on either the black or yellow block.	"The brown block is more on the yellow block. That's why it will be stable".

Mass Theory (2)	The child mentions that the weight is on a specific side of the brown blocks, comments on its heaviness, or emphasizes the significance of the vertical block.	"The left side is heavier".

Spatial Language. We evaluated children's spatial language using a self-designed test, based on the categorization system developed by Cannon et al. (2007). The test consisted of three tasks. The first task required the children to identify a specific shape by pointing to it (8 items, e.g., "*Show me the triangle*"). The second task involved placing a toy figure in a specific location on a game board while considering various environmental factors (10 items, e.g., "*Can you put the figure to the left of the horse?*"). The third task required the children to identify spatial properties and dimensions by pointing to the correct response (8 items, e.g., "*Can you show me which of these lines are parallel?*"). Internal consistency was α_{t1} = .79, α_{t2} = .77, α_{t3} = .77.

Mathematics. We used the Würzburger Vorschultest (WVT, Endlich et al., 2015) to assess the mathematical knowledge of the participants. Four tasks were administered, including counting (14 items, e.g., "*Can you count the candles on the cake?*"), comparing quantities (8 items, e.g., "*On which side are more biscuits*"), addition and subtraction (14 items, e.g., "*How much is 7 plus 2?*"), and word problems (7 items, e.g., "*Stefan has 8 biscuits. He has 3 more biscuits than Lisa. How many biscuits does Lisa have?*"). Internal consistency was α_{t1} = .91, α_{t2} = .92, α_{t3} = .93.

Intelligence. Intelligence was measured once at t1 with the German version of the Wechsler Preschool and Primary Scale of Intelligence, Fourth Edition (WPPSI IV; Petermann & Daseking, 2018). Three subscales were administered: matrices (26 items, α = .88), vocabulary (31 items, α = .90), and working memory (35 items, α = .87). The matrices test assessed children's fluid intelligence (Cattell, 1987), while the vocabulary subscale measured crystallized intelligence (Cattell, 1987). The working memory subscale was a delayed retrieval test that required children to recall as many items as possible. Testing for each subscale was terminated when the child answered three consecutive items incorrectly.

Statistical Software

For data analysis, we employed the statistics software R, Version 4.2.1 (R Core Team, 2022). We used the packages "psych" (Revelle, 2022), "dplyr" (Wickham et al., 2022), "car" (Fox & Weisberg, 2019) and "tidyverse" (Wickham et al., 2019) for data-processing and -preparation. We computed descriptive statistics with the R-package "DescTools" (Signorell et al., 2022). Pillai's Trace was employed as a robust effect estimator for the MANOVA-models. We computed partial η^2 to estimate effect sizes (η^2_p = .01 small effect, η^2_p = .06 medium effect, η^2_p =.14 large effect).

7.3 Results

Research Question 1: Is there a pre-post-change in preschool teachers' CK and PCK and teachers' practice in free play before and after the training?

To investigate whether there was a change in preschool teachers' practice, CK and PCK and if this change depended on the teacher training, we computed the difference scores between pre- and post-training and conducted one-way ANOVAs. Change scores were used as the dependent variable, and experimental condition as the independent variable. Preschool teachers' content knowledge ($F(1, 60) = 0.10$, $p = .988$, $\eta^2_p \leq .01$) and pedagogical content knowledge ($F(1, 60) = 0.01$, $p = .941$, $\eta^2_p \leq .01$) did not change (see table 5). Preschool teachers' scaffolding in free play significantly changed from pre- to post-test ($F(2, 44) = 5.02$, $p = .011$, $\eta^2_p = .19$). The difference between the CG and both EGs was significant ($F(1, 44) = 6.09$, $p = .018$, $\eta^2_p = .12$), however, the EGs did not differ significantly in their amount of scaffolding ($F(1, 44) = 3.96$, $p = .05$, $\eta^2_p = .08$). Further, teachers' spatial language ($F(2, 44) = 1.81$, $p = .176$, $\eta^2_p = .08$) and math language ($F(2, 44) = 0.16$, $p = .857$, $\eta^2_p = .01$) did not change before and after the training (see figure 2).

Table 5.

Descriptive statistics pre- and post-training of teacher knowledge

Variable/ Group	Content Knowledge		Pedagogical Content Knowledge	
	pre	post	pre	post
CG	9.69 (4.03)	11.31 (3.16)	34.44 (3.95)	34.06 (3.32)
EG2	9.70 (4.28)	9.70 (4.04)	33.30 (4.50)	33.85 (3.10)
EG1	9.40 (4.14)	10.53 (3.79)	34.42 (4.73)	34.21 (3.52)

Note. The table shows means and standard deviations (in brackets) of teachers' knowledge. Maximal score CK = 16, PCK = 40.

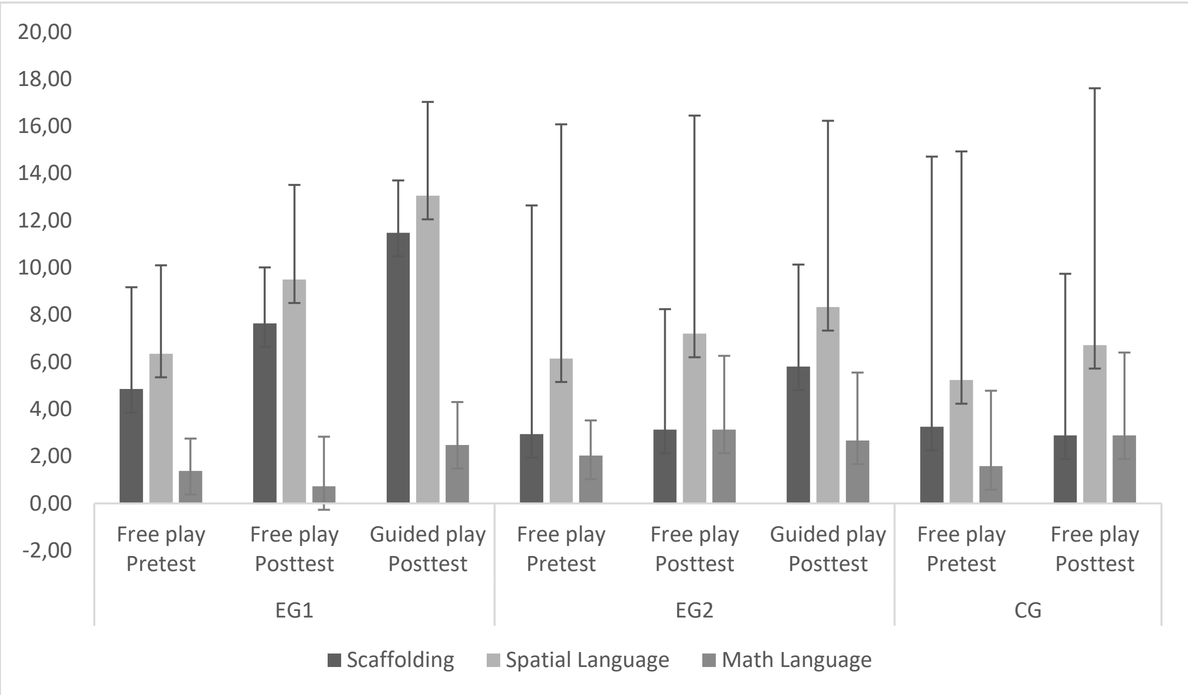

Figure 2. Preschool teachers' use of verbal support pre- and post-training.

2. Are there differences between the groups after the training regarding preschool teachers' use of scaffolding, spatial language and math language?

Research Question 2a: Are there differences in verbal support in a free block play episode (CG vs. EG1 vs. EG2)?

To answer research question 2a, we carried out a one-way MANOVA to examine differences in scaffolding and the use of spatial language between EG1, EG2 and CG at the post-test. Overall, we found statistically significant differences between the groups (Pillai's Trace = .12, $F(1, 75) = 3.20$, $p = .028$). The use of scaffolding during the free play was higher in the experimental groups than in the control group ($F(1, 75) = 5.82$, $p = .018$, $\eta^2_p = .07$), but did not differ significantly between the two experimental groups ($F(1, 74) = 0.74$, $p = .394$, $\eta^2_p = .10$). However, the use of spatial language ($F(1, 75) = 1.08$, $p = .301$, $\eta^2_p = .01$) and math language ($F(1, 75) = 1.28$, $p = .262$, $\eta^2_p = .02$) did not differ significantly between the groups in the free block play episode.

Research Question 2b: Are there differences in a guided block play episode (EG1 vs. EG2: effect of additional training in EG1)?

To examine the differences in the use of spatial and math language as well as scaffolding during the guided play episode ("Add-a-block"-game) between the two experimental groups, we carried out a one-way-MANOVA. The analysis revealed significant differences between the groups (Pillai's Trace = .17, $F(1, 46) = 2.98$, $p = .042$). EG1 used significantly more scaffolding during guided play than EG2 ($F(1, 46) = 4.56$, $p = .038$, $\eta^2_p = .09$). However, the use of spatial language ($F(1, 46) = 1.76$, $p = .191$, $\eta^2_p = .04$) and math language ($F(1, 46) = 0.04$, $p = .848$, $\eta^2_p \leq .01$) did not differ significantly between the groups.

Research Question 2c: Are there differences in a free play episode compared to a guided block play episode in EG1 or EG2?

We carried out a one-way repeated measures MANOVA to examine whether the experimental groups applied more spatial and math language as well as scaffolding in a guided play episode compared to the free play episode. The analysis revealed a significant difference between guided and free play (Pillai's Trace = .17, $F(1, 47) = 9.96$, $p = .003$). Both experimental groups used more scaffolding ($F(1, 47) = 6.99$, $p = .011$, $\eta^2_p = .13$) spatial language ($F(1, 47) = 4.37$, $p = .042$, $\eta^2_p = .09$) and math language ($F(1, 47) = 19.52$, $p \leq .001$, $\eta^2_p = .30$) in guided play compared to free play.

Research Question 3: Is there an association between preschool teachers' practice and children's stability knowledge, their spatial language and mathematical skills?

Stability knowledge. Children's theories about stability are shown in table 6. The majority of the children neither considered an object's mass nor its geometrical center to assess stability. At pre-test, 74% of children expressed their stability knowledge with no consistent theory. At post-test, 70% had no consistent theory. At follow-up-test, 71% of the children had no consistent theory. Children's theories about stability neither differed between the groups at t1 (χ^2 (4) = 5.40, p = .249), t2 (χ^2 (4) = 3.50, p = .477) nor t3 (χ^2 (4) = 5.67, p = .225).

Table 6.

Children's theories about stability at t1, t2 and t3.

	Pre-test (t_1)				**Post-test (t_2)**				**Follow-Up (t_3)**			
	0	*1*	*2*	*N*	*0*	*1*	*2*	*N*	*0*	*1*	*2*	*N*
CG	84	19	10	113	102	22	13	137	77	17	16	110
EG_2	82	19	11	112	89	17	12	118	70	13	18	101
EG_1	57	6	12	75	60	13	15	88	63	4	15	82
∑	**223**	**44**	**33**	**300**	**251**	**52**	**40**	**343**	**210**	**34**	**49**	**293**

Note. 0 = No Theory, 1 = Center Theory, 2 = Mass Theory.

Spatial language. To examine the differences in children's spatial language and mathematical skills, we computed difference scores at t1, t2 and t3. To investigate whether there was a significant change between the three groups, we conducted one-way-ANOVAs. At t1, children's spatial language did not differ between the three experimental groups (M_{KG} = 19.31 (3.49), M_{EG2} = 19.49 (3.24), M_{EG1} = 19.87 (3.69); F(1, 420) = 1.74, p = .188). We found neither a significant change in children's spatial language between pre- and post-test (ΔM = 0.67 (2.68); F(1, 345) = 0.77, p = .382) nor between post-test and follow-up-test (ΔM = -0.18 (2.46); F(1, 255) = 1.22, p = .271). An overview of the descriptive statistics of children's spatial language and math knowledge is given in table 7.

Mathematics. At t1, children's math knowledge did not differ between the three experimental groups (M_{KG} = 14.49 (7.53), M_{EG2} = 16.57 (7.67), M_{EG1} = 15.63 (9.14); $F(1, 406)$ = 1.75, p = .187). However, we found a significant change in math knowledge between pre- and post-test (ΔM = 1.35 (4.95); $F(1, 333)$ = 4.24, p = .040). Children in the first experimental group showed the largest increase in math knowledge (ΔM_{KG} = 0.75 (4.27), ΔM_{EG2} = 1.25 (5.84), ΔM_{EG1} = 2.19 (4.18).

Table 7.

Descriptive statistics of children's spatial language and math knowledge.

	Spatial Language			**Math Knowledge**		
Time	T1	T2	T3	T1	T2	T3
EG1	19.87 (3.69)	20.75 (3.33)	20.25 (3.72)	15.63 (9.14)	17.32 (9.23)	17.41 (10.01)
EG2	19.49 (3.24)	20.24 (3.03)	20.24 (2.88)	16.57 (7.67)	17.95 (8.06)	17.54 (8.11)
CG	19.31 (3.49)	19.62 (3.15)	19.32 (3.42)	14.49 (7.53)	15.11 (7.89)	15.29 (8.38)

Note. The table shows means and standard deviations (in brackets) of children's spatial language and math knowledge.

We computed a multiple regression to examine which variables predicted this change from pre-test to post-test (see table 8). The model accounted for 63% of the variance (R^2 = .63, F (7, 454) = 111.20, $p \leq .001$). Children's change in math knowledge was significantly predicted by their math score at age, fluid intelligence, working memory as well as by experimental condition (i.e., increase in math knowledge for children in the EG1). Children's math knowledge did not change significantly between post-test and follow-up (ΔM = 0.47 (4.76), $F(1, 245)$ = 1.33, p = .250).

Table 8.

Results of the Multiple Regression Analysis on children's change in math knowledge (t2/t1).

Variable	*B*	*SE (B)*	*t*	*p*
Math (t1)	.55	2.39	16.42	≤.001***
Age	.13	0.03	4.08	≤.001***
Sex	.97	0.51	1.90	.058
Working Memory	-.08	0.06	-2.46	.014
Fluid Intelligence	.27	0.06	7.52	≤.001***
Crystallized Intelligence	.07	0.04	1.53	.127
ΔEG2	.43	.68	0.63	.530
ΔEG1	2.51	.69	3.67	≤.001***

Note. *** $p < .001$.

7.4 Discussion

Developing preschool teachers' competences in the STEM-fields has been identified as one core aspect of teacher professional development (e.g., Piasta et al., 2014). In science education, incorporating curriculum material serves as a supportive element in the improvement of teacher professional competences (e.g., Trundle & Saçkes, 2012). Nevertheless, research findings indicate that preschool teachers demonstrate limited alterations in their professional competences, particularly in their capacity for facilitating learning, such as the use of verbal support, even after receiving training with curriculum material (e.g., Piasta et al., 2015; Studhalter, 2017). Furthermore, empirical evidence points towards a discrepancy between intended curricula and teachers' classroom practice (e.g., Krajcik & Delen, 2017). This could lead to a misalignment between the intended goals of the curriculum and the teachers' instruction in the classroom. However, research on the successful implementation of early science curricula and especially the interplay between teachers' practice and children's learning remains sparse.

Therefore, the aim of this study was to introduce a block play curriculum and to provide teachers with the knowledge needed for its implementation. Moreover, we examined the effect of guided and free play on teachers' practice as well as the effect of the implementation of the curriculum material on children's learning of stability knowledge, spatial language and mathematics. First, we were interested in preschool teachers' change in their use of verbal support during free play and in CK and PCK before and after the training.

Our results have shown that preschool teachers exhibited no changes in CK nor PCK, regardless of the experimental condition. This aligns with previous research, which has shown that changes in preschool teachers' knowledge remain limited even after additional training with curriculum material (e.g., Diamond et al., 2014; Piasta et al., 2015; Studhalter, 2017). However, the training had a significant effect on preschool teachers' practice (i.e., the use of scaffolding and spatial and math language during play). Most importantly, our results have shown that teachers did improve in their scaffolding practice in free play after the training when being compared to their free play before the training. In contrast to that, Diamond et al. (2014) found their one-year-training to improve teachers' science knowledge however, they could not find an impact of their training on preschool teachers' classroom practice. The varied outcomes between the studies might be attributed to several factors, including the specific professional development programs implemented in each study, the individual characteristics and expertise of the participating teachers, as well as to contextual factors influencing teachers' practice.

We assume that our training was successful in bringing about a change in teachers' practice, primarily because it had a strong emphasis in limited, well-known are such as block play (e.g., linking the material with verbal scaffolds, spatial language and math language). Further, we hypothesize that the observed effects on teachers' practice might occur relatively close to a specific training. In our study, the post-test took place approximately three weeks. In contrast to that, Diamond et al. (2014), have examined teachers' practice over a five-month-period and might thus have not observed changes in teachers' practice. Yet, the effect of the training might have been even stronger if the teachers had made use of the curriculum between the measurement points. However, the teachers' protocols revealed that teachers rarely used the material.

However, we assume that if we had extended the duration of our teacher training program and the observation period, we might have been also able to identify significant changes in teachers' knowledge. Longer-term engagement and repeated exposure to the training and curriculum materials, which was the case in the study of Diamond et al. (2014), may have had the potential to foster teachers' deeper understanding and knowledge. This assumption is supported by the fact that we only examined teachers' CK in terms of stability knowledge and teachers' PCK in terms of recognizing learning opportunities in block play. By extending the duration of the training, we could have provided more time and opportunities for teachers to internalize CK and PCK, potentially leading to more pronounced changes in their knowledge.

Besides, we found that EG1 made significantly more use of scaffolding-techniques during guided play than the EG2. We consider this as the beneficial effect of our additional training in EG1, which goes beyond the mere effect of time-on task. In this group, the experimenter demonstrated the use of material and additional verbal scaffolds to the preschool teachers with a small group of children and thus served as a role model for the implementation of age-adequate science. Further, preschool teachers in the EG1 had the opportunity to engage in active learning (Garet et al., 2001; Howes et al., 2012), as they were encouraged to implement parts of the curriculum and discuss it with the trainer. The finding that EG1 made more use of scaffolding after the training thus aligns with research that emphasizes the significance of active learning as a core feature in professional development courses to change teachers' classroom practices (e.g., Garet et al., 2001). We further hypothesize that the establishment of behavioral models plays a crucial role in developing professional teaching practices among preschool teachers. This hypothesis is in line with the review of Zaslow et al. (2010), which has shown that professional development was more effective when it concentrated on clearly defined objectives, thereby prioritizing teaching practice. In our case, the priority given to teaching practice was significantly greater in EG1 than in EG2 trough the modelling carried out by the experimenter.

Nevertheless, our results also show that teachers in EG2, who had received no additional training, improved in their practice in guided play compared to free play as well. This underlines that the basic training (i.e., the provision of curriculum material and verbal support in block play) was also successful in changing teachers’ practice in the defined context. Thus, our findings have significant implications for the development of early science curricula, highlighting the importance of incorporating guided play activities that integrate both, material and verbal scaffolds in well-defined, constrained, and every-day learning context such as block paly. However, a more extensive training emphasizing teacher knowledge might lead preschool teachers to better understand the potential of the newly designed curriculum and implement verbal support even more, possibly showing more impact on children's learning.

Our results show that the implementation of the curriculum material fostered children's mathematical learning, as we found a significant rise in children's mathematical knowledge from pre- to post-test in the first experimental group. This finding is consistent with prior research conducted by Clements and Sarama (2008) and Lee and Kim (2018), which have shown a positive impact of block play curricula on the improvement of children's mathematical skills. Thus, we provide further evidence for the effectiveness of professional development in block play in promoting mathematical learning in young children.

The finding that children did not improve in their spatial language skills aligns with the results of Ferrara et al. (2011), suggesting that children between the ages of 3 and 5 tend to focus more on physically manipulating the materials during block play, resulting in less attention on teachers' spatial utterances during play. Ferrara et al. (2011) also hypothesized that older children, around 6 to 7 years old, would exhibit higher levels of spatial language during block play. Thus, in our study, the 4 to 6-year-old children might have been too young or too absorbed by the materials to fully benefit from the use of spatial language by their preschool teachers to improve in their spatial language skills.

The outcome that children did not improve in their stability knowledge contrasts the findings of Weber et al. (2020), which have shown that children profited in their acquisition of a mass theory from the experimenters' guided play and her provision of verbal support. However, in the present case, teachers were expected to implement the curriculum materials themselves. Teachers' low CK in stability might have resulted in unease to teach the subject of stability to children.

At last, our study demonstrated the beneficial effect of guided play compared to free play. In both treatment groups, we enriched preschool teachers' block play with curriculum material and handouts for verbal support. The results suggested that both treatment groups used significantly more scaffolding, spatial language and math language during guided play compared to free play. Moreover, children in the first experimental group improved their mathematical skills. Thus, our results are in line with studies which indicate that guided play, complemented by verbal scaffolding, facilitates children's learning more effectively in comparison to free play (Hadzigeorgiou, 2002; Fisher et al., 2011; Leuchter & Naber, 2019; Weber et al., 2020). Drawing on these findings, we suggest designing early science curricula in a well-defined, constrained, and every-day learning context and on the backdrop of guided-play activities with material and verbal scaffolds.

Limitations and Conclusion

The first limitation identified in this study concerns the frequency of teachers' implementation of the curriculum materials. Despite the explicit encouragement for teachers to use the curriculum materials, exploratory analysis of the protocols revealed that teachers infrequently incorporated the curriculum into their instructional practices (on average about 2 times per week). The limited use of materials by teachers may explain the lack of change in children's knowledge acquisition regarding stability or spatial language. Furthermore, the infrequent use of the curriculum materials indicates underlines a gap between the intended use of the curriculum and its actual implementation in the classroom in our case as well (e.g., Krajcik & Delen, 2017). To address this limitation, future studies should explore strategies to enhance teacher commitment and actively motivate them to engage with the curriculum materials. Additional efforts should be made to provide ongoing support and professional development opportunities to teachers, helping them to understand the value and benefits of using the curriculum materials, e.g., by increasing the frequency of visits of the preschools and gather more video recordings of classroom activities More frequent classroom analyses might also deliver more valid results about preschool teachers’ practice in block play. Our findings are based on the results of one short video-recorded play session between teachers and children at two measurement points. Besides, we do not know how often preschool teachers implemented the curriculum between the training and the post-test or the follow-up, respectively. Despite distributing protocols, the majority of preschool teachers did not fill them out. Data collection took place during the COVID-19 pandemic, which led to intermittent closures of several kindergartens. This circumstance might be a factor contributing to the inadequate documentation of the protocols.

A second limitation of our study relates to the limited set of material and verbal scaffolds that were applied during the training. Although the scaffolds used in this study were carefully selected based on existing research, it is possible that a broader range of scaffolding techniques could have further enhanced the effectiveness of the training.

Lastly, we discovered a slight ceiling effect on the PCK-scale with teachers scoring on average 34 points out of 40 in the pre-test. This suggests that the PCK-scale used in our study might not have been able to fully assess the potential growth and development of teachers' PCK during the training. Additionally, it should be considered that we did not assess teachers' PCK focused on scaffolding. This aspect was a significant component of the training and could have provided valuable insights into the impact of the training on teachers' PCK. Future studies should thus assess all aspects of PCK addressed in the training in a pre- and post-test and avoid ceiling effects by adding more difficult items to the PCK-scale.

In conclusion, our study bears two important findings: First, we found that the implementation of a block play curriculum has a beneficial effect on preschool teachers' practice, but not on their CK or PCK. Second, and most importantly, our results show that guided play encourages teachers to implement more verbal support. Moreover, our results show that the implementation of the block play curriculum promoted children's mathematical learning. With our research, we make a valuable contribution to the existing research on the professional competences of teachers in early childhood science education., as we shed light on important aspects of in-service teacher training, curriculum design, and instructional practices that can enhance young children's learning.

7.5 Literature

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8. Discussion

Early childhood education should include inquiry-based approaches to promote children's understanding of scientific concepts (e.g., Trundle & Saçkes, 2015). When teaching STEM subjects, research recommends that preschool teachers should carefully select instructional methods that are considered developmentally appropriate to foster children's science learning (e.g., Zendler et al., 2018) and consider children's cognitive (e.g., Trundle & Saçkes, 2015) and self-related aspects (e.g., Chapman, 1988). However, research has shown that preschool teachers lack CK and PCK in science teaching, and validated science curricula remain scarce to date (e.g., Spektor-Levy et al., 2013; Trundle & Saçkes, 2012). The limited availability of science curricula poses a significant challenge for preschool teachers, as effective science instruction requires not only adequate CK and PCK, but also appropriately structured materials (e.g., Weisberg et al., 2016). However, research on the effects of science curricula on teaching practice and research on the interplay between teachers' practice and children's knowledge is limited. Further, several inconsistencies remain unsettled such as the interplay between teachers' dispositions and their practice, the associations between teachers' practice and children's knowledge or the effectiveness of teacher training in changing teachers' knowledge and teaching practice. The present dissertation addresses the research gaps identified above.

8.1 Summary of the findings

The first article *Preschool teachers' pedagogical content knowledge predicts willingness to scaffold early science learning* was concerned with the validity of the instrument to assess willingness to teach science, which was examined in a sample of N = 151 preschool teachers. Further, associations between teachers' dispositions (i.e., knowledge, beliefs, and willingness) and teachers' practice (i.e., use of scaffolding in a free block play episode) were analyzed. To examine factorial validity of the instrument to assess willingness, a confirmatory factor analyses (CFA) was applied. Further, to investigate the relationship between teachers' dispositions and their practice, bivariate correlations were examined and multiple regression analyses were carried out. The CFA showed that the three-dimensional structure of teachers' willingness to engage in scaffolding, diagnosis or inactivity was valid. Significant correlations between teachers' PCK, co-constructivist beliefs and their willingness to engage in scaffolding were found. A multiple regression analyses revealed that only teachers' PCK bearded incremental validity in the prediction of willingness to engage in scaffolding. Besides, preschool teachers' willingness to engage in diagnosis was significantly associated with teachers' co-constructivist beliefs, autonomy beliefs and PCK. Incremental validity was found for co-constructivist beliefs and PCK. None of the dimensions of preschool teachers' dispositions (i.e., knowledge, beliefs, willingness) was associated with their scaffolding practice. Only age was positively associated with teachers' amount of scaffolding in a free block play episode. Associations between preschool teachers' beliefs, willingness and practice were partly inconsistent and will be discussed in more detail in the following subchapter.

The second article *First Insights into Preschool Teachers' Instructional Quality in Block Play and its Associations with Children's Knowledge, Interest, Academic Self-Concept and Cognitive Aspects* focused on preschool teachers' instructional quality and its associations with children's knowledge. The study applied a correlational approach and considered generic dimensions of teachers' instructional quality (i.e., general language use, sensitivity) but also domain-specific dimensions (i.e., verbal support). N = 73 interactions between preschool teachers and children in a free block play episode were videotaped and coded independently by three raters. Results showed that teachers' generic and domain-specific dimensions of instructional quality were interrelated. Further, children's learning was associated with cognitive, but not with self-related aspects. Further, significant variation was observed in teachers' use of verbal support (i.e., spatial language, math language, and scaffolding). Study 2 found a rather small, but significant correlation between preschool teachers' overall instructional quality and children's stability knowledge. Moreover, a more fine-grained analysis revealed that scaffolding was the only significant predictor for children's stability knowledge. Besides, teachers' general language use and sensitivity were positively associated with children's self-concept in block play.

The third article *Preschool Teacher Training of a Block Play Curriculum in Kindergarten Enhances Preschool Teachers' Scaffolding Activities and its Implementation Promotes Mathematical Learning in Children* was concerned with the implementation of a teacher training with a parsimonious block play curriculum and its effects on teachers' knowledge and practice as well as on children's learning. N = 74 preschool teachers were assigned to three experimental conditions: the first experimental group 1 (EG1) received the curriculum with the basic and the additional training, the second experimental group (EG2) received the curriculum with the basic training, and the control group (CG) did not receive any training. Teachers' knowledge was compared before and after the training. Moreover, teachers' practice was examined in 15 minutes of free play pre-and post-test and 15 minutes of guided play with the curriculum materials (only EGs in the post-test). MANOVAs were computed to examine preschool teachers' changes in knowledge and practice before and after the training. Further, a multiple regression analysis was applied to examine the predictors for children's change in math knowledge between pre- and post-test. The findings revealed no significant changes in teachers' knowledge before and after the training, however, a significant change in teachers' practice was observed. Both experimental groups used more scaffolding during free play after the training compared to the pre-test. Moreover, during free play, both experimental groups used more scaffolding than the control group and during guided play, both experimental groups exhibited an increased use of scaffolding, spatial language, and math language compared to free play. The impact of the additional training was evident through the finding that EG1 used significantly more scaffolding during guided play compared to EG2. Children showed no increase in their stability knowledge or spatial language, however, their math knowledge significantly increased from pre- to post-test. Children in the first experimental group exhibited the most significant improvement in math knowledge. The change in children's math knowledge was further influenced by several factors, including age, fluid intelligence, and working memory. However, children’s math score at the pre-test had the most substantial impact on their overall progress. In the following subchapters, the findings of the articles are discussed with regard to the three research questions.

8.2 Research question I

How are preschool teachers’ dispositions and their teaching practice interrelated?

The model of professional competence by Fröhlich-Gildhoff and colleagues (2011) served as a theoretical framework to investigate the association between preschool teachers’ dispositions and practice. The model postulates that teachers’ practice is primarily shaped by their dispositions (i.e., knowledge, motivation, abilities and skills), and that these dispositions predict teachers’ practice, which is mediated by teachers’ planning of action. However, within the professional competence model, definition of teachers’ intention to engage in a specific behavior remains vague.

Willingness

To conceptualize teachers’ intention and to bridge the gap between teachers’ dispositions and their practice, in study 1, a willingness component was introduced, which was derived from the theory of planned behavior (Fishbein & Ajzen, 2010). Five vignettes, which displayed playful science learning opportunities were designed to investigate willingness to teach science. First, factorial validity of the proposed three-dimensional structure of willingness was analyzed with a confirmatory factor analysis. The three-dimensional-structure showed a good fit to the empirical data and was backed up by the results of a pilot study. Further, the path coefficients suggested convergent and discriminant validity of the three factors, as coefficients between teachers’ willingness to engage in scaffolding and diagnosis were positive and those between scaffolding and inactivity were negative. Teachers were more willing to engage in diagnosis than to engage in scaffolding or inactivity, which might be interpreted as an indicator of the socio-pedagogic tradition in Germany, stressing children's autonomy development and the development of social skills (ECEC/OECD, Anders, 2015). By comparing the results of German preschool teachers' willingness with the results of countries pursuing more academic curriculum approaches, more insight might be gained into the relationship between curricular approaches and teachers' intentions to foster early learning.

In a next step, teachers' self-reported willingness was combined with the results of a video analyses of teachers' practice in block play. The association between teachers' willingness to engage in scaffolding and their amount of scaffolding in a free block play episode was not significant. One possible reason could be that the willingness to engage in scaffolding was assessed across five science learning opportunities, including only one block play scenario. Therefore, the aggregated sum score of teachers' willingness across five different science contexts may not have accurately reflected teachers' context-specific readiness to participate in scaffolding activities during block play. As pointed out earlier, teachers' willingness to engage in learning activities might depend on their CK and PCK, which is strongly dependent on the content area being taught (e.g., Barenthien et al., 2018). A post-hoc exploratory analysis of the block play vignette and teachers' practice revealed no significant associations between teachers' willingness and their practice either. This contradicts the assumptions of the model proposed by Fröhlich-Gildhoff and colleagues (2011), however, certain limitations in measurement have to be considered, which will be outlined in chapter 8.7. Nonetheless, the dichotomy between teachers' dispositions and their actual practice is a concept that is often discussed in educational theory. On the basis of the results of study 1, no definitive inferences can be drawn about the associations between teachers' intention and their teaching practice. While it is theoretically assumed that teachers' dispositions linearly influence their practice, the missing correlation between teachers' willingness and their practice found in study 1 sheds light on the complex nature of this relationship. This is in line with a recent meta-analysis, which has demonstrated that the associations between teacher practice and its predictors are vague (Opoku et al., 2021). This might be due to the various factors which moderate the associations between teachers' dispositions and their practice, such as motivation, self-efficacy, or organizational circumstances (e.g., Kuo & Yang, 2008).

Knowledge

Another important aspect of teacher professional competence is knowledge. The model of Fröhlich-Gildhoff and colleagues (2011) highlights the impact of teachers' knowledge on their practice and the perception of learning opportunities. In line with this, Dunekacke and colleagues (2015) have demonstrated that preschool teachers' math CK significantly predicted their ability to perceive learning situations in math. Moreover, studies suggest that teachers' knowledge might be a significant predictor for quality and frequency of science teaching (Kallery & Psillos, 2001; McCray & Chen, 2012). On the basis of the empirical findings of Dunekacke and colleagues (2015), significant associations between teachers' CK or PCK and their willingness to engage in science teaching were expected. In study 1, teachers' willingness to engage in scaffolding or diagnosis teachers' recognition of the learning opportunity displayed in the vignette was an important premise. The results showed that PCK was positively associated with both, teachers' willingness to engage in scaffolding and their willingness to engage in diagnosis. This mirrors the importance of teachers' PCK in the recognition of learning opportunities, which is an important prerequisite for the provision of high-quality early science learning.

However, in Germany, preschool teachers' professional development does not prioritize science education, and limited access to dedicated workshops, training, and resources, focused on science teaching, can contribute to a lack of knowledge among preschool teachers (e.g., Lillvist et al., 2014). In line with this, the findings of study 1 indicated that teachers' CK in early science was limited, which mirrors previous empirical results (Garbett, 2003; Kallery &

Psillos, 2001; Yildirim, 2021). However, teachers' PCK was considerably higher, which might be attributed to the PCK-scale applied in the study (see chapter 8.7).

Beliefs

Next, the results of study 1 will be discussed regarding teacher beliefs. The results showed that preschool teachers valued the co-constructivist belief the most. Besides, autonomy beliefs were more pronounced than instructivist beliefs, but less than co-constructivist beliefs. At first glance, this might contradict the socio-pedagogic tradition in Germany, which stresses children's autonomy development (e.g., ECEC/OECD, Anders, 2015). However, it should be considered that (a) teachers' approval for the autonomy belief was still noticeably high and that (b) the items assessing co-construction did not focus on children's knowledge acquisition in preschool, but rather on the joint impact of teacher and children in conversations in inquiry-based activities (e.g., Schmidt & Smidt, 2021). Thus, preschool teachers might have also valued co-constructivist learning beliefs along with their autonomy-oriented beliefs. Further results showed that older teachers did not express co-constructivist beliefs to the same extent as their younger colleagues. This may be attributed to the influence of the autonomy-oriented tradition in Germany (e.g., ECE/OECD, Anders, 2015).

Moreover, the low reliability of teachers' autonomy-oriented beliefs points at the inconsistent nature of teacher beliefs, as stated by Buehl and Beck (2015). The authors have asserted that beliefs are components of a multidimensional system that permits the coexistence of contradictory viewpoints. Thus, preschool teachers may simultaneously hold co-constructivist, instructivist, and autonomy-oriented beliefs, each of which may have an impact on their context-specific teaching practices. The coexistence of contradictory beliefs among teachers makes it challenging to establish a causal relationship between their beliefs, willingness and teaching practices. Due to the inconsistent associations between beliefs and practice, some authors have argued for a mediating role of teacher beliefs on the association between knowledge and practice (e.g., Perren et al., 2017). Thus, when examining the association between teachers' dispositions and their practice, it might be valuable to conceptualize teacher beliefs in terms of self-efficacy to further clarify the relationship between teacher beliefs and teaching practice.

Interplay between willingness, knowledge, beliefs and practice

Next, the interplay between teachers' dispositions and their practice will be discussed in more-depth. The lack of associations between teachers' dispositions and their practice may be attributed to a discrepancy between teachers' knowledge, their learning beliefs, and their teaching practice. For example, teachers may acknowledge the significance of early science education and hold co-constructivist beliefs about science teaching and learning. Study 1 has shown that teachers who held co-constructivist beliefs were more willing to engage in scaffolding. This is in line with the idea that teachers, who hold co-constructivist learning beliefs, view learning as a dialogic and interactive relationship between teacher and children, wherein knowledge is collaboratively constructed and children's learning is scaffolded by the teacher (Chi & Menekse, 2015).

However, co-constructivist beliefs did not serve as predictors for preschool teachers' actual classroom practice. The finding that teachers' co-constructivist beliefs are not aligned with their teaching practice mirrors previous research findings (e.g., Leuchter et al., 2020; Mengstie, 2022). Some authors have argued that putting co-constructivist beliefs into action poses high demands on teachers' competences and especially on their knowledge, which might account for the missing association (e.g., Mansour, 2013). If teachers have limited knowledge about a specific content, their actual teaching practice may not align with their beliefs, as they might miss out the opportunity to foster children's science learning (e.g., Dunekacke et al., 2015). In other words, despite valuing certain educational approaches and holding specific beliefs, teachers' lack of knowledge may hinder them from effectively implementing those beliefs in their teaching practice. From that, it might be assumed that teachers' willingness remained vague due to their lack of knowledge and inconsistent beliefs, and thus had no predictive power for their actual teaching practice. Additionally, study 1 also showed that teachers' scaffolding was rather infrequent. This is in line with research, which has shown that in the rare occasion they engage in science teaching, they rarely apply scaffolding (Leuchter et al., 2020; Leuchter & Saalbach, 2014).

Besides, results indicated that preschool teachers' appreciation for co-constructivist beliefs decreased with age, however, age was the only significant predictor for teachers' use of scaffolding techniques, indicating that teachers' scaffolding activities increased with age. A possible explanation for this startling finding may be found in Hu and colleagues (2017). The authors argue that teachers' awareness and understanding of children's needs, development, thinking processes, and effective teaching strategies tends to increase with age. This is backed up by a cross-sectional study of Jenßen and colleagues (2022), however, it was mainly teachers PK, which increased with experience. Nonetheless, it is plausible that a similar pattern emerged in the present study, explaining the increased use of scaffolding by older teachers due to their enhanced PK, resulting in a higher understanding of children's learning and development. Nonetheless, teachers' CK and PCK was not associated with age. Thus, future studies should further examine this relationship.

To sum up, the associations between teachers' dispositions and their practice still remain unclear. However, it should be considered that the relationship between teachers' dispositions and their practice could strongly depend on resources, such as the availability of science materials, access to professional training, and time to play with the children. Currently, the lack of adequate science materials has shown to be one of the primary reasons why teachers may not engage in science learning (e.g., Sandstrom, 2012; Yildirim, 2021), which could weaken the associations between teachers' dispositions and practice. Besides, recent findings of Trauernicht and colleagues (2023) have shown that early childhood educators experiencing higher levels of emotional exhaustion tend to report engaging in fewer educational activities. This finding underscores the complexity of the relationship between teachers' dispositions and their actual teaching practices, emphasizing the necessity to consider manifold factors when examining this association.

Ultimately, the present dissertation cannot provide an exhaustive understanding of the association between teachers' dispositions and their practice, however, the consistencies found between teachers' beliefs and their willingness suggest that research on this association still remains a promising approach in the field of educational research. Future research should provide a deeper understanding of the mechanisms underlying the relationship between teachers' dispositions and their practice. This includes investigating mediating factors, exploring the role of contextual factors, and examining the impact of professional development programs on aligning teachers' dispositions with their instructional practices.

8.3 Research question II

Is preschool teachers' instructional quality related to

(a) children's domain-specific knowledge (i.e., stability in block play), their spatial language and math knowledge?

(b) Further, is preschool teachers' instructional quality related to children's academic self-concept?

Instructional Quality and children's knowledge

Study 2 was concerned with the examination of the relationship between teachers' instructional quality and children's knowledge. Some authors have hypothesized that the influence of instructional quality on children's knowledge may be subject-dependent rather than generic (e.g., Hall-Kenyon et al., 2009; Pohle et al., 2022; Senden et al., 2022). Thus, study 2 took a subject-specific approach and focused on the generic (i.e., sensitivity, general language use) and domain-specific dimensions (i.e., spatial and math language, scaffolding) of teachers' instructional quality in a free block play episode. To this end, a two-step approach was applied. First, an overall quality score of instructional quality in block play was computed. The findings showed that teachers' instructional quality during block play was associated with children's stability knowledge, but not with children’s spatial language or math knowledge. In a second step, correlations between teachers’ dimensions of instructional quality revealed that children’s stability knowledge was not associated with teachers’ generic dimensions of instructional quality, but with teachers’ domain-specific dimensions (i.e., teachers’ provision of verbal support by using spatial language, math language and scaffolding). Further, multiple regression analysis showed that only scaffolding was a significant predictor for children’s stability knowledge.

Both findings highlight that teachers’ instructional quality is associated with children's knowledge, particularly in the domain of stability. Nonetheless, the small correlation found in study 2 aligns with research, which has shown that associations between preschool teachers' instructional quality and children's knowledge are relatively small (e.g., Weiland et al., 2013). Further, the associations between teachers’ domain-specific verbal support and children’s stability knowledge as well as the lack of associations between teachers’ generic dimensions of instructional quality with children’s knowledge supports the hypothesis that the effectiveness of instructional quality may rather be subject-specific than generic (e.g., Hall-Kenyon et al., 2009; Pohle et al., 2022; Senden et al., 2022). Moreover, the association between teachers’ instructional quality in block play and children’s stability knowledge seemed to be mainly mediated by teachers’ scaffolding activities. This corroborates research on the beneficial effects of scaffolding on children’s knowledge (e.g., Hadzigeorgiou, 2002; Mermelshtine, 2017; Leuchter & Naber, 2019; Pine et al., 1999; Weber et al., 2020).

Overall, preschool teachers scored high in generic aspects of instructional quality dimensions. However, preschool teachers significantly varied in specific dimensions of instructional quality, i.e., their provision of verbal support during block play. Overall, teachers’ verbal support was rather infrequent. These findings are consistent with previous research indicating substantial variation in instructional quality among preschool teachers in providing enriching learning support (Hamre et al., 2014; Klibanoff et al., 2006; Pianta et al., 2008;

Spektor-Levy et al., 2013). Nonetheless, a striking finding is that scaffolding was positively associated with sensitivity and timing in instruction. This addresses one key feature in the scaffolding model of van de Pol and colleagues (2010), namely that effective scaffolding should be context-specific aligned to a child's efforts within its zone of proximal development (i.e., contingency aspect). Thus, preschool teachers seem to be able to provide contingent support, however, this support occurs quite infrequent. Besides, scaffolding was positively associated with spatial and math language. This indicates that teachers' scaffolding encompassed the use of content-specific language to promote children's understanding.

Instructional Quality and children's spatial language

Children's spatial language was significantly associated with teachers' stimulation of communication. This indicated that children might benefit in their ability to use spatial language from the frequency of teachers' general language use. However, children's spatial language was neither associated with other dimensions of instructional quality nor with teachers' use of spatial language, which contradicts the findings of Ferrara and colleagues (2011). This might have been due to the conceptualization of spatial and math language, which will be discussed in the next paragraph.

Instructional Quality and children's math skills

A rather surprising finding was that children's math knowledge was negatively associated with teachers' use of math language und unrelated to teachers' use of spatial language. One reason may be the conceptualization of math language in study 2. Studies have predominantly categorized shape names in terms of math language (e.g., Cannon et al., 2007; Verdine et al., 2019). The dichotomization of spatial and math language in study 2 could have contributed to the observed negative association between teachers' math language and children's math knowledge, as a significant portion of variance in math language might have been bound to spatial language, which impeded the isolation of specific effects of teacher language on children's skill development. A second reason may be that teachers' use of spatial and math language was only observed in a single block play episode. Studies, which have found significant correlations between teachers' math language and children's numeracy skills have used longitudinal study cohorts with at least 4 measurements (e.g., Purpura et al., 2021: 24 weeks; Toll & van Luit, 2014: 2 years). Third, it is important to acknowledge that, in study 2, preschool teachers infrequently used spatial and math language, which potentially led to an underestimation of the relationship between teachers' spatial and math language and children's math knowledge in our study.

Instructional quality and children's self-concept

The results showed that preschool teachers' generic dimensions of instructional quality in block play (i.e., general language use, interaction quality, sensitivity) as well as their verbal support (math language) were significantly associated with children's academic self-concept in block play. This significant association of children's academic self-concept with teachers' sensitivity shows that providing responsive and child-contingent feedback (i.e., sensitivity and interaction quality), as well as teachers' age-appropriate language (i.e., general language) use in block play might foster children's self-concept. Moreover, children's self-concept was found to be overly positive, which is in line with previous findings (e.g., Harter, 2015; Weber & Leuchter, 2022).

Children's self-concept and their knowledge

The lack of a significant relationship between children's academic self-concept and their knowledge contradicts the reciprocal effect model (Guay et al., 2003). According to this model, children's achievement should influence their self-concept (skill-development model) and children's self-concept should influence their achievement (self-enhancement model; Guay et al., 2003). However, research has shown that the correlation between academic self-concept and achievement is rather moderate, but tends to be stronger when specific parts of a person's academic self-concept related to particular subjects are considered (e.g., Valentine & DuBois, 2005). In study 2, children's academic self-concept was measured in the block play domain, and might thus not have had a direct impact on children's perception of their math or spatial language skills.

However, children's academic self-concept in block play was also unrelated to their stability knowledge. Weber and Leuchter (2022) have also examined preschool children's stability knowledge and their self-concept and found no significant associations. Following their reasoning, this might be the case because (a) the measurement of self-concept was primarily about children's self-concept in block play, which did not correspond to children's specific self-concept about stability and (b) preschool teachers' feedback during block play might have been overly positive and primarily focused on the visual aspects of children's block buildings, such as admiring their appearance. Thus, children might not have had many chances to learn about stability and consequently, their self-concept in block play shows weak associations to their stability knowledge (e.g., Weber & Leuchter, 2022). However, the design of study 2 did not allow to test for this hypothesis.

Further, the missing link between children's academic self-concept and their knowledge might be explained by (a) their relatively young age and (b) methodological issues that arised due to their age. Research has shown that the correlation between children's academic self-concept and their academic achievement increases with age (e.g., Arens et al., 2016; Guay et al., 2003). With children's growth, their academic self-concept becomes more accurate and thus aligns more with their subject-specific performance with school entry. This is probably related to children's school entry, as children begin to compare their performance with those of their peers (Arens et al., 2016; Helmke, 1999). As discussed above, children who participated in study 2 were not yet enrolled in school and thus might have received overly positive feedback from their preschool teachers and parents or no feedback at all (e.g., Harter, 2015; Helmke, 1999; Weber & Leuchter, 2022). Due to children's overly positive self-concept, ceiling effects occurred, which might account for the missing link between children's self-concept and their knowledge.

Children’s cognitive aspects and their math skills

To examine the associations between children’s cognitive aspects and their knowledge, bivariate correlations were examined. Children's math skills had significant associations with their spatial language capacity, age, cognitive abilities (including fluid intelligence, crystallized intelligence, and working memory), and language proficiency. The finding that children's math abilities were associated with their spatial language aligns with previous studies, which have shown that block play can effectively promote spatial and math skills through the use of spatial and math language (e.g., Borriello & Liben, 2018; Ferrara et al., 2011; Klibanoff et al., 2006; Toll & van Luit, 2014; Verdine et al., 2019). With this, the findings of study 2 underpin the assumption that math and spatial language are key factors in children’s development of spatial skills and math knowledge and that they help children to understand quantity and numerical relationships (e.g., Casey et al., 2008; Neumann et al., 2013).

The association between children's math knowledge and fluid intelligence, crystallized intelligence, and working memory can be explained by several factors. The math tasks applied in study 2 required abstract reasoning and the ability to apply logical thinking to solve numerical problems. Children with higher levels of fluid intelligence may be better equipped to understand math concepts, recognize patterns, and apply problem-solving strategies flexibly. Children with higher cognitive skills might thus perform better in math tasks as they can quickly analyze problems and generate solutions. This result shows that it is important for preschool teachers to consider children’s individual prerequisites when engaging in early science and math teaching.

Moreover, the positive relation between crystallized intelligence and math knowledge can be attributed to the acquisition of knowledge and expertise through prior learning and experience (e.g., Thorsen et al., 2014). As children learn and comprehend math concepts, they become better equipped to apply them in problem-solving scenarios. Moreover, in study 2, text-based math tasks built on children’s vocabulary and receptive understanding. The finding that native German-speaking children tended to outperform those whose native language was not

German further supports the notion that children's language ability is closely associated with their performance in math.

In addition, the math tasks in study 2 required the simultaneous retention of multiple information, such as remembering numbers and following steps in a calculation. Children with stronger working memory abilities are thought to have greater capacity to store, process and manipulate math information. This might explain the positive association between children’s working memory and their math scores (e.g., Emslander & Scherer, 2022; van den Bos et al., 2013). Besides, the finding that math knowledge and stability knowledge increased with age mirrors developmental effects of children’s cognitive skills (e.g., Grammer et al., 2013). However, longitudinal designs are needed to examine developmental trajectories of children’s skills as well as their association with age (Grammer et al., 2013).

Children’s cognitive aspects and their stability knowledge and spatial language

Further, the results of study 2 showed that children’s stability knowledge increased with age, which is in line with previous studies (e.g., Krist, 2010; Krist et al., 2005). It can be assumed that children acquire more knowledge about stability with age, as they continue to engage in block play. Further, study 2 showed that boys outperformed girls in the math test and displayed a greater level of interest in block play. This aligns with previous studies, which have shown a greater interest of boys in block play (e.g., Weber & Leuchter, 2020). Further, children’s interest in block play was found to have a positive association with math knowledge, which, in turn, was positively associated with knowledge of stability. This suggests that children’s interest in block play might mediate the relationship between boys’ stability knowledge and math achievement.

Besides, children's spatial language was found to be linked to their cognitive abilities, age, language proficiency, and math knowledge. This is in line with the justifications discussed above (i.e., developmental effects, general language proficiency and the close association of children’s numeracy skills and math, see Neumann et al., 2013; Toll & van Luit, 2014).

Moreover, the finding that children’s spatial language proficiency showed stronger correlations with (a) crystallized intelligence compared to (b) children’s working memory or their fluid intelligence, suggests convergent (a) and discriminant (b) validity of the applied measures.

Summarizing, study 2 provided initial insight into associations between preschool teachers’ instructional quality and children’s knowledge and academic self-concept. The study shows the importance of conceptualizing instructional quality and child outcomes in a well-defined way. As emphasized by Pohle and colleagues (2022), domain-specific aspects of instructional quality need to be considered in order to gain a comprehensive understanding of its effects on children's outcomes. By examining domain-specific instructional practices and children’s knowledge, researchers can better capture the nuances and complexities of the teaching-learning process in a particular context. Summarizing, based on the findings of study 2, it is plausible that teachers’ domain-specific instructional quality is associated with children’s domain-specific knowledge.

8.4 Research question III

Is the implementation of a block play curriculum effective with regard to

(a) a change in preschool teachers’ CK, PCK and practice (in free vs. guided play)?

(b) children’s learning in stability, spatial language and math knowledge?

(c) Further, how do different teacher trainings affect teachers’ practice in block play?

To examine the third research question concerning the implementation of a teacher training with a parsimonious block play curriculum, teachers were assigned to three different experimental conditions. Study 3 used a pre-post-follow-up design with two experimental groups (EG1 and EG2) and a control group (CG). Between the pre-test and post-test assessments, a training session aimed at enhancing CK and PCK of preschool teachers in block play was conducted in the experimental groups (EG1 and EG2). EG2 received a basic training, which encompassed the provision of handouts summing up relevant information about CK and PCK and verbal support in block play. EG1 also received an additional training, which involved modelling verbal support by the experimenter and promoted teachers’ active learning. Both groups received material and verbal scaffolds. The material scaffolds encompassed five playful activities to foster children’s stability knowledge. Verbal scaffolds encompassed information on stability, the use of scaffolding, and the integration of spatial and math language to promote children's learning. Children’s learning outcomes were defined in terms of stability knowledge, math knowledge and spatial language and were assessed in the pre-and post-test as well as in the follow-up session. In contrast to study 1 and 2, children's theories about stability were assessed with a standardized interview that included the presentation of pictures depicting six asymmetrical block constructions. Based on this interview, children were categorized into three groups: those, who had no theory, those who argued with an object’s geometrical center, and those who argued with an object’s mass.

Changes in knowledge and practice

Results indicated that, regardless of the experimental condition, preschool teachers did not exhibit any changes in their CK or PCK. This aligns with previous research that has shown limited changes in preschool teachers' competences after undergoing additional training (e.g., Jenßen et al., 2022; Piasta et al., 2015; Studhalter, 2017). However, contrary to the findings of Diamond and colleagues (2014), the present study revealed significant changes in teachers' practice. While Diamond and colleagues (2014) observed changes in teachers' disposition but not in their classroom practice, the current study shows the opposite. Different reasons might explain this discrepancy, such as (a) the specificity of the trainings or professional development programs implemented in each study, (b) the broadness of the curriculum and (c) the characteristics of the participating teachers. (a) The study of Diamond and colleagues (2014) comprised a 3-year professional development program with 5 days of workshops throughout the year. In contrast to that, the present study applied a short-term training, which was delivered during half an hour in the kindergarten classrooms. Thus, the teacher training in study 3 might have been too short to build up teachers’ CK and PCK. (b) The curriculum of Diamond and colleagues (2014) encompassed all science content standards for grade 5 in the United States and was not limited to a specific content area, whereas the curriculum material of study 3 only focused on children's stability knowledge in block play. Thus, the broadness of the transmitted content varied substantially between the two studies. A narrowly defined content might have facilitated teachers' change in practice, as the teacher training in study 3 encompassed the provision of verbal support, which was specifically aligned to the context of block play A review by Zaslow and colleagues (2010) indicated that professional development is more effective when it focuses on specific and clearly defined objectives that prioritize teaching practice. Thus, the difference in duration of the training and broadness of the content content may have contributed to the divergent findings between the studies. (c) The study of Diamond and colleagues (2014) was carried out with primary school teachers and children in the United States. Primary school teachers differed in their professional training from the preschool teachers of the present study. Further, primary school teachers might differ from preschool teachers regarding their PCK (Leuchter & Saalbach, 2014). Accordingly, primary school teachers might build more upon their prior PCK and CK when acquiring new knowledge, which might account for the difference in knowledge change between the studies.

In the present study, preschool teachers in the treatment groups demonstrated a higher level of scaffolding during free play after training compared to the control group. This shows that the teacher training was successful and that teachers also integrated verbal support in the free play. Hence, the positive impact of teacher training on teachers' verbal support was independent from the curriculum materials. Nonetheless, EG1 used more scaffolding during free play than EG2. During guided play, both experimental groups showed a significant increase in the use of scaffolding, spatial language, and math language during guided play with the curriculum materials compared to free play. This result shows that the provision of curriculum material had an additional positive effect on teachers' practice beyond the teacher training. This finding also highlights the effectiveness of guided play in promoting the integration of scaffolding strategies and language development in early science education, which mirrors the findings of previous studies (e.g., Casey et al., 2008; Ferrara et al., 2011; Weber et al., 2020). However, the control group did neither change in their use of scaffolding, nor in their use of spatial and math language in the pre- and post-test.

Furthermore, EG1, which received additional training, showed a significantly higher use of scaffolding techniques during guided play compared to EG2. This suggests that the additional training showed incremental effects on teachers' change in practice in EG1. The additional training involved (a) the modelling of the provision of verbal support during guided play by the experimenter and (b) active learning opportunities for teachers with recommendations being made by the experimenter on how to improve teaching practice. With that, the additional training in EG1 addressed the second core feature of teacher training effectiveness, as discussed by Garet and colleagues (2001), which is active learning. The findings of study 3 thus corroborate research, which has shown that active learning and giving feedback on teaching practice heightens the effectiveness of teacher education programs (e.g., Garet et al., 2001) Further, it can be hypothesized that the experimenter might have served as a role model for preschool teachers in the application of verbal support. Based on this, the opportunity to observe behavioral models might be identified as another key factor in developing professional teaching practices among preschool teachers. Further, following Garet and colleagues (2001), the training was carried out within the kindergartens and teachers participated collectively. Both aspects have been identified as structural features, which have been shown to impact the effectiveness of teacher professional development in changing teachers' practice.

Children's reasoning about stability

Children receiving material and verbal scaffolding during guided play did not improve in their ability to explain stability with mass, which contradicts the findings of Weber and colleagues (2020). However, children in study 3 did not participate in an intervention led by the experimenter. Instead, preschool teachers were provided with training and were encouraged to implement the curriculum themselves. Additionally, teachers were instructed to keep a record of how frequently they used the curriculum materials. Exploratory analyzes revealed that preschool teachers in both experimental groups (EG1 and EG2) used the curriculum material less than two times during the three-week period between training and post-test, and even less than one time on average between post-test and follow-up. Thus, the lack of a change in children's theory acquisition regarding stability may be attributed to the infrequent use of the materials by the teachers. However, the study of Weber and colleagues (2020) has shown that children can adopt mass theory after having participated in a one-hour-session of playful instruction with the experimenter. Nonetheless, the experimenter of their study was an expert in providing verbal support. Yet, in the present study, teachers had to implement the playful activities themselves. Based on the finding of study 1 that teachers' CK about stability was found to be low, it can be hypothesized that their infrequent teaching approaches might have been ineffective, which aligns with the prior research findings about teachers' process quality in math and science teaching (Engel et al., 2013; Tu, 2006). Regarding teachers' infrequent use of the curriculum, future studies should (a) promote implementation fidelity among preschool teachers and (b) provide more assistance in planning and teaching early science (e.g., Diamond et al., 2014).

Children's spatial language

Regarding the effect of the curriculum on children's spatial language, the findings of the study indicated that children did not improve in their spatial language ability over time. This observation aligns with the findings of Ferrara and colleagues (2011), who have found similar results with 3- to 5-year-old children. However, Ferrara and colleagues (2011) suggested that children between the ages of 3 and 5 may be more focused on the physical manipulation of materials during block play, which may have led to fewer spatial utterances in their interactions with parents or peers. Further, Ferrara and colleagues (2011) hypothesized that older children, around 6 to 7 years old, possess a broader range of conversational and block-building skills, and would thus exhibit higher levels of spatial language during block play. The lack of improvement in children's spatial language ability over time may suggest that the development of spatial language skills during block play follows a developmental trajectory, with notable progress occurring during later stages of childhood. However, in study 3, children’s lack of improvement was probably missing due to their high performance in the spatial language test at the pre-test. The occurrence of ceiling effects in the spatial language test will be discussed more in-depth in chapter 8.7.

Growth in Math

Regarding the effect of the curriculum material on children’ math knowledge, the results indicated a significant improvement in math from pre-test to post-test of the children in the experimental groups. This finding aligns with previous studies which have highlighted the effectiveness of block play curricula in enhancing children's math skills (Bower et al., 2020; Giebitz, 2018; Lee & Kim, 2018; Zhang & Lin, 2015). In the present case, children’s change was significantly predicted by their math score at pre-test, their age as well as their fluid intelligence. Hence, study 3 corroborates the findings of study 2 about the role of children’s cognitive aspects for their knowledge.

Furthermore, the experimental condition in this study yielded a positive effect on children's growth in math knowledge. Results showed that the increase in math understanding was higher for children in the experimental groups compared to the control group. This suggests that the teacher training with the block play curriculum had a beneficial impact on children's math learning. This change might be attributed to the specific characteristics of the curriculum materials given to the EGs. The material scaffolds were designed to foster children’s spatial thinking, which might, in turn, have had a positive impact on children’s math knowledge (e.g., Bower et al., 2020; Verdine et al., 2019). Moreover, teachers’ increased use of scaffolding, spatial language, and math language observed during the play after the training might account for children’s enhancement in math. Nonetheless, exploratory analyses showed that teachers rarely used the curriculum material. Two reasons might explain children's increase in math knowledge regardless of teachers' infrequent use of the curriculum. First, the training might have caused teachers to engage more in early math instruction as the potential of block play to foster children's math knowledge was emphasized in the training sessions. Second, Bower and colleagues (2020) have shown that inherent features of block play itself might foster children's math skills: they found children's structural complexity in block play at age 3 to significantly associated with children's numeracy knowledge at that age (Bower et al., 2020). Thus, children's additional time spent with building blocks might have enhanced their math understanding. However, the finding that the control group exhibited no increase in math knowledge despite having access to the same set of blocks contradicts this assumption.

Teacher language

Regarding the effect of teacher language on children's learning, exploratory analyses revealed that children's improvement in math was not associated with preschool teachers' use of scaffolding, spatial language, or math language. This finding contradicts the results of several studies, which have shown positive associations between math and spatial language and children's math knowledge (e.g., Espinas & Fuchs, 2022; Ferrara et al., 2011; Gibson et al., 2020; Purpura et al., 2021; Purpura et al. 2019; Toll & van Luit 2014). However, it is important to note that study 3 assessed preschool teachers' use of spatial and math language only during a 30-minute block play episode. To fully understand the effects of math and spatial language on math knowledge, it may be necessary to analyze these factors over a longer period of time. Furthermore, it is important to acknowledge that the two constructs of spatial and math language partially overlap. For instance, geometrical terms can be attributed to either spatial or math language, which complicates the process of disentangling the two constructs and isolating their individual effects on math learning (e.g., Cannon et al., 2007; Verdine et al., 2019). This inherent overlap adds another layer of complexity to the study of the relationship between spatial and math language and their impact on math learning outcomes and might have accounted for the missing effects between teachers' language use and children's increase in math knowledge.

Summarizing, study 3 showed that teacher training with parsimonious curriculum can change preschool teachers' practice in a specific domain. Moreover, results showed that children in the experimental groups improved in their math skills. Based on these findings, the present dissertation calls for designing early science curricula that incorporate guided play activities with both, material and verbal scaffolds, to enhance children's learning experiences. Further, the results of study 3 show that it is possible to change teachers' practice without necessarily changing underlying knowledge. Nevertheless, the sustainability of such changes in practice may be questionable if there has been no fundamental shift in teachers' CK and PCK. In this case, it might be hypothesized that important steps for maintaining professional practice, such as self-reflection and evaluation (e.g., Fröhlich-Gildhoff et al., 2011), may not occur. Therefore, the question of long-term sustainability of practice changes without corresponding shifts in knowledge and beliefs remains unanswered and should be addressed in future studies. Summarizing, study 3 provides evidence supporting the effectiveness of teacher trainings with early science curricula in transforming preschool teachers' instructional practices and promoting children's learning.

8.5 Synthesis of the findings

Taken together, the present dissertation shows that research on the interplay between teachers' dispositions, their practice and children's learning is an important, yet understudied research topic. The results of the three studies can be framed within the model of professional competence of Fröhlich-Gildhoff and colleagues (2011). First, study 1 showed that the interplay between teachers' dispositions and their practice is not as linear as proposed in the theoretical model. Further, the results corroborated research on preschool teachers' limited science knowledge and the contradictory nature of teacher beliefs. Teachers' willingness did not predict teachers' classroom practice, which might be attributed to their low CK. This might imply that path coefficients between different competence facets (i.e., dispositions) and teachers' intention might depend on the strength of individual precursors (i.e., amount of knowledge). Considering this, the predictive power of willingness for teacher practice might vary across different contexts and situations, but also within the same context, depending on teachers' preparedness for teaching and on individual characteristics, such as self-efficacy. Further, the competence model hypothesizes that teachers need to perceive learning situations as potentially fruitful (e.g., Fröhlich-Gildhoff et al., 2011). In study 1, this was the case for the majority of preschool teachers, however, their willingness to engage in diagnosis was higher than their willingness to scaffold early science learning, which might also mirror the effect of preschool teachers' limited science CK.

Study 2 expanded this view by examining preschool teachers' practice (i.e., instructional quality) more in-depth and its associations with children's knowledge. The results indicated that teacher practice was associated with children's knowledge, although effect sizes were rather small. Moreover, children's individual cognitive prerequisites accounted for differences in children's skill level. Regression analyses showed that teachers' scaffolding was the only predictor for children's knowledge. As pointed out earlier, teachers' need adequate CK and especially PCK to foster children's knowledge. PCK also includes knowledge on how to structure and adapt the topic to align with individual interests and abilities of preschool-aged children. However, in the competence model of Fröhlich-Gildhoff and colleagues (2011), teachers' knowledge is introduced in a rather generic way. The present dissertation took a closer look at teachers' knowledge and differentiated between teachers' CK and PCK.

Study 3 built on the findings of study 1 and 2 and examined whether the implementation of a parsimonious curriculum accompanied by a teacher training changes teachers' knowledge, their practice and children's learning. The findings of study 3 showed that preschool teachers' practice is malleable, as significant changes in teachers' use of scaffolding were found after the training. Moreover, study 3 corroborates the findings of study 2: children in the experimental groups increased their math knowledge, which suggested that teachers' change in practice had an impact on children's knowledge. However, changes in teachers' knowledge were missing. This points at a limitation of the theoretical model by Fröhlich-Gildhoff and colleagues (2011), as the results show, that the association between teachers' knowledge and their practice are not linear. Future studies should examine more variables, which influence teacher practice. Besides, according to the competence model, teachers evaluate their teaching and draw inferences about it, which, in turn, should affect their knowledge and skills (Fröhlich-Gildhoff et al., 2011). However, this path remains unexplored in the present study. Nevertheless, it might be hypothesized that this feedback process is also strongly influenced by both, teachers' knowledge and teaching practice, which makes it even more valuable to promote these two components

Up to date, the theoretical model of competence proposed by Fröhlich-Gildhoff and colleagues (2011) has seen limited conceptualization so far. The present dissertation adapted the model by introducing a willingness-component and differentiating teachers' knowledge into CK and PCK. The thesis shows that the model can serve as a fruitful theoretical groundwork to examine teacher dispositions and practice as well as their association with children's knowledge and learning.

8.6 Method Discussion

This subchapter is concerned with methodological issues when carrying out experiments in preschool settings. The methodological issues faced in this dissertation in relation to research in preschool settings concern (a) the experimental manipulation of instructional quality, (b) small sample sizes and high drop-out rates and (c) threats to internal validity. Specific limitations regarding the measures, the sample and the procedure of the present dissertation are discussed in subchapter 8.7.

(a) Establishing a causal relationship between teachers' instructional quality and children's knowledge or learning is difficult for several reasons, which was particularly relevant for study 2. Isolating the effects of instructional quality in an experimental design is hardly possible, as exposing children purposefully to low instructional quality bears significant ethical obstacles. Thus, quasi-experimental approaches without randomization and manipulation have to be applied when examining associations between teachers' instructional quality and children's outcomes. In study 2, teachers' practice was observed in a pre-test, and it was hypothesized that their observed practice in a free block play episode corresponded to their overall instructional quality in early science learning. However, this correlational approach did not allow to draw causal inferences about the relationship between instructional quality and children's knowledge. Moreover, establishing a causal relationship between teachers' instructional quality and children's knowledge is challenging not only due to experimental designs but also due to a) the complex and multifaceted nature of classrooms (e.g., Hamre & Pianta, 2007; LaParo et al., 2009), b) contextual factors, which confound with teachers' instructional quality, such as resources (e.g., availability of materials, staffing) or access to professional development programs aimed at enhancing teachers' practice (e.g., Tu et al., 2006), (c) children's individual characteristics (e.g., cognitive and self-related aspects; Weber et al., 2020; Weber & Leuchter, 2022), and (d) children's home environment (e.g., Campbell & Verna, 2007). Besides, in longitudinal designs, children's learning may also be a product of their developmental progression that they undergo during the course of the study (e.g., Grammer et al., 2013). Consequently, it becomes difficult to isolate the specific impact of instructional quality on children's knowledge, which further challenges the studies' scope to establish a causal relationship.

(b) Another methodological problem in preschool settings and in longitudinal studies is the high drop-out rate, which generally leads to small sample sizes and thus a limited statistical power for statistical analyses. Many reasons can explain the high drop-out rate (e.g., limited teacher or parent involvement or unforeseen circumstances, data acquisition during COVID-19 pandemic). The high drop-out rates impair data quality and thus reduce the power of statistical analyses, which affected all three studies of the dissertation. Further, a high drop-out rate limits the number of participating classrooms, which restricts the use of advanced statistical techniques such as multilevel modelling or higher order linear modelling. This was particularly problematic for the confirmatory factor analysis (CFA) in study 1. Latent or structural equation modelling, require an adequate number of participants too to ensure the reliability of the results and to make models converge. In study 1, an item-based model did not converge, thus, items were parceled. However, this seems to have negligible effects on parameter estimates or standard errors in CFA (Nasser-Abu Alhija & Wisenbaker, 2006). In study 3, multilevel modelling of teacher practice was not feasible due to small classroom sizes. Moreover, in study 3, varying sample sizes at pre-test, post-test, and follow-up accounted for differences in statistical power between analyses in detecting significant effects of teachers' practice on children's learning and the effects of teacher training on teachers' practice. Other researchers have encountered similar statistical limitations as the author of this dissertation (e.g., Nayfeld et al., 2011).

(c) The abovementioned methodological issues pose a significant threat to internal validity of the results, whereas external validity, i.e., the generalizability to real-world settings, is less affected. Validation considerations play a crucial role in preschool studies, and researchers should reflect on whether maintaining strict control over variables and minimizing confounding influences must be prioritized throughout the course of their study. Despite the inherent methodological limitations of conducting studies within the preschool context, the finding of study 3, that the implementation of a block play curriculum had a positive impact on children's math knowledge, holds ecological validity and carries practical implications for preschool settings. However, it is important to note that every factor that threatens internal validity also poses a threat to external validity, as valid conclusions are only feasible if causality between variables is ensured. Therefore, researchers must strike a balance between ensuring internal validity and maintaining external validity.

Based on the abovementioned restrictions and limitations of longitudinal studies in preschool settings, the following recommendations for researchers are made. First, researchers should consider the factors that can be controlled for through their study design. This involves identifying variables that can be manipulated or held constant, the careful selection of reliable and valid instruments, good training of the research assistants or the use of automated scoring systems to minimize potential biases. Further, background variables on the teacher (e.g., knowledge, beliefs, self-efficacy, exhaustion) and child level (e.g., size of the classroom, years of experience, language capacity, home environment) should be carefully assessed. In a next step, researchers can account for these variables in their analyses, allowing for a more precise control and examination of their potential influence on the children's outcomes. Moreover, as outlined by Grammer and colleagues (2013), when carrying out longitudinal studies, researchers should invest in good relationships with the participants to ensure their commitment over the course of the study (Grammer et al., 2013).

Taken together, an effective approach in preschool research involves a multimethod strategy, which includes the application of questionnaires, behavioral analyzes, and interviews. Combining data from different sources expands the scope for statistical analyzes and researchers might be able to identify more nuanced relationships and patterns. This allows for a more precise and comprehensive interpretation of the results and contributes to a deeper understanding of the complex interplay between teachers' instructional quality and children's outcomes.

8.7 Limitations and future research

The specific limitations of the present dissertation will now be discussed in more detail. First, limitations regarding the measurement will be discussed.

Limitations regarding measurements

The measurement of children's stability knowledge had a 50% probability of guessing the correct answer. Given this, the validity of the measurement of children's stability knowledge is limited. Further, children's behavior during block play, e.g., children’s spatial utterances, was not analyzed. This might have provided a deeper understanding of children’s spatial language development and offered more fine-grained analyses about the association between children’s spatial language and their math knowledge.

Furthermore, it is worth noting that children's academic self-concept was measured only in block play. As mentioned earlier, certain aspects of children’s academic self-concept, which are particularly related to their understanding of stability, might have not been assessed. This could potentially explain the lack of correlations between children’s stability knowledge and academic self-concept in study 2.

Another limitation in the measurement concerns the occurrence of ceiling effects in children’s spatial language test applied in studies 2 and 3. The test might have been too easy for children, particularly for the older ones. This might also explain that children showed no further improvement in their spatial language between pre- and post-test. Future studies should assess children’s spatial language either with a situation-based approach (i.e., counting spatial utterances in a defined sequence) or adapt the spatial language test by adding more difficult items.

Moreover, the same test that was used to assess children’s stability knowledge was also applied with the teachers. Thus, teachers had the same 50% probability of guessing the right answer, which is a significant limitation in the measurement of teachers’ CK. Whereas children’s theories about stability were examined with a standardized interview, preschool teachers’ theories about stability were not measured. Future studies should also assess teachers’ theories about stability to gain deeper insights into teachers’ understanding of stability. Besides, ceiling effects occurred within the PCK-scale. The ceiling effect might mirror social desirability since teachers’ PCK was assessed with statements, that had to be rated concerning their appropriateness for block play (e.g., *is it feasible to foster children’s stability knowledge in block play?*). Further, all 10 statements only encompassed aspects, which were considered to be appropriate in block play. Future studies should expand this scale by adding items containing inappropriate aspects (e.g., fostering children's reading skills during block play) to differentiate more validly between teachers with high or low PCK and to control acquiescence response bias (i.e., the tendency to select a positive response).

Another limitation encountered in study 1 was the mediocre reliability of teachers' autonomy beliefs. However, teachers' beliefs were only measured via 4 items per dimension. It can be hypothesized that an increase in the number of items per dimension would have enhanced the reliability of the measurement. Further, beliefs are thought to constitute a multidimensional system, which allows for the coexistence of contradictory beliefs (Buehl & Beck, 2015). Following this assumption, the low internal consistency might reflect teachers' inconsistency regarding their own beliefs. Moreover, viewing beliefs as multifaceted amplifiers for teachers' practice would also suggest considering beliefs as a more formative construct. A formative construct is primarily developed through manifest observations whereas a reflective model primarily reflects in manifest behaviors (Stadler et al., 2021). Based on the assumption that beliefs are formative rather than reflective constructs, the missing association between teacher beliefs and teacher practice can be better understood. Further, it has been argued that, in the case of formative constructs, items should be carefully selected based on the theoretical background rather than on their intercorrelation or homogeneity within the scale (e.g., Stadler et al., 2021). Moreover, future studies should assess and conceptualize teacher beliefs in terms of teacher self-efficacy as research suggests that self-efficacy is more predictive for teacher behavior than teachers' attitudes (Perren et al., 2017).

A further limitation of the studies concerned the rating of teachers' scaffolding activity. In study 1, preschool teachers' scaffolding activity was rated on a four-point scale. Thus, a rather generic method was employed, while in study 2 and 3, 10-second-blocks of the video sequences were analyzed and the occurrence of eight different scaffolding techniques was coded, which was a more fine-grained approach. This lowered the comparability between the results of the three studies. Besides, teachers' knowledge regarding scaffolding, spatial language, and math language was not assessed after the training. This might have been a potential misalignment between the content of the teacher trainings and the knowledge aspects covered by the questionnaire.

Moreover, teachers' willingness was measured with 5 vignettes, each of which displayed a science learning opportunity. However, only one vignette was concerned with block play. At the same time, there is evidence that the predictive power of teachers' unspecific beliefs and attitudes on specific classroom practices remains rather small (e.g., Kuo & Young, 2008). Nonetheless, an explorative analysis showed that teachers' willingness in the block play vignette was not associated with preschool teachers' practice either. Yet, to gain deeper insights into the association between teachers' intentions and their practice, future studies should expand the number of items to measure preschool teachers' willingness to engage in block play more precisely.

Moreover, the approach to measure teachers' willingness with vignettes allowed to draw inferences about teachers' intention to engage in a specific behavior; however, the question why they intended to do so remained unanswered. Hence, to draw inferences about teachers' motivation to engage in a particular teaching practice, the vignettes should be accompanied by an open-ended question, asking teachers about their reasons for their willingness to engage in learning support or why they decided to stay inactive.

Besides, future research should consider contextual factors (i.e., classroom sizes, availability of science materials and curricula) as well as individual factors (i.e., exhaustion, years of experience) more in-depth. Taking these aspects into account might contribute to the clarification of the association between teacher dispositions and their practice. Ultimately, technical artefacts posed challenges in the analysis of the videos, resulting in the exclusion of two videos from the data analysis.

Limitations regarding sample

A significant limitation regarding the sample was the high drop-out rate of teachers and children over the course of the study, which has already been discussed in chapter 8.6. This might have lowered the representativeness of the sample. Moreover, the problem of nonrandom missingness emerges. However, the main reason for the high drop-out concerned intermittent closures of kindergartens due to the COVID-19 pandemic. Thus, it can be considered unlikely that missing values were not at random (i.e., dependent on the participants’ motivation or compliance).

Limitations regarding procedure

In study 1, factorial validity of the vignette-based approach to measure willingness was tested. However, other aspects of validity were not considered. Future studies should also investigate criterial and predictive validity of the instrument.

Study 2 took a correlational approach, which did not allow to draw inferences about causality. However, considering the restricted possibilities in manipulating instructional quality (see subchapter 8.6), the results provided first insights into the relationship between teachers’ practice and children’s knowledge. Nonetheless, future studies should carefully consider their experimental design to further investigate this relationship. One potential approach could involve using a pre-post-follow-up design to investigate teachers' instructional quality in a new domain or subject area that the children are unfamiliar with or have limited exposure to. By doing so, researchers can better isolate the potential impact of teachers' practice on children's learning outcomes in a new and unknown context. This approach would provide valuable insights into the transferability of instructional quality across different domains and shed light on the effectiveness of teachers' practices in a specific subject area.

In study 3, the duration of the teacher training program was relatively short and the curriculum material was quite parsimonious compared to other studies (cf. Diamond et al., 2014). This might have negatively affected the frequency of teachers’ implementation of the curriculum materials. Despite the encouragement for teachers to use the curriculum materials as frequently as possible, an examination of the protocols revealed that teachers rarely implemented the curriculum. However, it should be noted that the training in study 3 only aimed to foster teachers' CK and PCK, but not to change their beliefs or attitudes towards teaching or early science learning. Thus, future studies should target teachers' beliefs and attitudes concerning the curriculum in order to promote implementation fidelity (e.g., Darling-Hammond & Bransford, 2005). This can involve providing recommendations for modifying or expanding the activities outlined in the curriculum (Howes et al., 2012) or promoting the transfer of effective teaching practices by offering illustrative examples (Howes et al., 2012). Further, university seminars with preservice-teachers have been shown to be successful in changing student's expectations and values towards a specific teaching content and might be a promising approach to enhance teacher commitment (e.g., Weber et al., 2022).

To this end, it is crucial for future studies to delve deeper into the exploration of strategies for building professional knowledge and transforming teacher beliefs to foster teachers' active involvement in high-quality early science education. Yet, it is worth noting that the significant change in teachers' practice and the improvement observed in children's math skills within the experimental groups are remarkable findings, which highlight the effectiveness of short interventions in enhancing teachers' practice and facilitating children's learning outcomes. In future studies, it is crucial to address the methodological issues outlined in chapter 8.6. Additionally, it is recommended that future studies extend the duration of the teacher training. Longer training periods would allow for a more comprehensive exploration of the training's impact on the desired outcomes. Furthermore, future research should foster teachers' implementation fidelity and carry out follow-up tests over an extended period of time (i.e., follow-up-test after six months) to examine the long-term effects of the teacher training.

Despite these limitations, the present dissertation significantly contributes to research on early science education. The three articles provide valuable insights into the associations between teachers' dispositions and their practice, the relationship between teachers' instructional quality and children's knowledge, and the implementation of early science curricula as well as the effects of guided play and teacher training.

8.8 Conclusion and implications

The primary objective of this dissertation was to contribute to the existing research on preschool teachers’ knowledge in science, their instructional quality, and the interplay between dispositions and practice. Moreover, the thesis aimed to provide first insights into the association between teachers’ instructional quality and children’s knowledge, thereby considering children’s self-related and cognitive aspects. Further, the present dissertation drew upon research on the successful implementation of teacher trainings accompanied by science curricula and examined the effect of a play-based block play curriculum on teachers’ knowledge, and practice as well as children’s learning. The three articles presented within the dissertation demonstrated that preschool teachers’ willingness to engage in science learning can be validly measured. However, there are still inconsistencies within teachers’ dispositions, and the associations between teachers’ dispositions and teachers’ practice remain inconsistent. The findings of study 2 indicate that preschool teachers’ instructional quality in block play is associated with children’s knowledge about stability. Moreover, study 3 underscores the effectiveness of teacher trainings with parsimonious curricula in preschool settings. The results demonstrated that the block play curriculum led to positive changes in preschool teachers' teaching practice and fostered children's math knowledge. This finding highlights the potential of block play as a valuable tool for promoting the development of math skills in young children. The implications of this finding are significant, as it suggests that integrating block play activities into the curriculum can be a promising approach to enhance children's math learning experiences in preschool. Further, the thesis shows that guided play should be integrated into preschool teachers’ practice (study 3) and emphasizes the need to consider children's individual prerequisites when teaching early science (study 2 and 3). The thesis suggests that teacher professional development should focus on enhancing teachers' understanding of scientific concepts and inquiry-based approaches, as well as providing them with strategies for scaffolding children's learning. Overall, the dissertation contributes to the research on teachers' professional competences in early childhood science education. The dissertation highlights the importance of preparing teachers for early science education to foster children's learning and draws attention to the need for further research in the field of curriculum development. Further, the present findings serve as a basis for advancing teacher training programs to improve the teaching quality of early science in preschool.

9. References

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10. Appendices

Appendix A CV

Appendix B Declaration of originality

Appendix C Authorship and publication status

Appendix D Supplementary materials (curriculum material)

Appendix E Supplementary materials (handouts)

Appendix F Articles 1 and 2 (first site)

Appendix A: CV

LUKAS SCHMITT

CAREER

Research associate	**University of Koblenz-Landau/ RPTU Kaiserslautern-Landau** | Landau, Germany *Institute for Children and Youth Education, Primary School Education*
Since 2021-10	Conception, planning and realization of science seminars for primary school teacher students; supervising master theses
2021-07/2023-06	Project PFKiNaT – Playing with building blocks, funded by the German Research Association. Development of test instruments, planning and conducting of experiments on children's knowledge in block play and training of preschool teachers with a block play curriculum; data analyzes; supervising the student researchers
Student Researcher	**Saarland University** | Saarbrücken, Germany
2020-10/2021-02	Tutor for multivariate data analysis (Prof. Dr. Dirk Wentura)

EDUCATION

Doctoral studies	**University of Koblenz-Landau/ RPTU Kaiserslautern-Landau** | Landau, Germany
Since 2021-07	As a psychologist in educational sciences
M.Sc. Psychology	**Saarland University** | Saarbrücken, Germany

2019-10/2021-05 Graduation grade: 1.1 (very good)

B.Sc. Psychology • **Saarland University** | Saarbrücken, Germany

2016-10/2019-09 Graduation grade: 1.2 (very good)

Abitur • Kaiserslautern, Germany

2016-03 Graduation grade: 1.0 (very good)

KNOWLEDGE & SKILLS

Languages: fluent German (native language), English; basic French

Technical skills: office suites; statistics software R, SPSS

Statistical procedures: cross-sectional and longitudinal data; structural equation models, path analyzes, item response modelling, latent state-trait modelling, higher linear models

Landau, 2023-07-13

Lukas Schmitt, M.Sc.

Appendix B: Declaration of originality

I hereby declare that I have written the present dissertation independently, without assistance from external parties and without the use of other resources than those indicated. During the preparation of this work the author used DeepL Write and ChatGPT. AI did not write paragraphs or generated content, but was used to improve language and readability. After using these tools, the author reviewed and edited the content as needed and takes full responsibility for the content of the dissertation. This dissertation has not been submitted previously for grading at this university or any other academic institution.

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Appendix C: Authorship and publication status

The articles presented in the present dissertation were submitted for publication or have been published in international peer-reviewed journals. In collaboration with the co-authors, the articles were primarily written by Lukas Schmitt, doctoral candidate at the Institute for Children and Youth Education, RPTU Kaiserslautern-Landau. The authors and publication statuses of the articles are entitled in the following.

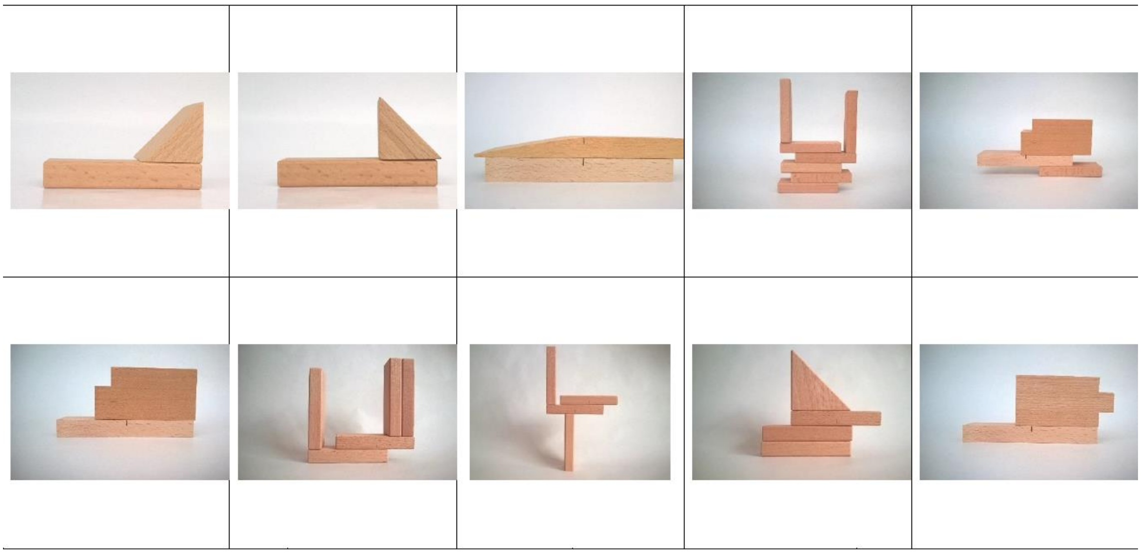
Article 1: Schmitt, L., Weber, A., Venitz, L., & Leuchter, M. (2023). Preschool Teachers' Pedagogical Content Knowledge Predicts Willingness to Scaffold Early Science Learning. *British Journal of Educational Psychology*, online first, 0-0. https://doi.org/10.1111/bjep.12618

Article 2: Schmitt, L., Weber, A., Weber, D., & Leuchter, M. (2023). First Insights into Preschool Teachers' Instructional Quality in Block Play and its Associations with Children's Knowledge, Interest, Academic Self-Concept and Cognitive Aspects. *Early Education and Development*, online first, 0-0. https://doi.org/10.1080/10409289.2023.2233879

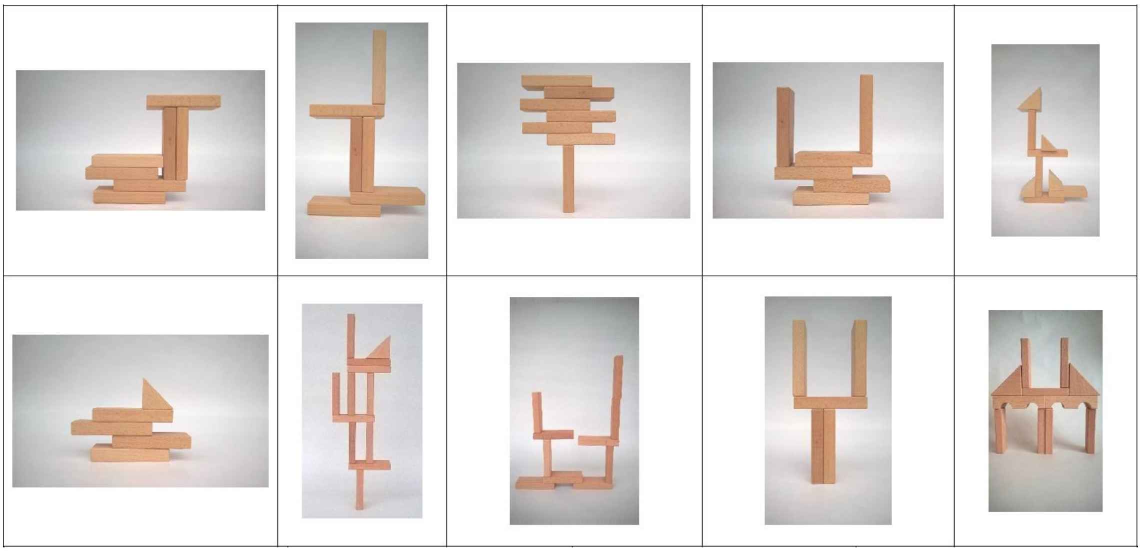
Article 3: Schmitt, L., Weber, A., & Leuchter, M. (2023). Implementation of a Block Play Curriculum in Kindergarten Enhances Preschool Teachers' Scaffolding Activities and Promotes Mathematical Learning in Children. Manuscript submitted for publication at *Early Childhood Research Quarterly*.

Appendix D: Supplementary materials (curriculum material)

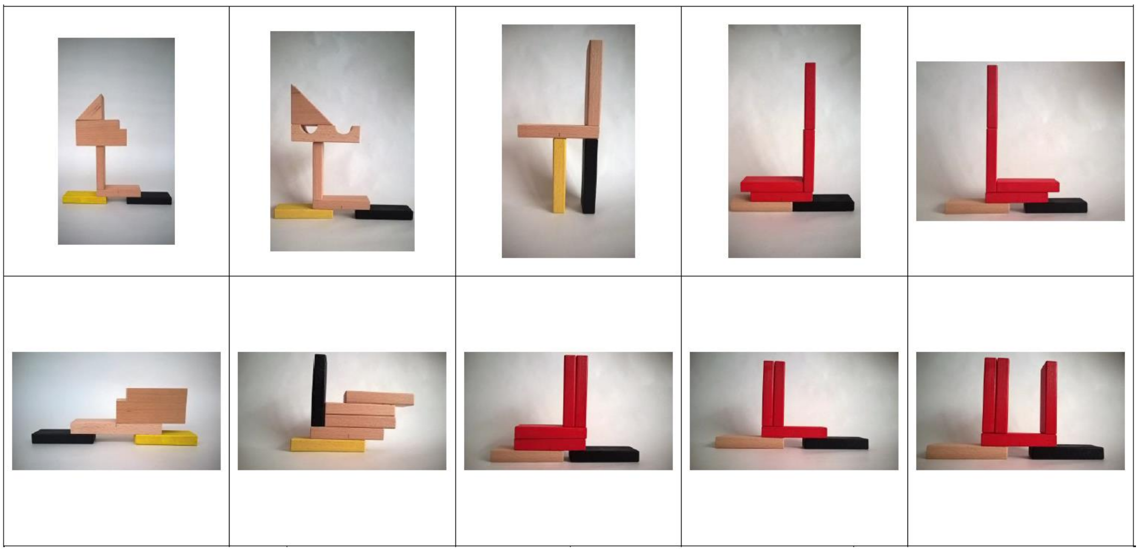
(1) Sliding (10 photographs): This activity is called the sliding play. First, you reconstruct the building shown in the photograph. Next, you move the upper block across the lower block until it eventually collapses (as demonstrated by the experimenter). That's noisy, isn't it?



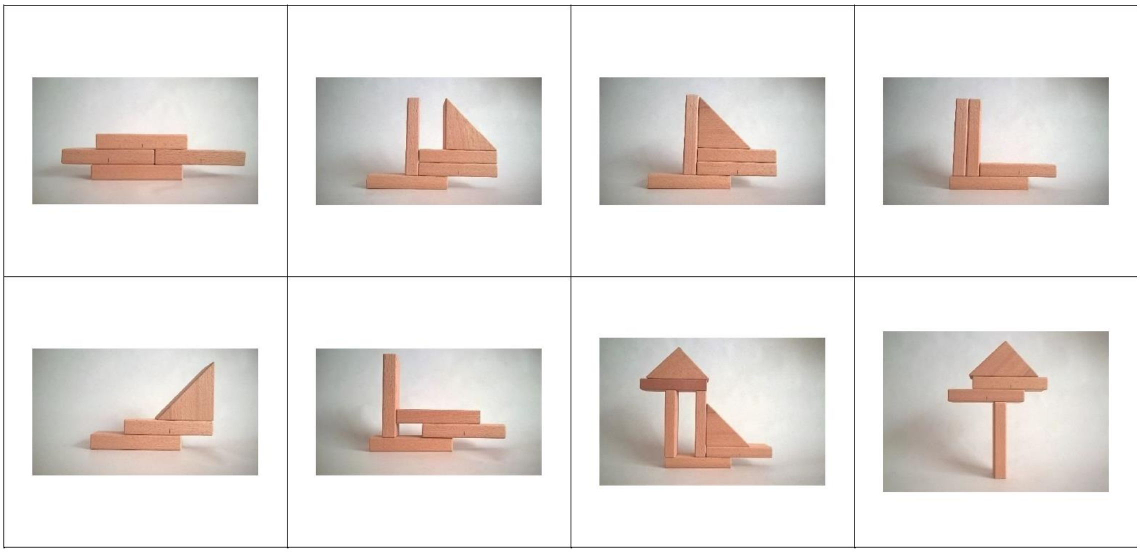
(2) Rebuild (10 photographs): By looking at these photographs, you can simply reconstruct the buildings and see how well you did. While some structures are simple to build, others may be harder. But, if you construct them right, each building will remain stable.



(3) Black block (10 photographs): Construct the building that is shown in the photograph and say whether the blocks will stay in place or tumble, if the black block is removed.

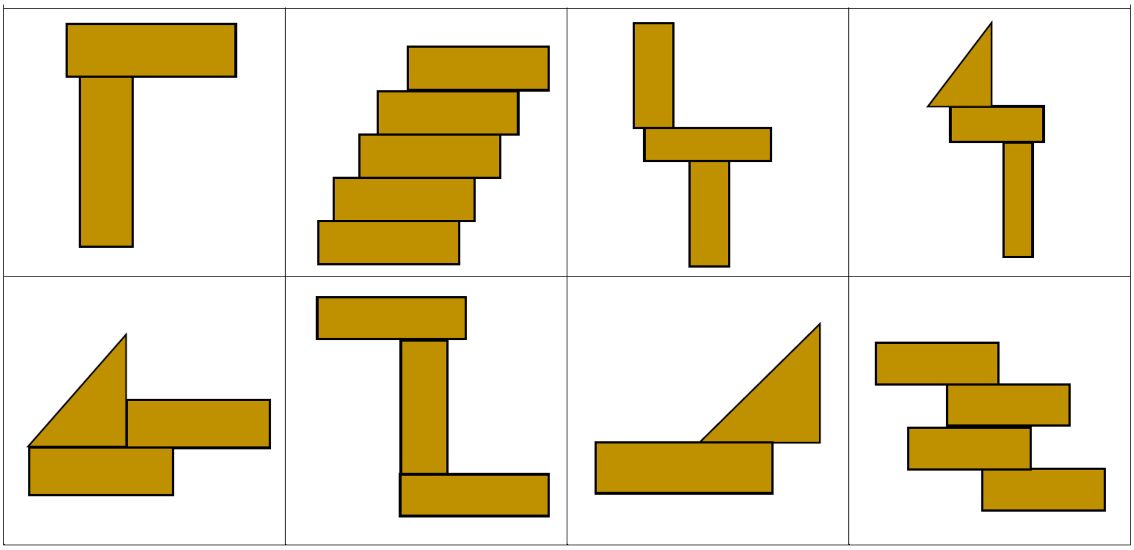


(4) Stable/Tumble (8 photographs): The buildings shown in the photographs may either be stable or unstable. Your task is to examine the picture, choose "stable" or "tumble", and then see whether you are right by constructing the building and observing whether it stays in place or falls over.



(5) Add-a-block (8 photographs): The blocks in the photographs were bewitched to remain stable. Your task is to build the building so that it will be stable. (In case a child fails to achieve

stability, the teacher will provide a green block as assistance, which can be used to stabilize the building.)



Appendix E: Supplementary materials (handouts)

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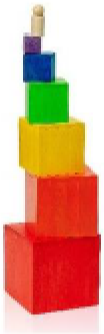

Handout for PFKiNaT

- For your information -

Prof. Dr. Miriam Leuchter
M.Sc. Lukas Schmitt

UNIVERSITÄT KOBLENZ · LANDAU

Gemeinsames Bauspiel (PFKiNaT)

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Handout: Understanding and Stimulating Children's Learning Processes

This Handout

This handout provides information about children's learning processes in the area of block play. First, learning is described as a co-constructive process. Then it is shown which content-related and process-related competencies can be built up in block play game. Finally, content-related aspects that play a role in block play are presented.

(1) Learning as a co-constructive process

The development of a basic scientific and technical education is understood as a lifelong learning process that begins in childhood. This is supported by recognizing and encouraging the child's playful explorations by the preschool teacher. By doing so, children's curiosity is stimulated, and their motivation and self-assurance in problem-solving are reinforced.

Children have their own ideas and prior knowledge at the beginning of a learning process. This can be easily explained with the phenomenon "weight": For children, the weight of an object is mostly its felt weight. Children express the idea that a grain of rice weighs nothing - since you can't feel its weight in your hand. This idea is based on pure observations that the child makes during play.

The learning process is understood as a co-constructive process between children and preschool teachers. The task of preschool teachers is to support children's ways of acting and thinking that the child would not yet be capable of on its own. In doing so, the child's prior knowledge and theories should always be kept in mind. We have clearly presented various possibilities for stimulating and structuring learning processes on the overview board.

Learning is a co-constructive process between children (left) and between children and preschool teachers (right).

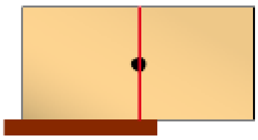
(2) Content-related and process-related competencies

Learning consists of two components: The development of **content knowledge** and the acquisition **process-related competencies**.

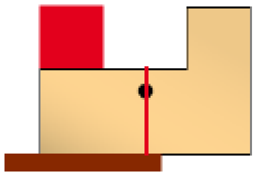
In block play, the content-related competence is knowledge about stability and balance. The process-related competence includes performing simple experiments and thinking about them.

(3) Content knowledge in block play

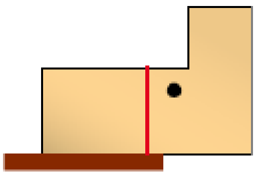
Block play is about **stability** and **balance**. Achieving stability is one of the basic tasks of engineering: buildings must be built stable enough to withstand wind, weather and earthquakes. The content-related competence is the acquisition of an appropriate **theory about stability**.



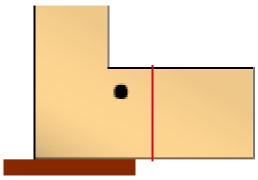
Block with evenly distributed mass



Stabilization through a counterweight



Block with unevenly distributed mass



Building block with unevenly distributed mass

The red line (|) represents an object's geometrical centre.

The black point (●) represents an object's mass centre.

The brown line (⟷) represents the supporting surface.

(4) Performing simple experiments and thinking about them

Block play can be understood as a scientific experiment in which process-oriented competencies such as observing, assuming, classifying, verifying and generalizing play an important role.

Organizational notes

In your role at the kindergarten, you consider the unique talents and interests of each child. During playtime with the children, it is possible that some may have a greater knowledge or grasp of learning materials compared to others, leading to diverse and heterogeneous learning groups.

In this case, the learning content and approach can be adapted to meet the needs of the children. This can be done through selecting similar children for a group, engaging them in the same games (**external differentiation**). Another option for adaptation is selecting different children for a group and providing them with various games (**internal differentiation**). Internal differentiation, in particular, requires didactic and organizational measures to challenge and support children in different ways.

Differentiation measures can promote children's motivation and strengthen their sense of responsibility. They can also encourage group learning processes that enhance children's independence and cooperation skills. In this guide, we have provided a learning situation and options for both internal and external differentiation.

Learning Situation

A group of five children is playing with building blocks. Two children are having significant difficulties constructing stable structures, while the other children are not.

Possibilities for internal and external differentiation:

1. Division of groups into regular group/support group: The regular group can build independently or engage in other activities, while the support group receives separate assistance (external differentiation).

2. Providing open-ended or additional tasks for the advanced children while simultaneously supporting the understanding of the weaker children (internal differentiation).

3. Level differentiation: Assigning more challenging exercises to the advanced children while simultaneously providing simpler tasks for the weaker children (internal differentiation).

4. Formation of learning tandems/pairing: Advanced children explain and assist the weaker children under your supervision (internal differentiation).

5. Co-facilitation of the learning group with another preschool teacher: While one teacher organizes and supports the play, the second teacher assists and helps the weaker children. If necessary, individual support may be provided to one child while others continue learning (internal and external differentiation).

Note

The various types of internal and external differentiation can be effectively combined. It is important to utilize your diagnostic skills to identify which child requires more or less support.

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Overview: Material names

Below, we present you with the names of the different building blocks included in your materials box. We encourage you to incorporate these names into the children's play.

Wedge

Triangular building block

Square building block

Short rectangular building block

Long rectangular building block

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Overview: Verbal Scaffolding

General introduction of the games

Today, we are going to play with building blocks! Look, I have brought along many games for us to play. You can choose which game you want to play and with whom. I will give you the cards, and you can build what is shown on them. Let me show you the first game.

Simple learning supportive behaviors

Simple support measures are often used to maintain the game. The following examples can serve as helpful phrases.

Learning support	Examples
Leading the game	▪ *"Look, let me show you how it's done."* ▪ *"Now, try placing the brown one on top of the red block and see what happens."*
Agree on rules of conversation	▪ *"One person speaks, and the others listen!"*
Ask questions of understanding	▪ *„How did you mean that?"*
Motivating	▪ *„That was a very good idea from you!"*

Verbal Scaffolding

Verbal scaffolding techniques aim to challenge children's thinking during play. The following examples can serve as helpful phrases:

Scaffolding Technique	Examples
Reflecting back children's statements	▪ *"You just mentioned that you think the structure is not stable or might fall."*
Encouraging children's further thinking	▪ *"That was a great idea from you. Now, think even further. What else could happen?"*
Activating prior knowledge	▪ *"Have you ever seen this before?"* ▪ *"Do you remember the games we played last time?"* ▪ *"How high have you built before without them falling? How can you achieve that with these building blocks?"*
Fostering assumptions	▪ *"What do you think, will it hold or fall?"* ▪ *"What do you think, which side is heavier?"*
Encouraging comparisons	▪ *"Look closely! What's the difference?"* ▪ *"The shape looks different from this one. What's different about it?"*
Asking for precise explanations	▪ *"What have you found out?"* ▪ *"Why do you think it holds/falls? What makes it stable/unstable?"*
Modeling	▪ *"Exactly! The building blocks don't always have to rest on their center to stay upright."* ▪ *"When the heavier side is hanging in the air, it collapses or becomes unstable."* ▪ *"The structure remains intact and stable because it's heavier above the red block."*
Directing children's attention towards relevant aspects	▪ *"Take a look at the block that is resting on top of the red one."* ▪ *(Pointing with finger/ mirroring the child's gesture)*

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Overview: Using spatial and mathematical language in block play

Spatial and mathematical language

This handout provides you with information about spatial and mathematical language. By using spatial and mathematical language, you can support children in their learning process. Below, we provide you with examples of words that you can use during block play.

Spatial Language

Category	Examples
Spatial Dimensions	▪ *large, small, wide, narrow, huge, tiny, long, short, deep, high, thick, thin* ▪ *size, length, height, width, depth, volume, area*
Shapes and Bodies	▪ *2D: circle, semicircle, triangle, square, pentagon, hexagon* ▪ *3D: sphere, cube, prism, pyramid*
Place and Direction	▪ *towards/away, inside/outside, below/above, next to, over, right, left, front, back, vertical (upright), horizontal (flat)* ▪ *near, far, together, apart, between* ▪ *parallel, diagonal, straight, equilateral, uniform, non-equilateral, non-uniform* ▪ *location, position, direction, place, distance*
Spatial Properties	▪ *round, curved, bent, straight, odd, smooth* ▪ *circular, round, rectangular, spherical, angular-shaped* ▪ *side, corner, boundary, edge, line* ▪ *corner, point* ▪ *surface, base*

Math Language

Category	Examples
Quantities	▪ *whole/everything, part, piece, section* ▪ *half, third, quarter*
Scale Units	▪ *millimeter, centimeter, meter, kilometer*
Mathematical Operations	▪ *more/to (alternatively: "plus")* ▪ *less (alternatively: "minus")* ▪ *"X times" (alternatively: "multiplied by")* ▪ *divided into X parts (alternatively: "divided")*

General notes

Please note that not every use of the listed words should be understood as spatial or mathematical language in every case. You should use the words during play to help children understand the meaning of "in front of," "over," and "behind." This way, you can best support children's learning during building play.

If you use the words **figuratively** ("Let's play a little game"), speak in **metaphors** ("You have a big heart"), or use the words in **different contexts** ("We'll meet between 5 and 6 o'clock"), you have not used spatial or mathematical language in the strict sense

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Appendix F: Articles 1 and 2 (first site)

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the british psychological society

ARTICLE

Preschool teachers' pedagogical content knowledge predicts willingness to scaffold early science learning

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Deutsche Forschungsgemeinschaft, Grant/Award Number: 446745359

Abstract

Background: The importance of diagnostic and scaffolding activities for early science learning has been shown consistently. However, preschool teachers scarcely engage in them. We developed an instrument to assess preschool teachers' willingness to engage in diagnostic and scaffolding activities in science learning situations and examined its relation with teachers' knowledge, beliefs and practice.

Aims: We validate an instrument to assess willingness to engage in scaffolding and diagnostic activities and study the interplay between willingness, learning beliefs, content knowledge (CK) and pedagogical content knowledge (PCK) in the context of science learning, particularly block play.

Sample(s): A total of $N = 151$ preschool teachers from 41 kindergartens in Germany participated in our study.

Methods: Preschool teachers completed a questionnaire, which took approximately 1 hour of time. We drew a subsample of $N = 73$ teachers and observed their practice during a 30 min block play episode.

Results: With our instrument, we were able to distinguish between preschool teachers' willingness to diagnose and to scaffold. Preschool teachers' co-constructivist beliefs and PCK predicted willingness to engage in diagnosing, PCK also predicted willingness to engage in scaffolding. Associations between learning beliefs and practice were inconsistent.

Conclusions: Our study highlights aspects of the association between preschool teachers' PCK and their willingness

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First Insights into Preschool Teachers' Instructional Quality in Block Play and Its Associations with Children's Knowledge, Interest, Academic Self-Concept and Cognitive Aspects

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ABSTRACT

Research Findings: Promoting children's science knowledge by adequate measures such as guided or free play is a cardinal goal of preschool. However, there is considerable variability in preschool teachers' instructional quality in block play, which might be associated with children's domain-specific science skills but also their mathematic and language achievement. To examine preschool teachers' instructional quality in a free block play episode we used a video-based assessment. We assessed children's knowledge in block play along with mathematics, language capacity, self-concept and cognitive skills. In order to obtain first insights into the association between teachers' practice and children's knowledge, we took a correlational approach. The sample consisted of $N = 73$ preschool teachers and $N = 431$ children. The results revealed considerable differences between preschool teachers' instructional quality. Overall instructional quality during block play as well as specific dimensions such as the use of spatial language, math language and cognitive activating scaffolding were positively associated with children's stability knowledge in block play. Moreover, preschool teachers' general language use and stimulation of communication as well as their sensitivity were positively associated with children's self-concept in block play. *Practice and policy*: Our study emphasizes the importance of preschool teachers' support for children's knowledge and self-concept and expands prior findings on early science learning.

Theory

Promoting children's school readiness by age-adequate means is a fundamental goal of preschool. Teacher-child-interactions are considered a foundation for promoting children's development in e.g., cognitive and motivational facets (e.g., Weisberg et al., 2016). Children develop their own intuitive theories to explain the world around them and continuously adjust these theories as they gain new knowledge (Gopnik & Wellman, 2012). To support children's science learning, it is important to consider developmental constraints and to incorporate everyday activities, such as play (Zosh et al., 2018). One way to implement early science learning with young children is through block play, which offers the opportunity to foster children's concepts about stability, spatial knowledge as well as mathematical knowledge (e.g., A. M. [Author] et al., 2020; Borriello & Liben, 2018; Casey et al., 2008; Gunderson et al., 2012; Levine et al., 2012; Park et al., 2008; Verdine et al., 2014). Spatial abilities are important prerequisites for children's science, technology, engineering and math (STEM) learning (Uttal

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