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Research paper

Building minds with blocks: The impact of a play-based professional development on preschool teachers' competencies and children's learning

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ABSTRACT

The study examined the impact of Professional Development (PD) on preschool teachers' content knowledge (CK), pedagogical content knowledge (PCK), and scaffolding practice. In a pre-post-follow-up design, 77 teachers were assigned to three groups (EG1: block play curriculum materials + PD, EG2: block-play curriculum materials, CG: no materials). Results showed improvements in teachers' scaffolding after the PD, but no changes in CK or PCK. The use of block-play curriculum materials and scaffolding was associated with an improvement in children's math knowledge, but not with their stability knowledge. The study highlights the need for practice-oriented PD aligned with preschool teachers' everyday practice.

1. Introduction

The field of early childhood education (ECE) in Germany has undergone significant changes since the so-called PISA shock, which revealed that German students were performing below the OECD average in reading, mathematics, and science (Anders & Rossbach, 2015; Baumert et al., 2001; Lee et al., 2024). Empirical studies have shown that children already differ in their competencies upon entering elementary school, e.g., in mathematics, and that these differences tend to persist or even widen over time (e.g., Anders et al., 2013). In response to the PISA findings, policymakers introduced new qualification standards for preschool teachers aimed at improving the overall quality of ECE environments and children's early learning experiences (Anders & Rossbach, 2015; Lee et al., 2024). Central to these reforms was a shift in the educational focus of preschools: greater emphasis was now placed on nurturing children's cognitive and pre-academic skills (Anders & Rossbach, 2015).

Despite this increased emphasis on early learning, the pedagogical approach in German ECE remains predominantly play-based rather than relying on structured instruction (Lee et al., 2024). This emphasis on play presents challenges for preschool teachers in implementing early learning opportunities, especially in science and math: Studies indicate that many preschool teachers feel ill-prepared to integrate high-quality instruction in these domains into play-based activities and to support children's learning (e.g., Anders & Rossbach, 2015; Besser et al., 2023; Egert et al., 2020; Oppermann et al., 2024; Piasta et al., 2014; Wadepohl et al., 2024). Thus, while reforms have aimed to enhance children's pre-academic skills in ECE, their implementation reveals tensions between teachers' competencies, traditional play-based approaches, and the push for early academic instruction.

To effectively address these challenges, there is a clear need for in-service professional development (PD), that focuses on improving teachers' expertise in two key areas. First, PD must focus on strengthening in-service preschool teachers' content knowledge (CK), to ensure teachers' deep understanding of the subject matter (e.g., Shulman, 1987). Moreover, PD should address teachers' pedagogical content knowledge (PCK), which is defined as the integration of subject matter expertise with effective instructional strategies to support children's learning (e.g., Anders & Rossbach, 2015; Shulman, 1987). Second, effective PD should equip teachers with evidence-based strategies to support children's learning, such as scaffolding. In doing so, PD must align with preschool teachers' current practice, particularly by integrating elements of play-based learning (Weisberg et al., 2013). One such practice is block play, a widely implemented activity in ECE settings that supports children's math and scientific understanding (e.g., Bower et al., 2020; Lee & Kim, 2018; Verdine et al., 2014; Weber et al., 2020). In the context of our study, block play refers to children's construction activities with wooden blocks, either individually or in small groups.

Empirical research highlights the importance of PD in improving

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both teaching practices and child outcomes (e.g., Brunsek et al., 2020). Theoretical models of change suggest a multi-step process in which teacher training influences latent factors (e.g., knowledge) and observable outcomes (e.g., instructional practices), ultimately contributing to children's learning gains (Egert et al., 2018). Beyond its potential benefits for children's cognitive development, block play also serves as a meaningful context for preschool teachers to reflect on and to refine their professional competencies. Specifically, it provides opportunities to assess and strengthen their content knowledge (CK) - such as understanding scientific principles like stability or math concepts like number sense - and their pedagogical content knowledge (PCK), particularly in how effectively they scaffold and support children's learning within play-based activities.

In our pre-post-follow-up-study, we drew on a German sample of preschool teachers and examined whether a short in-service block-play-based PD program enhanced teachers' CK, PCK, and learning support (i.e., scaffolding) in block play. Moreover, we examined whether teachers' use of the play-based materials within their classrooms was associated with children's understanding of stability and math knowledge. Therefore, 77 preschool teachers were assigned to either one of two experimental groups (EG1: playful materials + PD; EG2: materials only) or to the control group with no training and were provided with a standardized set of building blocks.

1.1. ECE in Germany

In Germany, ECE services fall under the child and youth welfare sector, with each federal state having its own orientation plans, varying in length, topics, and implementation control (Lee et al., 2024; Melhuish et al., 2015). Children typically attend a *kindergarten* before entering primary school. *Kindergarten* refers to early childhood education for children aged approximately 3–6 years old and is considered equivalent to preschool in many other countries. The attendance is not compulsory, however, as of 2025, 91.3 % of the 3- to 6-year-old children attend a kindergarten (Statistisches Bundesamt, 2025). Despite the introduction of a university track in 2004, the proportion of preschool teachers holding a university degree remains low. As of 2022, only 6 % have obtained such a qualification, and the vast majority continues to enter the profession through vocational training (Autorengruppe Fachkräftebarometer, 2023). Moreover, a considerable proportion of German preschool teachers received their training during a period when professional education programs prioritized areas other than the development of children's early academic competencies, particularly in domains such as science and mathematics (Anders & Rossbach, 2015). This limited focus on children's (pre)-academic skills is closely aligned with the widespread adoption of the situational approach in German kindergartens, which conceptualizes learning as a child-centered, autonomous and self-regulated process (Lee et al., 2024). However, formal academic instruction typically begins with primary school in Germany.

1.2. In-service preschool teacher PD

The OECD broadly defines PD as activities aimed at enhancing an individual's skills, knowledge, expertise, and other competencies as a teacher (OECD, 2009). According to Egert et al. (2018), in-service PD for preschool teachers comprises different in-service training opportunities to improve teachers' knowledge, skills, and practice without the attainment of a formal degree. Thereby, PD pursues two primary goals: (a) enhancing the practices of in-service teachers, and (b) promoting better outcomes for children. In ECE, PD activities vary greatly, and theoretical perspectives on what defines high-quality PD are still inconsistent (e.g., Brunsek et al., 2020; Egert et al., 2018). While many in-service training programs for preschool teachers exist, only a few of them have been systematically evaluated, which limits our knowledge of what constitutes effective PD programs (e.g., Egert et al., 2018; Hamre et al., 2017; Schachter, 2015).

Egert et al. (2018) conducted a meta-analysis of (quasi)-experimental studies examining the effects of in-service training for preschool teachers on both pedagogical quality and child development. The analysis of 36 studies revealed a moderate positive effect on process quality (ES = .68), while the impact on children's outcomes was relatively small (ES = .14). However, 53 % of the variation in children's outcomes could be attributed to improvements in pedagogical quality resulting from the PD program, highlighting the indirect association of teacher training with child development. Complementing these findings, a more recent meta-analysis by Egert et al. (2020) demonstrated that PD had a positive effect on the quality of preschool teachers' instructional support, with a medium effect size (ES = .43).

When considering child outcomes directly, evidence from another meta-analysis suggests that teacher PD can have beneficial effects on children's learning (ES = .07–.26), though the investigated studies did not include early science and math domains (Brunsek et al., 2020). Despite the overall benefits of PD, its focus within ECE remains uneven. Schachter (2015) highlighted a significant gap, noting that while most PD initiatives emphasize language, literacy, and social-emotional development, only 1 % address science and 6 % focus on mathematics. Moreover, many science or math PD programs have been published in the US-American context (e.g., Clements & Sarama, 2008; Weiland et al., 2013), with only a few exceptions for the German context (e.g., floating and sinking, Hardy et al., 2017; magnetism, Steffensky & Hardy, 2020). Given this disparity, there is a need to examine the effectiveness of science and math PD in ECE, not only in terms of teacher development but also its impact on children's learning.

PD approaches range from traditional, offsite training sessions to more integrated trainings that embed professional learning within the classroom environment, often accompanied by ongoing support (e.g., Egert et al., 2018, Snyder et al., 2012). Garet et al. (2001) have investigated the effectiveness of science and math teacher PD programs in a representative US sample and identified three key features of teacher trainings in these domains: (a) emphasis on content knowledge and pedagogical knowledge; (b) opportunities for active learning; and (c) alignment of training content with teachers' everyday practice. When addressing the ECE sector in particular, research suggests that PD for preschool teachers is most effective when it is intensive, and when it integrates feedback components aligned with specific instructional goals (Buysse et al., 2009; Dunst, 2015; Gropen et al., 2017; Peleman et al., 2018; Snyder et al., 2012). Further, research has pointed out that in-service PD should be context-specific, grounded in practical application, embedded within teachers' regular work environments, and supported by rich, relevant resources (Ayvaz-Tuncel & Çobanoğlu, 2018; Polly et al., 2017).

However, the effective implementation of such PD approaches encounters several obstacles, particularly in supporting teachers in translating their newly acquired knowledge into the provision of meaningful learning opportunities within their everyday classroom practices (e.g., Ayvaz-Tuncel & Çobanoğlu, 2018). In line with this, preschool teachers have reported that PD programs partly fail to address their own learning needs (Ayvaz-Tuncel & Çobanoğlu, 2018). Results from Veliz et al. (2025) point towards a discrepancy between teachers' formal knowledge and knowledge that they draw upon in their daily practice. In their qualitative study, participants reported that their preparedness for working in culturally diverse settings stemmed more from hands-on experience than from formal training. This reveals the situated nature of professional knowledge, especially in terms of teacher PCK, and raises important questions about how PD programs can better bridge the gap between knowledge and practical application.

Building on these considerations, we will begin by outlining strategies to (a) support teachers in acquiring content knowledge (CK) and pedagogical content knowledge (PCK), and (b) how to support teachers in integrating play-based science and math learning in their daily classroom practice using play-based materials, while scaffolding children's learning.

1.2.1. Addressing teachers' knowledge in ECE PD programs

PD for preschool teachers must address content-specific CK and PCK, i.e. in the science and math domain (e.g., Kind & Chan, 2019). The concept of CK refers to a teacher's understanding of the subject matter, encompassing its concepts and frameworks (Neumann et al., 2019). The concept of PCK is described as a combination of CK and pedagogical knowledge (PK) and comprises teachers' knowledge on how to teach the respective subject in an age-adequate and adaptive manner (Anders & Rossbach, 2015; Neumann et al., 2019). Conceptualizations of PCK in the ECE context, where learning is often embedded in less formal contexts such as play, encompass teachers' knowledge of instructional strategies (i.e., on how to support children's learning), their recognition and planning of learning opportunities, as well as an understanding of children's (mis-) conceptions of a particular topic (e.g., Barenthien & Dunekacke, 2022; Gropen et al., 2017). Both, CK and PCK, can be regarded as important prerequisites for teachers' instructional quality, and seem to be interdependent (Kind & Chan, 2019). For example, PCK may have a more immediate impact on teaching quality, as recent models of teacher professional competence define it as the ability to translate domain-specific content knowledge into effective, context-specific instructional strategies (e.g., Gasteiger & Benz, 2016; Gess-Newsome et al., 2019). Consequently, a lack of PCK might be a major obstacle for developing high quality science and math teaching and learning (e.g., Dunekacke et al., 2015; Nilsson & Elm, 2017). Teachers' CK, however, seems to be an important predictor for teachers' ability to identify math learning opportunities during children's play (Dunekacke et al., 2015; Oppermann et al., 2016). Considering this, we argue that effective PD should address both CK and PCK to enhance teaching quality and improve children's learning outcomes.

Concerning teachers' science CK, studies have found that many teachers held misconceptions about scientific phenomena, and that teachers felt uncomfortable in teaching science (Garbett, 2003; Kallery & Psillos, 2001; Yildirim, 2021). A recent study by Barenthien et al. (2018) has examined German preschool teachers' science-specific CK, using items related to common and real-world scenarios (e.g., magnets on a fridge). The results showed that German preschool teachers scored rather low (Barenthien et al., 2018).

To examine preschool teachers' math CK, Dunekacke et al. (2015) have used a paper-pencil test with multiple-choice and open-ended items in a sample of 354 German preschool teachers in training. The results showed that participants solved only half of the items correctly, with significant variability between teachers. Oppermann et al. (2016) assessed preschool teachers' math CK in a sample of 221 teachers. Participants were presented four typical math problems in ECE content areas (numbers, operations, geometry and patterns, data and measurement). The results showed that teachers solved two to three problems out of four, however, teachers' performance showed considerable variation, and no participant solved all items correctly (Oppermann et al., 2016). Summarizing, these results highlight a significant need for PD to support teachers' acquisition of domain-specific CK in science and math.

Research on preschool teachers' science PCK has indicated that teachers struggle to support children's science-specific procedural skills and to adequately scaffold children's science learning (Barenthien et al., 2018; Piasta et al., 2014). Although previous research has delineated scaffolding as a distinct construct from PCK (e.g., Schmitt et al., 2023, 2024), effective scaffolding might depend on teachers' PCK, as it requires an understanding of both the content as well as developmentally appropriate instructional strategies. Thus, pre-service teachers need PCK to diagnose learning needs, anticipate misconceptions, and provide contingent scaffolding (Leuchter et al., 2020).

Concerning preschool teachers' math PCK, studies have shown that preschool teachers yield medium scores in terms of situation perception and action planning (e.g., Dunekacke et al., 2015). Further, there is evidence that teachers' PCK differs with respect to the math subcategories (e.g., high scores for number sense and low scores for spatial relationships; (Lee, 2017). Also, recent research highlights notable discrepancies, e.g., between preschool teachers' self-reported confidence in their math PCK and their actual classroom practices (Papic & Papic, 2025). Although teachers were confident about their own PCK, observations of classroom practice revealed low to moderate quality learning environments. These findings highlight that, despite high self-reported confidence, many teachers may lack awareness of the specific PCK required to effectively support and advance children's math skills (Papic & Papic, 2025). This offers a critical perspective on PD that goes beyond building teachers' knowledge, to also consider reflective practice, diagnostic abilities and developmentally appropriate instruction.

When designing in-service PD interventions to enhance teachers' CK and PCK, it is crucial to consider that covering an overly broad range of topics may limit teachers' ability to develop a deep understanding of specific subject matter and pedagogical strategies (e.g., Gropen et al., 2017; Steffensky, 2017). To mitigate this, PD programs should prioritize a focused, subject-specific approach that allows teachers to develop a thorough understanding of a topic's CK and PCK, and its application in the classroom (Buysse et al., 2009; Dunst, 2015; Gropen et al., 2017; Peleman et al., 2018; Snyder et al., 2012; Steffensky, 2017). Gropen et al. (2017) have examined the impact of a PD program in physical science on in-service preschool teachers' science activities in the domain of water flow. Teachers in the experimental group attended four 1.5 day-long instructional sessions over a period of 6 months. The sessions included elements such as a general introduction into the subject matter (CK), preparing environments for inquiry (PCK), children's concepts about water flow (PCK), the use of facilitating science language (PCK), and discussing issues in the context of the curriculum's topic. The results showed that the trained teachers outperformed teachers in the control group, and that children attending trained teachers' classes performed better in tasks concerning the topic of floating and sinking.

Nilsson and Elm (2017) have used prompts to improve in-service preschool teachers' science-related PCK (i.e., *what do you intend children to learn about this topic?*). The qualitative analysis of teachers' reflective reports revealed that these prompts were helpful for in-service teachers in developing their science-specific PCK. Yet, teachers often expressed to see their role as engaging children in playful activities and creating opportunities for them to explore science, rather than explaining all scientific concepts in-depth (Nilsson & Elm, 2017).

Wullschleger et al. (2023) have examined the impact of two math-based PD programs on 132 in-service preschool teachers from Switzerland and Germany. Participants were assigned to one of three groups: one focused on micro-adaptive learning support (teacher-child interactions), another on macro-adaptive learning support (planning, preparation, and reflection), and a control group. Each PD comprised three training sessions, lasting 3 h, over a six-months period. They found that both PD programs significantly improved the specific type of adaptive learning support they targeted: The micro-adaptive PD led to higher-quality teacher-child interactions in terms of learning support during play-based math learning situations, but not to better planning or diagnosing children's competencies. The macro-adaptive PD enhanced teachers' ability to plan, prepare, and reflect on learning activities, including the diagnosis of children's math competencies and the alignment of activities with learning goals, but not their instructional support. These results highlight the importance of targeted, domain-specific PD that addresses the provision of learning support as well the broader instructional planning process (e.g., by the help of materials).

1.2.2. Addressing teachers' practice in PD

Supporting teachers' practice requires a PD approach that addresses instructional strategies and the use of play-based materials in the classroom. At the instructional level, integrating active learning processes and feedback elements is essential to foster teachers' meaningful engagement with the respective topic (e.g., Egert et al., 2020; Polly et al., 2017; Yang et al., 2022). At the material level, providing play-based materials designed for everyday classroom use enables teachers to integrate instructional goals into child-centered activities, such as play, in a way that is developmentally appropriate and aligned with their current practice.

An effective form of active learning in PD programs involves teachers participating as learners, engaging directly with the materials they will later use in their own classrooms with children (Darling-Hammond et al., 2017). As pointed out earlier, the prevalent educational approach in German preschools is the situational approach (Lee et al., 2024), which highlights the significance of play for children's learning, and focuses on promoting children's autonomy and self-education (Lee et al., 2024). Thus, German preschool teachers see their role as expanding and deepening children's interests based on children's needs (Oppermann et al., 2016). Considering this, block play emerges as an ideal activity to design a PD, which is aligned with the idea of learning through play. Block play is a widely recognized and commonly used activity in preschools (e.g., Jirout & Newcombe, 2015), and offers learning opportunities for science (e.g., stability; Bonawitz et al., 2012; Weber et al., 2020) and math (e.g., numbers, spatial thinking; Clements & Sarama, 2008; Lee & Kim, 2018). The design of playful block play materials helps teachers to initiate children's learning with hands-on activities during their play, in a way that is developmentally appropriate and consistent with the situational approach's emphasis on child-centered learning (e.g., Anderson, 2007; Lee et al., 2024).

For example, teachers may initiate guided play with the block play materials. Guided play is a form of play-based learning in which adults encourage children's active, minds-on engagement while providing learning support tailored to children's needs (e.g., Zosh et al., 2018). During guided play, teachers can enhance children's learning by offering verbal support in the form of scaffolding (Hmelo-Silver et al., 2007). According to van de Pol et al. (2010), a scaffold refers to the temporary support provided by the teacher to help learners to succeed in tasks, which they might not be able to accomplish on their own. Following this, scaffolding in this study is defined as teacher-guided verbal support strategies -such as prompting, questioning, or modeling - used during block play to help children develop mathematical or scientific concepts. For example, teachers could provide scaffolding by prompting assumptions or encouraging comparisons (i.e., asking children if they have experience with building blocks or if they recognize certain structures; Belland et al., 2013; van de Pol et al., 2010). Besides, teachers could support children in providing explanations concerning the concept of stability, or numbers, or encourage them to explain their own theories (e.g., Hsin & Wu, 2011; Renkl, 2002).

Schmitt et al. (2024) have found a significant correlation between preschool teachers' scaffolding during free play and children's understanding of stability concepts. Complementing these findings, Weber and Leuchter (2022) have shown that guided play led to greater gains in children's stability knowledge than free play alone. Similarly, other studies suggest that the combination of guided play and verbal scaffolding seems to be particularly beneficial to improve children's learning compared to free play (Fisher et al., 2013; Hadzigeorgiou, 2002; Weber et al., 2020, 2024). However, preschool teachers' use of scaffolding seems to be rare, with considerable variability between teachers (Cabell et al., 2013; Leuchter & Saalbach, 2014; Schmitt et al., 2024; von Suchodoletz et al., 2014).

Against this background, our PD program was designed to meet the demands of preschool teachers and to align with their current practice. Thus, we promoted active learning with play-based materials, encouraged teachers' hands-on engagement with the materials and provided feedback during the PD (e.g., Buysse et al., 2009; Egert et al., 2018; Peleman et al., 2018; Snyder et al., 2012).

1.3. Aspects of children's learning in block play

Block play offers the possibility to support children's science and math learning, particularly concerning children's (a) understanding of stability as a fundamental concept in physics (e.g., Bonawitz et al., 2012), and (b) math knowledge such as number sense (e.g., Clements & Sarama, 2008; Lee & Kim, 2018).

Stability. Many 4-to 6-year-old children face problems when evaluating stability, as they hold misconceptions about balance (Weber et al., 2020). For symmetrical objects, it's sufficient to consider the geometric center for assessing stability. In this case, the geometrical center aligns with the center of mass. However, when assessing an asymmetrical objects' stability, children have to consider an object's 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 (see Fig. 1). Bonawitz et al. (2012) have examined 4- and 5-year-olds' theories about stability and showed that 65 % of the 4- and 5-year-olds considered either an object's geometric center or its center of mass when balancing an object, while 34 % showed inconsistent balancing behaviors (Bonawitz et al., 2012). Weber et al. (2020) have shown that less than 20 % of 5- to 6-year-old children could be classified as mass theorists. However, children's acquisition of a mass theory can be supported by the use of playful block play materials (e.g., Weber et al., 2020).

Mathematics. Through block play, preschool teachers can naturally engage children in discussions about numbers (e.g., counting blocks), geometric shapes (e.g., rectangles), and basic math operations (e.g., addition) while playing with blocks. These interactions provide meaningful, hands-on experiences that strengthen early math concepts in an engaging and developmentally appropriate way. In line with this, studies have shown that structured interventions with building blocks can enhance children's math knowledge (Clements & Sarama, 2008; Lee & Kim, 2018).

Cognitive Prerequisites. Cognitive skills are crucial predictors of learning and achievement (e.g., Schneider & Preckel, 2017). Therefore, we examined children's fluid and crystallized intelligence, which might impact their understanding of stability and their math knowledge (e.g., Weber et al., 2020). Fluid intelligence refers to an individual's ability to reason abstractly and solve problems across a variety of novel or unfamiliar contexts and can be measured with tasks such as logical matrices (Cattell, 1987). Crystallized intelligence refers to an individual's use of acquired knowledge and skills (Cattell, 1987), and can be measured by vocabulary skills, which serve as a valid indicator (Flynn & Blair, 2013). Higher language skills might facilitate children's understanding of new concepts (i.e., stability), while greater fluid intelligence might enhance numerical and spatial reasoning (e.g., Weber et al., 2020). Working memory refers to the ability to temporarily maintain and manipulate information for a short period, typically ranging from a few seconds to a few minutes after stimulus presentation (Gathercole, Pickering, Ambridge, & Wearing, 2004). A recent study by Schaefer et al. (2024) showed that children's working memory capacity was significantly associated with their performance in a block stabilization task.

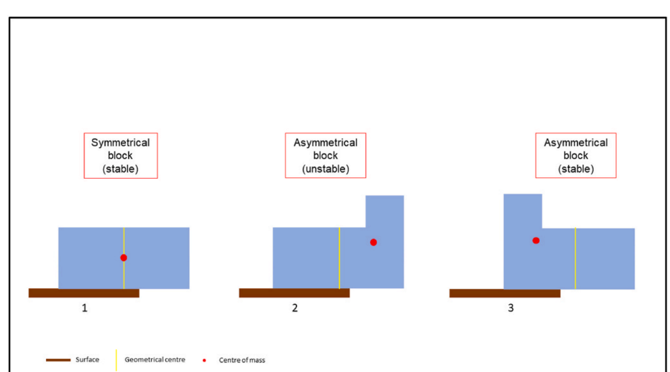

Fig. 1. Assessment of stability for symmetrical and asymmetrical objects.

1.4. Rationale of the study

Integrating science and math learning into play-based contexts remains challenging for many preschool teachers (Anders & Rossbach, 2015; Egert et al., 2020). Addressing this requires PD that enhances teachers' CK, PCK, and instructional practice within play-based situations (Lee et al., 2024; Weisberg et al., 2013). Block play, a common preschool activity, offers opportunities to foster children's understanding of scientific concepts like stability, and math knowledge (Bower et al., 2020; Verdine et al., 2014). It also serves as a practical context for researchers to design play-based materials, and for teachers to improve in their knowledge and their provision of learning support.

This study examines whether a block-play-based PD program improves German preschool teachers' CK, PCK, and scaffolding practices, and whether it enhances children's understanding of stability and math knowledge. 77 preschool teachers were assigned to two PD groups or a control group. To our knowledge, no prior study has tested whether a brief, workplace-based PD intervention can enhance teacher scaffolding and children's STEM-related learning outcomes in a German early childhood setting using block play. The study addresses this gap in PD on integrating early math and science education into play-based learning.

1.5. Research questions

1. Can a PD improve preschool teachers' CK and PCK?

H1a. Based on previous findings (e.g., Dunst, 2015; Gropen et al., 2017; Steffensky, 2017), we hypothesize that the PD program has a measurable effect on teachers' knowledge.

2. Does the PD influence preschool teachers' use of scaffolding (a) in a free block play episode? (b) in a guided block play episode?

H2a. Drawing on literature about the effectiveness of in-service PD on teacher practice in ECE settings (e.g., Egert et al., 2018, 2020), we hypothesize that teachers apply more scaffolding during free play after the PD (EG1/2) compared to the CG.

H2b. Based on findings from previous studies on the importance of active learning and feedback (e.g., Buysse et al., 2009; Darling-Hammond et al., 2017; Dunst, 2015), we hypothesize that teachers in the PD with an additional focus on scaffolding (EG1) will demonstrate significantly more scaffolding during a guided block play episode compared to those in the standard PD condition (EG2).

3. Is there an association between the implementation of the block-play curriculum materials and children's stability theory and their math knowledge?

H3a. Based on prior research demonstrating the effectiveness of guided play supported by verbal scaffolding in promoting children's understanding of scientific concepts (e.g., Fisher et al., 2013; Hadzigeorgiou, 2002; Weber et al., 2020, 2024), we hypothesize that children who played with the block-play materials in guided play will demonstrate a more consistent application of mass theory when explaining stability at t2.

H3b. Similarly, we hypothesize that children who played with the block-play curriculum materials in guided play will exhibit greater gains in math knowledge (e.g., Clements & Sarama, 2008; Lee & Kim, 2018).

2. Methods

The study consisted of a pre-post-follow-up design in an opportunity sample from Germany. Preschool teachers were randomly assigned to one of three conditions (EG1: Block-play curriculum materials + scaffolding focus, EG2: Block-play curriculum materials, CG: Block play). The sample consisted of $N_{(t1)} = 77$ preschool teachers (87 % female) and $N_{(t1)} = 288$ children (demographic characteristics see 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 ($F(1, 70) = .04, p = .835$). 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 native language. 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.

2.1. Procedure

The pre-test (t1) took place approximately three weeks before the PD. The post-test (t2) was administered three weeks after the PD and the follow-up (t3) took place approximately four to five weeks after the post-test, depending on teachers' availability. At t1, all groups were provided with a standardized set of building blocks (see Fig. 2). Teachers' CK, PCK, and scaffolding in block play was assessed at t1 and t2. Children's stability and math knowledge was assessed at all time points. Children's fluid and crystallized intelligence, and working memory were only assessed at t1. Throughout the study, teachers were provided with protocols and were asked to record how often they used the playful materials and how frequently children played with the building blocks.

To assess teachers' scaffolding, all groups were instructed to engage in 15 min of free play with the 3–5 children during the pre-test (free play). At the post-test, all groups (teacher and 3–5 children) were again asked to play freely with the blocks for 15 min. Additionally, the EG1 and EG2 were instructed to initiate guided play by using the playful materials for another 15 min (guided play). The free and guided play sessions were videotaped.

2.1.1. PD with block-play curriculum materials

The PD with block-play curriculum materials took place in the preschool teachers' kindergarten in a quiet room for both EGs. The duration of the PD was 30 min, deliberately kept as short as possible, due to the time constraints preschool teachers face when completing a PD at their workplace. In Germany, PDs in ECE are not compulsory, making it challenging for teachers to participate in PD during their free time. By conducting the PDs at their workplace, we aimed to minimize disruption to their daily routines and enhance participation.

The PD was conducted by the first author of this paper, who majored in Educational Psychology and had one year of experience teaching at a vocational school for preschool teachers. The design of the PD was developed together with the third author of the paper, who holds a Ph.D. in Educational Psychology and brings nearly 13 years of practical experience as a preschool teacher. The PD was piloted in one kindergarten with two preschool teachers, whose feedback was used to refine the content and structure. To align with the everyday practices of the preschool teachers, the PD took a play-based approach. The PD was delivered in small groups, with a maximum of four teachers per session,

Table 1
Descriptive statistics of 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, $M_{Experience}$ = mean of professional experience (in years).

Table 2
Descriptive statistics of children.

	M_{age}	SD_{age}	Min_{age}	Max_{age}
CG ($n = 108$)	5.91	.55	4.58	7.00
EG_2 ($n = 106$)	6.13	.61	4.58	7.50
EG_1 ($n = 74$)	5.99	.74	4.50	7.58

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

to ensure that participants had the opportunity to discuss the materials and to ask questions.

To standardize the procedure and as a manipulation check, the PD was monitored by a research assistant using a checklist. The block-play curriculum materials were provided to both EGs three weeks after the pre-test. Both EGs were introduced to the block-play curriculum material by unpacking it and reviewing the handouts together. The block-play curriculum material consisted of five playful activities, which were picture-based and provided in small boxes (see Supplementary Material A for a detailed description; see also Weber et al., 2020). For example, one game was called "Black block": in this game, children had to rebuild the structure shown on the photograph, and guess whether the blocks remained stable or tumbled if a black block was removed.

First, four of the five block-play curriculum materials were explained. One of the five playful activities ("Add-a-block", see Supplementary Material) was not introduced, and was used for the guided play activity in the post-test. Moreover, both EGs were provided with two handouts, (one page each): One about the importance of an object's mass to assess stability (CK) and children's understanding and misconceptions concerning stability (PCK), and a second about scaffolding strategies, which can be used within block play to foster children's learning about stability and mathematics (see Supplementary Material B). The PD with block-play curriculum took approximately 30 min.

2.1.2. Additional focus on scaffolding

The PD for EG1 included an additional focus on scaffolding for approximately 30 min, resulting in a total of 60 min for the PD. The experimenter modeled scaffolding strategies, demonstrating questioning, prompting, and providing structured support during a 10-min guided play session with 3–5 children who did not take part in the study. Preschool teachers then practised these strategies using the *Stable/Tumble game with the children.* The experimenter observed and provided feedback on their teachers' implementation and suggested improvements. This iterative process aimed to support teachers to refine their instructional strategies.

2.2. Instruments

2.2.1. Preschool teachers

(1) Teachers' CK in block play was assessed at pre- and post-test with the 16 items of the *Center-of-Mass-Test* (Weber & Leuchter, 2020). Teachers had to consider an object's center of mass to rate whether an asymmetrical block construction would tumble or remain stable after the removal of one particular block ($\alpha_{t1} = .84$, $\alpha_{t2} = .81$; Supplementary Material C).
(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 (e.g., using block play to enhance children's understanding of stability; see Schmitt et al., 2023; $\alpha_{t1} = .86$, $\alpha_{t2} = .73$; Supplementary Material C).

Video Analysis. To analyze preschool teachers' use of scaffolding during free and guided play, we partitioned the videos into segments of 10 s each and assessed the occurrence of scaffolding with the coding system in Table 3. Two raters independently analyzed 27 % of the videos (interrater reliability .85).

Table 3
Examined variables of preschool teachers' instructional quality in block play.

Scaffold	Derived from	Range	Explanation
Reflecting back children's statements	Weber et al. (2020)	0-†	e.g., you just said that you think the building will not stay/fall
Encouraging children's further thinking	Weber et al. (2020)	0-†	e.g., that was a good idea of yours. Now think even further. What else could happen?
Activating prior knowledge	Weber et al. (2020)	0-†	e.g., have you seen this before?
Fostering assumptions	Weber et al. (2020)	0-†	e.g., what do you think, will it hold or will it fall?
Encouraging comparisons	Weber et al. (2020)	0-†	e.g., look! What is the difference between X and Y?
Asking for precise explanations	Weber et al. (2020)	0-†	e.g., what have you found out? Why is it stable/unstable?
Modelling	Weber et al. (2020)	0-†	e.g., exactly! The building blocks don't always have to rest on their center to stay upright. It depends on their weight.
Directing children's attention towards relevant aspects	Weber et al. (2020)	0-†	e.g., look at the black block (accompany the child's gestures).

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

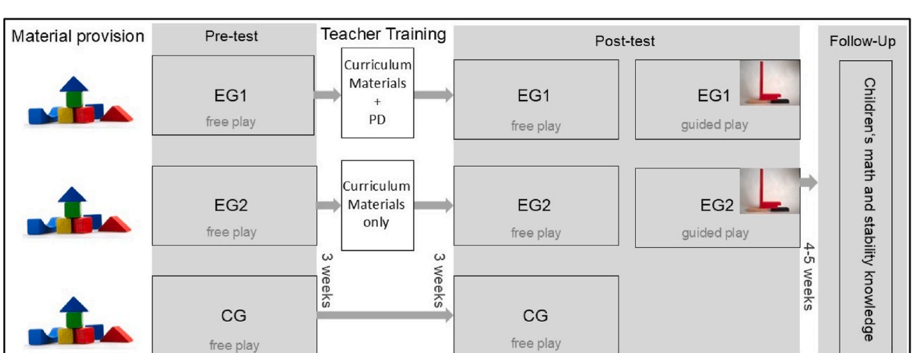

Fig. 2. Experimental design of the study.

2.2.2. Children

Children's theories of stability. Children's theories of stability were assessed with a standardized interview that involved showing children pictures of six asymmetrical block constructions (Fig. 3; Weber et al., 2020). The children were asked to predict whether the block construction would remain stable or not, if the black block was removed. After giving their answer, the interviewer asked the children to explain their theories ("*Can you tell me why you think this will stay/tumble when I take away the black block?*"). Children's answers were analyzed using the coding scheme developed by Pine et al. (2007) and Weber et al., 2020; see Table 4). Children were classified as center or mass theorists if they explained four out of six items with the respective theory; otherwise, they were classified as non-theorists. Two raters independently coded the explanations given by the children (κ = .64, see Supplementary Material C and Fig. 3).

Math knowledge. We used four subscales of the Würzburger Vorschultest (WVT, Endlich et al., 2015). The subscales encompassed 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 excellent ($\alpha_{t1} = .91$, $\alpha_{t2} = .92$, $\alpha_{t3} = .93$).

Cognitive Skills. We used the German version of the Wechsler Preschool and Primary Scale of Intelligence, Fourth Edition (WPPSI IV; Petermann & Daseking, 2018) with three subscales: matrices for fluid intelligence (26 items, α = .88), vocabulary for crystallized intelligence (31 items, α = .90), and working memory (35 items, α = .87; e.g., Cattell, 1987). The working memory subscale was a delayed retrieval test where children recalled as many items as possible. Testing ended when a child answered three consecutive items incorrectly.

2.3. Data analysis

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 mult.al, 2019) for data-processing and -preparation. To address research question 1, we computed change scores and ran a one-way-ANOVA and calculated partial η_p^2 to estimate effect sizes ($\eta_p^2 = .01$ small effect, $\eta_p^2 = .06$ medium effect, $\eta_p^2 = .14$ large effect). To answer research question 2, we ran an one-way ANOVA and independent t-tests and calculated Cohen's d as an effect size estimator ($d > .20$ small, $d > .50$ medium, $d > .80$ large; Cohen, 1992). To address research question 3, we carried out a multiple regression analysis. The degrees of freedom between analyses differed because not all teachers and parents provided their consent for filming.

Fig. 3. Asymmetrical item to assess children's theories of stability.

Table 4
Coding scheme.

Coding	Speech	Example
No Theory (0)	The child's answer is not related to stability, e.g., color.	"It tumbles, because it is green."
Center Theory (1)	The child talks about the center of the block or a larger portion of the block that is resting on either the black/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 one side, comments on its heaviness, or emphasizes the significance of the vertical block.	"The left side is heavier".

3. Results

3.1. Preliminary analyses

First, we examined whether preschool teachers' use of scaffolding differed at the pre-test between the groups (one-way ANOVA), which was not the case ($p = .174$, see Fig. 4). Also, teachers' use of scaffolding was independent from group size ($r = -.09$, $p = .458$). On average, preschool teachers in both experimental groups used the playful materials less than two times during the three-week period between PD and post-test, and even less than one time on average between the four-to five-week period between post-test and follow-up test.

3.2. Research question 1: can a PD improve preschool teachers' CK and PCK?

To investigate research question 1, change scores of CK and PCK ($M_{\text{post-test}}$ - $M_{\text{pre-test}}$) were used as the dependent variable, and experimental condition as the independent variable. Preschool teachers' CK ($F(1, 60) = .10$, $p = .988$, $\eta_p^2 \leq .01$) and PCK ($F(1, 60) = .01$, $p = .941$, $\eta_p^2 \leq .01$) did not change significantly (see Table 5). These results, together with the negligible effect sizes, indicate that participation in the PD did not lead to measurable changes in preschool teachers' knowledge.

3.3. Research question 2: does the PD influence preschool teachers' use of scaffolding (a) in a free block play episode? (b) iI a guided block play episode?

To investigate research question 2, teachers' scaffolding during free and guided play was analyzed. In line with H2a, both EGs used significantly more scaffolding than the CG at the post-test during free play ($F(1, 44) = 6.09$, $p = .018$, $\eta_p^2 = .12$) with a medium effect. However, teachers' scaffolding during free play at the post-test did not differ significantly between the two EGs ($t(1, 44) = 1.99$, $p = .05$, $d = 1.25$). Nevertheless, the effect size can be classified as large ($d > .80$), indicating a substantial practical difference in teachers' scaffolding during free play. The magnitude of the effect suggests meaningful group differences that may be obscured by sample variability.

Concerning preschool teachers' guided play (b), we found that the EG1 used significantly more scaffolding than EG2 ($t(1, 44) = 2.14$, $p = .038$, $d = .60$), which is in line with hypothesis 2b. The effect can be classified as medium ($d > .50$).

3.4. Research question 3: is there an association between the implementation of the block-play curriculum materials and children's stability theory and their math knowledge?

Stability knowledge. Children's theories of stability are presented in Table 6. Most of the children consider neither an object's mass nor its geometrical center to assess stability. At the pre-test, 74 % of children explained stability with no consistent theory. This percentage remained at 70 % in the post-test and at 71 % at the follow-up test. Children's

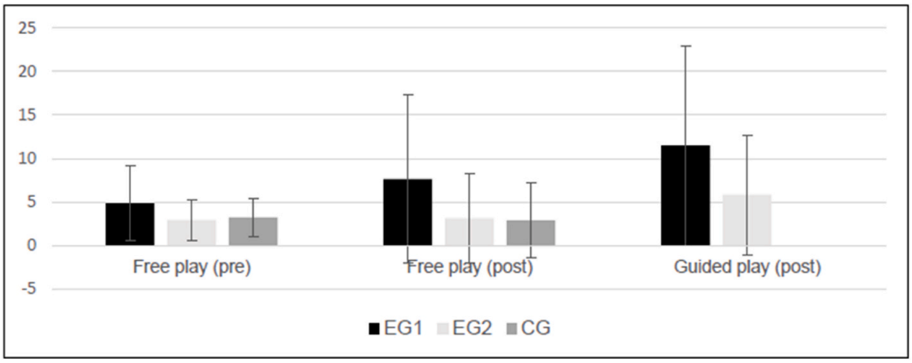

Fig. 4. Preschool teachers' use of scaffolding pre- and post PD. The height of the bars indicates the group mean, the whiskers indicate the standard deviation.

Table 5
Descriptive statistics of teacher knowledge.

Variable/Group	Content Knowledge (CK)		Pedagogical Content Knowledge (PCK)	
	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.

theories of stability neither differed between the groups at pre-test (χ^2 (4) = 5.40, p = .249), nor at post-test (χ^2 (4) = 3.50, p = .477) or at follow-up test (χ^2 (4) = 5.67, p = .225). Contrary to our expectations outlined in H3a, these findings indicate that the PD had no measurable effect on the development of children's theories of stability. However, when breaking down stability theories by children's age (4-5-year-olds vs. 6-7-year-olds) the proportion of mass-theorists increased notably among the older group (rising 7–19 % from t1 to t3), while the younger children predominantly remained non-theorists.

Math knowledge. At pre-test, children's math knowledge did not differ between the three groups (F(1, 406) = −1.75, p = .187; Table 7). However, we found a significant change in children's math knowledge between pre- and post-test (ΔM = 1.35 (4.95); F(1, 333) = 4.24, p = .040). Children in the EG1 showed the largest increase (ΔM_{KG} = .75 (4.27), ΔM_{EG2} = 1.25 (5.84), ΔM_{EG1} = 2.19 (4.18)).

We carried out a multiple regression analysis to examine children's change in mathematics scores from pre-test to post-test (see Table 8). Prior to the analysis, we verified that assumptions of normality, linearity, homoscedasticity, independence of errors, and multicollinearity were met (Supplementary Material D). Due to the very high drop-out at the follow-up, we did not analyze children's math scores at t3. The resulting model encompassing pre-and post-test explained 63 % of the variance in children's math knowledge (R^2 = .63, F (7, 454) = 111.20, p ≤ .001). Children's change in math knowledge was significantly predicted by their mathematics score at t1, age, fluid intelligence, working memory as well as by experimental condition (i.e., increase in math knowledge was higher for children in the EGs than for children in the CG). In sum, teacher practices, child-level cognitive skills, and initial math performance were highly predictive of children's math development. These findings corroborate our assumptions in H3b concerning the effects of the PD on children's math knowledge.

4. Discussion

Despite the increased emphasis on fostering children's cognitive and pre-academic skills in preschool, many preschool teachers struggle with providing high-quality learning opportunities in play-based contexts, especially in science and mathematics (e.g., Anders & Rossbach, 2015; Besser et al., 2023; Egert et al., 2020; Oppermann et al., 2024; Piasta et al., 2014; Wadepohl et al., 2024). PDs targeting teachers' CK, and PCK, while aligning with teachers' everyday practices, are a promising approach to improve the quality of children's learning opportunities.

Table 7
Descriptive statistics of children's math knowledge at t1, t2, t3.

Time	T1	T2	T3
EG1	15.63 (9.14)	17.32 (9.23)	17.41 (10.01)
EG2	16.57 (7.67)	17.95 (8.06)	17.54 (8.11)
CG	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.

Table 8
Results of the multiple regression analysis (t2/t1).

Variable	*B*	*SE(B)*	*t*	*p*
Math knowledge (t1)	.55	2.39	16.42	≤.001***
Age	.13	.03	4.08	≤.001***
Sex	.97	.51	1.90	.058
Working Memory	−.08	.06	−2.46	.014*
Fluid Intelligence	.27	.06	7.52	≤.001***
Crystallized Intelligence	.07	.04	1.53	.127
ΔEG2	.43	.68	.63	.530
ΔEG1	2.51	.69	3.67	≤.001***

Note. B = regression coefficient (unstandardized), $SE(B)$ = standard error of the regression coefficient, t = t-value, p = p-value; *p < .05, ***p < .001.

Table 6
Children's theories of 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, N = number of children.

The present study investigated the effects of a 30 min/60 min PD using block-play curriculum materials on preschool teachers' CK, PCK, and scaffolding practices and whether these improvements would translate into improvements in children's theories of stability and math knowledge.

4.1. Impact on teachers' professional competencies

The findings revealed no substantial changes in CK or PCK. suggesting that the PD neither impact teachers' theoretical understanding of the examined theory of stability (i.e., CK) nor their understanding on how to integrate science or mathematics learning in play-based situations (i.e., PCK). Considering the PD's focus on initiating guided block play with the materials and on scaffolding rather than on direct instruction, the limited impact on teachers' CK and PCK may be understood. As suggested by previous studies, CK and PCK require sustained, reflective practice to be effectively developed, and the lack of improvement in our study corroborates these findings (e.g., Gropen et al., 2017; Kind & Chan, 2019; Wullschleger et al., 2022).

Further, previous research has documented challenges in bridging the gap between knowledge transmission and achieving consistent implementation of instructional strategies through PD programs (Ayvaz-Tuncel & Çobanoğlu, 2018; Schachter, 2015; Veliz et al., 2025). Unfamiliar or overly complex materials may further impede the adoption of new instructional strategies (Granger et al., 2018). Future PDs should therefore use play-based materials and engage in ongoing reflection and feedback cycles together with teachers (Egert et al., 2020; Polly et al., 2017) to sustain instructional change. In our study, teachers who participated in the PD with an additional focus on scaffolding as (EG1) demonstrated a greater ability to support children's learning through scaffolding during free play as well as guided play compared to teachers in the materials only group (EG2) and the CG. This result is in line with the findings of Wullschleger et al. (2023), who found that PD focused on teacher-child interactions improved teachers' ability to provide adaptive learning support. Remarkably, even with only 30–60 min of training, our PD matched the effects of longer programs on overall pedagogical quality (Egert et al., 2018; Gropen et al., 2017). This highlights the value of short-term, workplace-based and practice-oriented PD as a viable model in ECE settings.

Our study contributes to models of teacher professional competence by showing that changes in instructional practice, such as increased scaffolding, can occur independently of measurable gains in teachers' CK or PCK. This aligns with Shulman's (1987) framework, suggesting that the focus on scaffolding in EG1 may have supported teachers' enactment of PCK in practice, even if their formal knowledge did not increase.

This finding aligns with Clarke and Hollingsworth's (2002) interconnected model of teacher professional growth, which emphasizes that professional learning can emerge through various domains of influence (e.g., personal, practical, external). Change can originate in any of these domains, with the nature of change reflecting the characteristics of the specific domain (Clarke & Hollingsworth, 2002). For example, a new instructional approach would represent change in the domain of practice; acquiring new knowledge or beliefs would fall within the personal domain. Through iterative cycles of reflection, change in one domain can lead to changes in others, highlighting the dynamic and non-linear nature of teachers' professional learning. Similarly, Gess-Newsome (2015) indicates that practice change can be initiated through pedagogical tools or reflection and may not manifest as increased declarative knowledge immediately. This theoretical perspective is supported by our findings: The PD program we developed led to observable improvements in teachers' instructional practice – particularly their scaffolding – despite limited changes in declarative knowledge such as CK and PCK.

4.2. Impact on children's outcomes

One of the key objectives of this study was to explore the relationship between the play-based PD for preschool teachers and children's learning, particularly in math and stability. Our expectation was grounded in theoretical models of change, which suggest that PD enhances teacher knowledge and instructional practices and improves children's learning outcomes (e.g., Brunsek et al., 2020; Egert et al., 2018). Children, whose teachers took part in the scaffolding PD, exhibited significant gains in math knowledge, whereas their stability theories remained unchanged.

We corroborate findings from prior research, which have emphasized the importance of combining child-initiated exploration with structured learning support to support children's learning (i.e., guided play, Weisberg et al., 2013; Zosh et al., 2018). The positive association between the PD and children's math knowledge is in line with prior studies demonstrating that block play-based materials can enhance children's math knowledge (e.g., Clements & Sarama, 2008; Lee & Kim, 2018; Verdine et al., 2014). Enhanced verbal scaffolding might have mediated the relationship between children's prior knowledge and their learning gains (Fisher et al., 2013; Zosh et al., 2018). However, due to the limited observational data, comprising only two free play and one guided play episode per teacher, and the lack of detailed information about how and with whom the curriculum materials were used, a formal mediation analysis was not conducted. We therefore suggest this analysis as a promising direction for future research.

Turning to children's individual differences in cognitive prerequisites, our analyses revealed that children with greater fluid intelligence and older age showed greater gains in math knowledge, indicating that developmental readiness plays a key role in harnessing the gains from play-based learning. Yet, children's prior knowledge was the strongest predictor for their knowledge at the post-test. Children's working memory was negatively associated with math improvement. To further explore this unexpected pattern, we conducted a post-hoc check for ceiling effects in the math pretest scores, particularly among children with high working memory capacity. However, we found no evidence of such effects. As an explanation, we tentatively suggest that the play-based activities may not have fully aligned with the learning preferences of children with higher working memory capacity, who might approach tasks in a more structured and analytical way (e.g., Case, 1992). Importantly, this counterintuitive result represents a key strength of our study: instead of reinforcing a Matthew effect, children with higher cognitive prerequisites did not show greater gains from the intervention.

Young children's intuitive theories about stability were notably resistant to change (Bonawitz et al., 2012; Pine et al., 2007). Across all groups, most children had inconsistent or naïve theories about stability, which may stem from children's reliance on perceptual experiences or surface features. As children's causal reasoning is still developing, they tend to draw incorrect or overgeneralized inferences from their observations (i.e., if an asymmetrical structure is unstable, all asymmetrical structures are unstable), ignore counterevidence to their theories, or draw false conclusions from confounded experiments (e.g., two blocks are removed at once; for an overview see Gopnik, 2013; Weber, 2021). Although Weber et al. (2020) could show that children can acquire the theory of mass after a play-based intervention led by a schooled experimenter, these findings did not translate to the teacher-child context in our study. Changing children's theories may require more scaffolding by an adult to be effectively challenged (Bonawitz et al., 2012; Hsin & Wu, 2011). The low frequency of the material use (i.e., only rare initiation of guided play) by the teachers further constrained children's learning opportunities about stability, while math knowledge may have been effectively supported through other activities than block play. We took a closer look at stability theories by age group, which revealed a developmental pattern: while most 4- to 5-year-olds remained non-theorists across the study period, the proportion of 6- to

7-year-olds categorized as mass-theorists increased from 7 % at pretest to 19 % at posttest. While the PD did not lead to widespread shifts in children's theories, the pattern observed among older children offers preliminary evidence that play-based approaches can support emerging scientific understanding, if children have reached a developmental stage that enables them to engage with abstract concepts.

4.3. Strengths and limitations

Despite its contributions, the study has several limitations. First, the brevity of our PD sessions likely constrained CK and PCK development. Integrating longer PDs could enhance the effectiveness in promoting teachers' knowledge and children's learning (Hsin & Wu, 2011; Renkl, 2002). Also, longer PDs could address preschool teachers' experiences, anxieties, and attitudes toward play-based science and math instruction. Future studies should also apply more objective measures of instructional implementation, such as classroom observations to validate our findings (Cabell et al., 2013; von Suchodoletz et al., 2014).

Second, the study was conducted with a relatively small sample of German preschool teachers, which limits the generalizability of the findings to other cultural contexts. Replicating the study in diverse educational settings with bigger samples would provide more robust evidence of the PD's effectiveness and the opportunity to apply structural equation modelling (SEM).

Third, the ceiling effects in teachers' PCK assessment limited our ability to detect smaller, but potentially meaningful improvements. We also have limited insight into how teachers implemented the curriculum materials in practice, as most preschool teachers barely took notes on the protocols. While some teachers reported that children enjoyed engaging with the materials during free play in age-mixed groups, these anecdotal accounts do not allow us to draw conclusions about teachers' implementation.

Fourth, while the PD was aligned with the situational approach commonly used in German kindergartens, we acknowledge that it was not explicitly designed to be culturally sensitive or responsive to the diverse backgrounds of teachers and children, which should be addressed in future studies (e.g., Veliz et al., 2025). Still, we cannot rule out that prevailing pedagogical beliefs within the German ECE section, particularly the widespread adoption of the situational approach (Anders & Rossbach, 2015; Lee et al., 2024), may also have hindered teachers' implementation fidelity of (semi)-structured play-based learning. Also, we did not assess the frequency of children's block play at home, which could influence the observed outcomes.

Finally, the study focused on short-term outcomes, assessing children's math knowledge and theories of stability relatively shortly after the PD. Longitudinal studies are needed to examine the sustainability of the observed effects and to explore the long-term impact of the PD on teachers' instructional practices and children's cognitive development.

4.4. Practical implications and future research

This study contributes to the growing body of research on play-based PD by highlighting the potential of block-play curriculum materials to enhance teachers' scaffolding strategies and children's math knowledge. Our results have several implications for the design of PD programs and education policy. First, they suggest that teachers' instructional quality in block play can be improved through short-term interventions focused on play-based learning approaches. Second, policy should support the implementation of PD formats that require minimal time investment and can be integrated into teachers' daily work environment.

Moreover, our study contributes to refining models of teacher competences by showing that shifts in instructional practice (e.g., scaffolding) may occur independently of measurable gains in teachers' knowledge (e.g., Clarke & Hollingsworth, 2002). This carries practical implications for PD design, suggesting that PD should prioritize changing teaching practice over knowledge transmission. However, future research should explore how teachers' knowledge can be effectively addressed in short-term PDs as well. Also, future studies should shed more light on the effectiveness of specific components - such as hands-on engagement, expert feedback, or focus on scaffolding techniques - in improving teachers' practice. Beyond that, research should examine how contextual factors (e.g., classroom resources, heterogeneity or group size) interact with PD effectiveness to inform more tailored program designs.

From a child development perspective, the study reinforces the connection between high-quality scaffolding and early math gains. Future studies should investigate how such improvements can be sustained over time, evaluated in culturally diverse contexts, and whether they translate into longer-term developmental outcomes.

CRediT authorship contribution statement

Lukas Lazzara: Writing – original draft, Formal analysis, Writing – review & editing, Methodology, Software. **Anke Weber:** Supervision, Conceptualization, Writing – review & editing, Resources, Writing – original draft, Funding acquisition. **Miriam Leuchter:** Writing – review & editing, Project administration, Conceptualization, Writing – original draft, Funding acquisition, Supervision.

Data availability statement

Since we deal with sensitive data from preschools that affects the rights of third parties, the data will not be made publicly available.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used ChatGPT in order to improve language and readability. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Lukas Lazzara reports financial support was provided by German Research Foundation. Miriam Leuchter reports financial support was provided by German Research Foundation. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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We confirm that this manuscript has neither been published elsewhere, nor is under consideration by another journal.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.tate.2025.105144.

Data availability

Data will be made available on request.

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