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ORIGINAL PAPER

Teaching quality in kindergarten: professional development and quality of adaptive learning support enhances mathematical competency

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Abstract

Adaptive learning support provided by kindergarten teachers before and after (macro-adaptive learning support) as well as during mathematical learning activities (micro-adaptive learning support) is a cross-cutting concept of teaching quality. Effective adaptive learning support enhances children's learning. However, providing it is challenging and teachers need professional development (PD) to improve the quality of their support. This study investigates the mediating role of teaching quality between PD programs for kindergarten teachers and the development of children's mathematical competency. 122 kindergarten teachers and their 825 pupils participated in the study. The teachers were randomly assigned to three groups. Two groups attended PD sessions designed to foster either macro- or micro-adaptive learning support. The third was the materials-only control group. The data was analyzed using a self-developed rating instrument focusing on generic and domain-specific elements of teaching quality related to macro- and micro-adaptive learning support. The multilevel latent change model analysis revealed that the PD programs had positive and significant effects on the teaching quality of kindergarten teachers. A significant positive relationship was also found between micro-adaptive learning support and changes in children's mathematical competency. However, an indirect effect of teaching quality could not be detected, and the PD programs did not have a total effect on children's mathematical competency. The study reinforces the importance of PD that specifically targets macro- and micro-adaptive learning support for kindergarten teachers. The mediation between PD and mathematical competency development requires further investigation.

Keywords Teaching quality in kindergarten · Macro-adaptive learning support · Micro-adaptive learning support · Professional development · Mathematical competency

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1 Introduction

Domain-specific learning has been empirically identified as an important aspect of children's development in literacy (Herrera et al., 2021), mathematics (Nelson & McMaster, 2019), and other domains. In early childhood education and care (ECEC), domain-specific learning is integrated with everyday activities and play (Vogt et al., 2018). The ability of the kindergarten teacher to provide adaptive learning support before and after (macro-adaptive support) and during (micro-adaptive support) this type of learning activity is thus a key aspect of teaching quality (Wullschleger et al., 2022).

Offering effective support to children in play-based settings is not straightforward (Pohle et al., 2022). The teacher has to be able to provide domain-specific tasks that spark cognitive activation (Siraj-Blatchford et al., 2002), diagnose a child's level of mathematical development (Bruns, 2014), and adapt learning support to suit their needs (Wullschleger, 2017). The recent move in many countries to introduce curricula with an increased emphasis on the academic development of young children also means that kindergarten teachers have to be more proactive when planning learning support and closely monitor children's learning progress (DeLuca et al., 2020).

Teaching quality in kindergarten comprises the teacher's preparation for, teaching of, and reflection on a learning activity. Ensuring kindergarten teachers have these skills is likely to require professional development (PD). If the key features of effective PD (Darling-Hammond et al., 2017; Sims & Fletcher-Wood, 2021) are delivered, then there should be a resultant increase in teaching quality and, ultimately, improvement in student achievement (Desimone, 2009).

To date, there has been little research on the theoretical assumption that teaching quality has a mediating function between the impact of PD and children's mathematical competency. This study addresses this research gap by examining the impact of two math-related PD programs on teaching quality: One focuses on the adaptive preparation of and reflection on mathematical learning activities (macro-adaptive learning support), and the other on math-related teacher-child interactions during learning activities (micro-adaptive learning support). We investigate the mediating role of teaching quality between these PD programs for kindergarten teachers and children's mathematical competency development.

2 Theoretical background: adaptivity as an important aspect of teaching quality

2.1 Three basic dimensions of teaching quality and their domain-specific operationalization

Teaching quality is often defined in terms of three basic dimensions: classroom management, student support, and cognitive activation (Praetorius et al., 2020). These dimensions also inform the quality of the pedagogical process in preschools (Hardy & Steffensky, 2014). This is apparent, for example, in the *Classroom Assessment Scoring System* instrument (CLASS) developed by La Paro et al. (2004), where the assessment of the quality of interactions in preschool is based on three criteria: management, emotional climate, and instructional support. The three basic dimensions show significant overlaps with the CLASS framework although these overlaps have not yet been clarified (Praetorius et al., 2018).

Classroom management is effectively addressing and preventing disruptions to ensure that learners are fully engaged and attentive (Freiberg et al., 2020). It is related to having structured daily routines and guiding children (Kuger & Kluczniok, 2009). *Emotional climate* is the emotional connection between the kindergarten teacher and the children and includes exhibiting supportive, trustworthy, and appreciative behavior to foster socio-emotional support. *Instructional support* considers the extent to which a teacher encourages higher-order thinking and problem-solving and maximizes learning opportunities by engaging children in various activities (La Paro et al., 2004). This includes challenging children in domain-specific learning situations (Kuger & Kluczniok, 2009) by, for example, providing hints or asking questions that activate cognition (Wullschleger, 2017).

There are both generic and domain-specific aspects of teaching quality (Reusser & Pauli, 2021). Researchers have therefore proposed the expansion of generic models of teaching quality by adding several dimensions for mathematics. One is the use of appropriate mathematical language (Schlesinger et al., 2018). In kindergarten settings, the teacher's math talk has been shown to have a positive impact on children's mathematical learning (Klibanoff et al., 2006; Swaminathan & Trawick-Smith, 2020). However, the domain-specific operationalization of teaching quality for ECEC is challenging because domain-specific adaptive learning support can be integrated in everyday activities and play or part of a curriculum-based approach (Dunekacke et al., 2022).

2.2 Adaptivity as a cross-cutting concept of teaching quality

Adaptivity is the extent to which teachers adapt their regulation of the learning process to the student's understanding (van de Pol et al., 2022). It is the fit between student's needs and teachers' instruction (Vaughn & Parsons, 2013) enabling learners to reach their "zone of proximal development" (Vygotsky, 1978). Because a student's level of learning and development is constantly changing, teachers "must monitor students' changing understanding and adapt instruction in this complex milieu" (Parsons et al., 2018, p. 208).

Adaptivity is a crucial aspect of teaching quality and, according to Parsons et al. (2018), a "widely accepted cornerstone of effective instruction" and "the gold standard for which teachers should strive" (p.206). However, the relationship between the three basic dimensions of teaching quality and adaptivity has not yet been clarified (Praetorius et al., 2018). We follow the conceptualization of Praetorius et al. (2018), who view adaptivity as a concept that is orthogonal to the three basic dimensions. Adaptivity thus cuts across dimensions; teachers need to adapt classroom management, student support, and cognitive activation during instruction to suit students' cognitive, motivational, affective, and socio-cultural needs (Plass & Pawar, 2020).

The concept of adaptivity does not, to the best of our knowledge, vary at different school levels. It is important, however, to take into account the specific learning context when investigating adaptivity. Because learning in kindergarten often happens in open and play-based settings, we use the term adaptive learning support rather than adaptive teaching.

2.3 Macro- and micro-adaptive learning support

When adapting instruction to children's needs, teachers engage in reflection. Parsons et al. (2018) discuss Schön's (2017) reflection theory, which distinguishes between reflection-on-action (reflecting on students' needs before and after a learning situation) and reflection-in-action (changing planned actions in the moment). On the basis of this distinction and the work of Corno and Snow (1986), Hammond and Gibbons (2005), and Hardy et al. (2019), we distinguish between macro- and micro-adaptation when looking at how teachers adapt their learning support to individual learners.

Macro-adaptive learning support occurs during the preparation and reflection phase of a learning situation (Wullschleger et al., 2022). It covers longer-term rather than immediate decisions about teaching situations (Corno & Snow, 1986). It describes a teacher's capacity to plan, select, and sequence tasks to meet the varied levels of individual or groups of students (Hammond & Gibbons, 2005). Macro-adaptive learning support in the preparation and reflection phase is linked to the adaptation of classroom management, student support, and cognitive activation.

Macro-adaptive support requires teachers to determine the actual developmental level of children and use diagnostic tools (Hardy et al., 2019). In kindergarten, different types of assessments, such as observations or the evaluation of work samples, can be used for diagnosing the learning processes and skills of the children (Brassard & Boehm, 2007).

Micro-adaptive learning support is the interaction between the teacher and the child during the learning situation (Wullschleger et al., 2022). The focus of the teacher-child interaction is on the teacher's responses (Corno & Snow, 1986) during "the dynamic unfolding of lessons" (Hammond & Gibbons, 2005, p. 20) and is based on a teacher's *moment-to-moment decisions* (Corno & Snow, 1986), and "their ability to make the most of the teachable moment" (Hammond & Gibbons, 2005, p. 11). Micro-adaptation is measured by looking at the fit between the student's understanding and the didactic action or response of the teacher. For example, if a student exhibits a low level of understanding, the teacher responds with a detailed explanation, but if a student exhibits a higher level of understanding, the teacher responds with a hint or an open question (van de Pol et al., 2022). The implementation of micro-adaptive learning support is related to classroom management, student support, and cognitive activation.

For the present study, we consider adaptivity as a cross-cutting construct across the three basic dimensions of teaching quality, delineating it into the elements of macro- and micro-adaptivity.

3 Empirical background

3.1 Research on macro- and micro-adaptive learning support

Several early childhood education studies have found that providing micro-adaptive learning support can be challenging. Research by Siraj-Blatchford et al. (2002) showed that very few learning support interactions are adaptive. Bruns (2014), Cabell et al. (2013), and Tournier (2017) all came to similar conclusions about the difficulty of micro-adaptive support for mathematical learning. Few studies have explored the relationship between the quality of macro-adaptive and micro-adaptive learning support. A video study found that while kindergarten teachers were proficient at diagnosing the mathematical competency of their children, they were less able to adapt their teaching during the interactions that followed and were rarely adaptive when planning mathematical game sessions (Wullschleger, 2017).

Adaptivity is accorded significant importance within the context of teaching quality. However, these research findings indicate that providing adaptive learning support is challenging. Professional development could therefore be of central importance.

3.2 Research on professional development in the context of ECEC

Professional development programs for kindergarten teachers aim to impart or develop skills that enhance teaching quality which should, in turn, increase learning progress of the children (Desimone, 2009; Egert et al., 2018) Evidence from meta-analyses supports the role of PD in the context of kindergarten (Egert et al., 2018, 2020; Werner et al., 2016). The ideal duration of PD programs is less clearcut (Egert et al., 2020; Werner et al., 2016). Researchers have found that under some conditions even short programs, lasting for less than 10 h, can be beneficial (Werner et al., 2016). Sims and Fletcher-Wood (2021) highlight the importance of ensuring that the content of the PD program is clearly defined and evidence-based.

Some recent research has investigated the effects of math-related PD on kindergarten children's mathematical competency without addressing the mediating effect of teaching quality. Meta-analyses found that overall, the PD of kindergarten teachers improves children's mathematical competency (Nelson & McMaster, 2019; Nguyen et al., 2019).

Only a few studies examine the mediated relationship between PD, math-related teaching quality, and children's mathematical competency on the basis of observation data on teaching quality. Clements et al. (2011) found that a PD program had an effect on kindergarten teachers' math-related teaching quality ($g=0.78$) and the number of mathematics activities ($g=1.02$). The program also had a direct effect on children's mathematical competency ($g=0.72$). There was also a small effect of the PD program on children's competency mediated by the number of mathematics activities ($\beta=0.16$) but not by math-related teaching quality. A study by Whittaker et al. (2020) showed an improvement in mathematics teaching quality after year one ($g=2.43$) and year two ($g=1.68$) of a PD program, as well as an increase in the proportion of time spent on mathematics after year two ($g=0.62$). The program significantly impacted children's mathematical knowledge ($g=0.26$) after two years. However, the mediated relationship between professional development, teaching quality, or proportion of time spent on mathematics, and children's mathematical knowledge was not significant. Both studies used the *Classroom Observation of Early Mathematics Environment and Teaching* Scale (COEMET) to assess mathematical teaching quality, which addresses, for example, whether children's mathematical thinking is engaged or focused (Clements et al., 2011).

In summary, the theoretical assumption that teaching quality has a mediating function for the effect of PD on children's mathematical competency has, to date, not been supported by empirical data. It would be illuminating if studies were not only able to determine the effect of the program at a particular point, possibly by using pre-test scores as covariates (Clements et al., 2011; Whittaker et al., 2020), but also measure the change in teaching quality or children's mathematical competency during the intervention period.

Of course, there is always the possibility that even high-quality PD is not linked to improvements in teaching quality; it may be that educational materials given to teachers, with guidelines for learning activities, are by themselves sufficient to account for any improvements. It is also possible that PD programs that address different aspects of teaching quality, for example, those focusing on adaptive preparation of and reflection on mathematical learning situations as well as those focusing on the math-related teacher-child interactions during learning situations, have differing impacts.

4 Research questions and hypothesis

Teaching quality has been identified as important for the development of children's achievement gains in mathematics. As outlined above, adaptivity is crucial in this context. However, most studies do not differentiate between adaptivity at the planning and reflection of a learning activity (macro-adaptation) and adaptive interactions which occur during learning situations (micro-adaptation). The focus in kindergarten education is usually on micro-adaptive support, but as new curricula are increasingly emphasizing the academic development of younger children, the macro-adaptation skills teachers need to implement these curricula must also be fostered. There is a theoretical assumption that PD programs increase teaching quality and, therefore, improve student learning (Desimone, 2009). However, the existing research does not present a consistent picture of the relationship between PD, teaching quality, and the achievement gain of children.

This study addresses these issues by examining the following research questions:

RQ1: What is the effect of two PD programs, designed to foster teaching quality through either macro- or micro-adaptive learning support, on children's achievement gain in mathematics?

RQ2: To what extent is this relationship mediated by the quality of kindergarten teachers' macro- and/or micro-adaptive support?

Based on what we know about effective PD programs for kindergarten teachers, our assumption is that the two PD programs will have a total positive effect on children's mathematical competency. In line with theoretical assumption, we further expect a positive indirect effect of PD on children's learning gains mediated by teaching quality. Specifically, we expect that kindergarten teachers who attended the PD program in macro-adaptive learning support will show higher quality in their macro-adaptive support, which will, in turn, have a positive impact on changes in children's mathematical competency. The same should hold true for the micro-adaptive PD program. While we assume that the effect of the program on the children is mediated in both cases, we do not expect a full mediation with respect to either mediator.

The focus of our study is children's numerical competency. Supporting the numerical achievement gain of children is an important goal of mathematics education in ECEC settings, and research shows that numerical competency in kindergarten predicts mathematical development in primary school (Nelson & McMaster, 2019). Providing proactive support for mathematical competency might be new for many kindergarten teachers (DeLuca et al., 2020).

5 Methods

5.1 Design and sample

The study was designed as a randomized field trial (Fig. 1). The children's mathematical competency and their teachers' micro- and macro-adaptive learning support were assessed before (PRE) and after (POST) the PD intervention programs.

This manuscript presents an original analysis within the context of a larger project. It should be noted that Wullschleger et al. (2022) used some of the same data to investigate research questions related to those addressed in this study. In particular, Wullschleger et al. (2022) investigated the effect of the PD programs on adaptive support quality, but not on children's mathematical competency, using sequential regression analysis. This partially overlaps with RQ2, so in this small instance, the study may provide information on the reproducibility of findings using different analytical methods.

Kindergarten teachers from Germany and German-speaking Switzerland were voluntarily recruited to participate. The Ethical Committee of the University of Zurich approved the study. To control for differences between countries, the teachers from each country were randomly assigned to the three groups. Children aged 4–6 were recruited via kindergarten teachers and their parents. Teachers and parents gave their informed consent. A total of 122 kindergarten teachers and 825 children participated in the study. Descriptive information about the sample is shown in Table 1.

Fig. 1 Study design

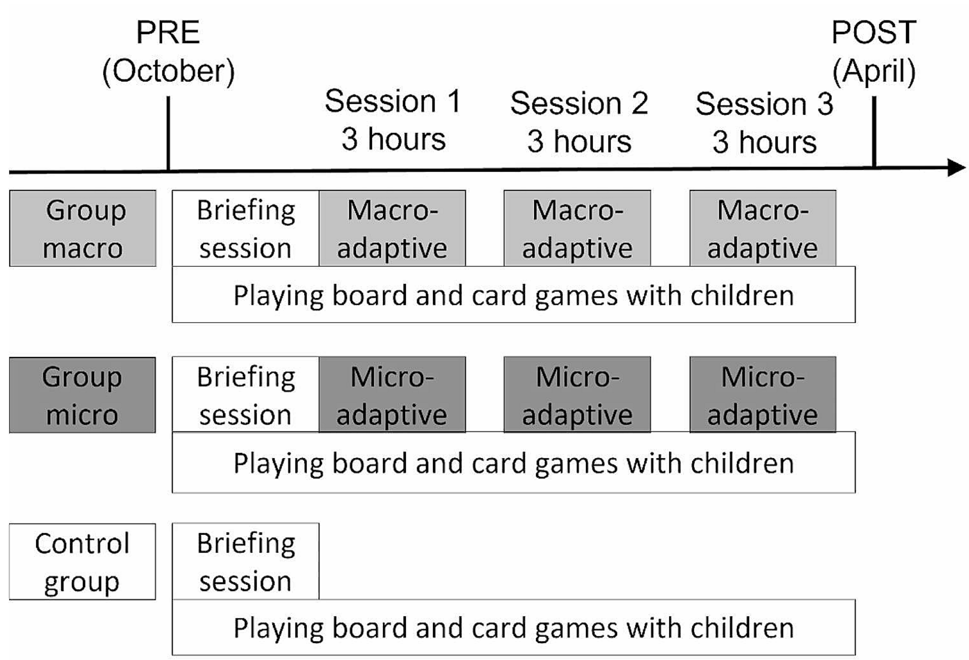

Table 1 Sample descriptors

		Germany n (%)	Switzerland n (%)	Total n (%)
Kindergarten teachers				
Professional training[1]	Academic	6 (10)	31 (48)	37 (30)
	Vocational	52 (90)	33 (52)	85 (70)
	Total	58 (100)	64 (100)	122 (100)
Children				
Gender	Female	152 (49)	255 (50)	407 (49)
	Male	158 (51)	260 (50)	418 (51)
	Total	310 (100)	515 (100)	825 (100)
First language	German	240 (85)	390 (76)	630 (79)
	Other	44 (15)	125 (24)	169 (21)
	Total	284[1] (100)	515 (100)	799[2] (100)

[1]For differences in professional training in the two countries see Brunner (2022); [2]26 missing data points

5.2 Professional development programs

The professional development (PD) programs were planned and implemented by project staff. To ensure comparability between PD programs they were delivered using standardized scripts. Figure 1 gives an overview of the amount of time participants spent on PD. More details can be found in the literature (Wullschleger et al., 2022).

All of the kindergarten teachers attended a briefing session during which they were introduced to a box of ten board games designed to promote numerical competency (Hauser et al., 2015). Participants were asked to use these games in their kindergarten groups three times a week for 20–30 min over six months. One group attended a program to improve the quality of macro-adaptive learning support, and the second a program to improve micro-adaptive learning support. A third group, the control group, had no PD. They were given the PD programs after the study had ended as a courtesy.

Participants in the macro-adaptive group learned how to make adaptive preparations for and reflections on mathematical learning situations. This program included the following topics: (1) Diagnosing children's numerical competency in play-based situations using video clips, (2) analyzing the difficulty level of the games and reflecting on their potential for mathematical learning, (3) adapting games to the children's competency level, and (4) practicing, between training sessions, the diagnosis of mathematical competency with their kindergarten groups.

Participants in the micro-adaptive group learned how to use adaptive support strategies during teacher-child interactions in mathematical learning situations. The PD program included the following topics: (1) Familiarization with support strategies (giving hints, asking cognitively activating questions, dealing with mistakes, structuring solution processes, illustrating mathematical content, and using mathematical language), (2) learning to use these strategies (video vignettes, role play), and (3) applying these strategies with their kindergarten group between the training sessions.

The PD programs focused on two of the basic dimensions of teaching quality - student support and cognitive activation. The classroom management dimension was only addressed in passing (e.g. by discussing group composition to implement the games).

The control group was materials-only; the teachers were just given the box of games and introduced to them.

5.3 Data collection and instruments

5.3.1 Assessment of macro-adaptive learning support

To assess macro-adaptive learning support, short, structured interviews were conducted immediately after a video-recorded mathematical learning situation (see 4.3.2) at both of the measurement points (pre- and post-intervention). The teachers were questioned about the learning situation they had implemented. The interview included questions on four elements of teacher macro-adaptive learning support related to the learning situation: (1) planning the mathematical learning situation, (2) diagnosing the children's level of mathematical competency, (3) their reflections on the learning situation, and (4) implications for the planning of future learning situations.

We developed a rating instrument for macro-adaptive learning support which included four items focusing on the domain-specific quality of learning support (Meier-Wyder et al., 2022; Wullschleger et al., 2022) (Table 2).

The ratings were conducted by four trained research assistants, two from Switzerland and two from Germany. 15% of the data was rated by all of the raters. Interrater reliability was assessed at three points: At the beginning of the process, after half of the data were analyzed, and at the end, after all of the data were analyzed. The interrater reliability of the four items resulted in G-coefficients between 0.78 and 0.90, which correspond to good to very good values.

5.3.2 Assessment of micro-adaptive learning support

Kindergarten teacher micro-adaptive learning support was assessed by rating video recordings from two semi-standardized learning situations per measurement point (pre- and post-intervention). The teachers played a board game with a group of two or three children for 15 min. At the first measurement point, the board game was pre-selected

Table 2 Rating instrument for assessing the quality of macro-adaptive learning support

Item	Indicator	Sample interview questions
Planning of the learning situation	• Use of professional knowledge to plan the game situation (game use, game allocation, group composition) in a targeted way.	• Why did you choose child X, Y and Z to play the games? • What was the reason for the group composition?
Diagnostic knowledge	• Explicit discussion of the mathematical competences of selected children in relation to the game.	• What mathematical competence did you expect from each child?
Reflection	• Critical reflection on the goals and planning of the activity and learning support provided.	• When was it particularly important to provide support to the children? • Which situations during the game were mathematically stimulating for the children?
Further learning support	• Explicit, relevant ideas about how to plan follow-up activities for specific children.	• What is important for the further mathematical support of each child?

Ratings: 4 = clearly observable; 3 = mostly observable; 2 = partially observable; 1 = not observable

Table 3 Rating instrument for assessing the quality of micro-adaptive learning support

Item	Indicator	Examples
Emotional warmth	• Non-verbal: warm gestures/mimicking; direct eye contact • Verbal: friendly and encouraging language • Responsiveness	• The kindergarten teacher uses encouraging nods and glances.
Classroom management	• Presence of kindergarten teacher to maximize time on-task • Maintaining motivation by drawing attention to the game • Preventing disturbances; appropriate regulation of disturbances	• The rules of the game are established and made explicit.
Adaptive learning process stimulation	• The fit between the actions of the kindergarten teacher and the mathematical activities of the children • Promotion into the zone of proximal development using targeted explanations or hints, challenging questions, etc.	• What is the quickest way to determine the number of eyes on the dice?
Stimulation of mathematical language	• Use of mathematical language by the kindergarten teacher • Demanding mathematical language from children	• How many more/fewer gold coins do you have than child X?

Ratings: 4 = clearly observable; 3 = mostly observable; 2 = partially observable; 1 = not observable

by project staff ('Gold Coin Game'; Schmassmann & Moser Opitz, 2007). At the second measurement point, teachers were asked to choose a board game from the box provided by the project. The data collection was carried out by trained project staff using a standardized manual.

To measure micro-adaptive learning support, we developed a rating instrument, based on existing instruments, that included four items that assessed generic and domain-specific elements of teaching quality (Meier-Wyder et al., 2022; Wullschleger et al., 2022) (Table 3).

The interrater reliability of the four items resulted in G-coefficients between 0.87 and 0.91, corresponding to good to very good values.

While the macro-adaptive learning support assessment focused primarily on cognitive activation, all three basic dimensions were considered by the micro-adaptive learning support assessment.

5.3.3 Assessment of children's mathematical competency

We used a modified version of the TEDI-MATH test (Kaufmann et al., 2009). The test is conducted as a standardized one-to-one interview and takes between 15 and 20 min per child. Since the test is intended for use on children in the second-to-last year of kindergarten through the middle of third grade, it was suitable for the wide mathematical performance range of young children (Kuratli et al., 2021). We had sets of 95 items usually used to assess children's numerical competency (Sample items: "Count the rabbits out loud. How many rabbits are there?"; "Here are some cards with numbers on them. Put them in a row with the smallest number here (show) and the biggest number here (show)."; "Here are some pencils. If you take five pencils and three pencils, how many pencils do you have?") with a good WLE-reliability of 0.94/0.93 (PRE/POST).

5.4 Statistical analysis

To test whether and how the two PD programs positively affect teaching quality and the children's mathematical competency, we used a multilevel latent change model (LCM) (McArdle, 2009). With LCM, development over time can be expressed as a latent change score. In the version used in this study, the latent change scores are based on two measurements of the same property at two different points in time. A latent factor is defined by constraining its loading on the second (POST) measurement as well as the regression coefficient of the first (PRE) measurement on the second measurement to 1. At the same time, the residual variance of the second measurement is constrained to 0. This way, the latent factor is specified to represent the true difference between the first and the second measurement.

The model comprises four LCM (Fig. 2). We take into account the hierarchical data structure of children nested in groups by applying a multilevel version of LCM (Raudenbush & Bryk, 2002). The two LCM at the classroom level represent the development of the teachers' macro-adaptive and micro-adaptive learning support from PRE to POST. The change scores are introduced as mediators between the two dummy-coded treatment condition variables and the development of children's mathematics at the classroom level. To model the latter, the children's individual test scores were decomposed into level-specific latent variance components (Lüdtke et al., 2008). For the within and the between variance components of the pre- and the post-measures, an LCM was modeled at each of the two levels.

Figure 2 shows a simplified representation of the model. At both levels, all effects were controlled for a set of potentially relevant baseline variables, such as teacher education and country. Treatment conditions were correlated with the control variables, pre-intervention measures and latent change scores were regressed on them. For clarity, all paths of the control variables and all covariances between them, at both levels, are omitted. All visible paths and covariances without a numeric parameter, except for those of the control variables, were freely estimated. All path coefficients and error variances marked with a numeric term (1 or 0) were fixed at their corresponding values. All invisible path coefficients and covariances, again except for those of the control variables, were set to zero. The path coefficients corresponding to the research questions are marked with a1, a2, a3, and b1, b2, and b3, respectively. The cross-path effects showing the impact of macro-adaptive PD on change in micro-adaptive learning support and the impact of micro-adaptive PD on change in macro-adaptive learning support are marked with x1 and y1, respectively.

The analysis was conducted using Mplus version 8.8 with the robust MLR estimator (Muthén & Muthén, 1998–2022).

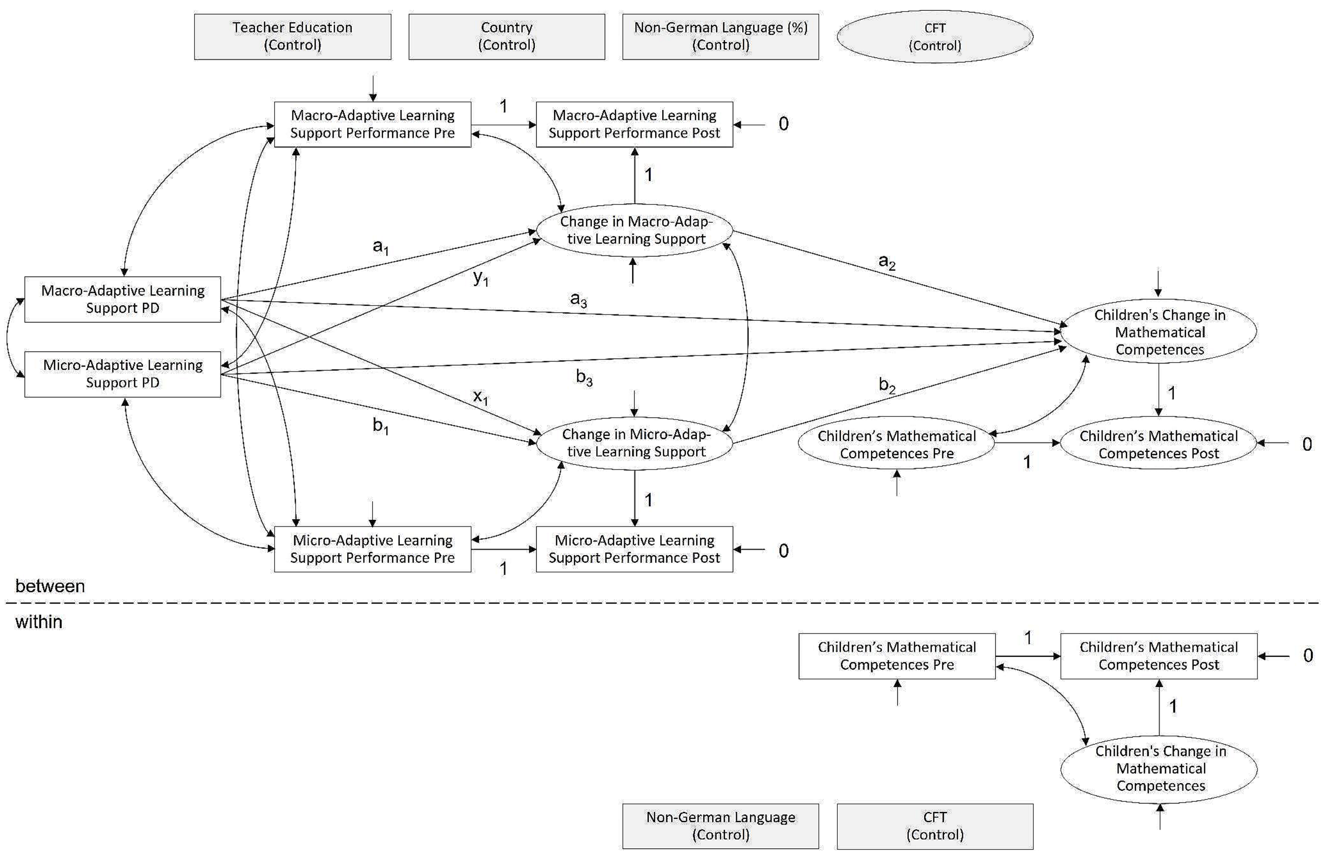

Fig. 2 Hypothesized multilevel latent change model. *Note* Error terms of variables without a visible path pointing to them are due to the blanked-out paths of the control variables. PD = Professional development; Pre = first measurement; Post = second measurement; CFT = Children's cognitive ability (CFT1-R Grundintelligenztest; Weiss & Osterland, 2012). Single-headed arrows represent a direct linear effect of a variable on another variable in the direction of the arrow. Double-headed arrows represent covariance, i.e. stochastic relationships between two variables with no presumed direction

6 Results

The multi-level latent change model (Fig. 2) showed a good fit, with a non-significant Chi^2 ($p > .05$), RMSEA < 0.05, and with relative fit measures CFI and TLI > 0.95 (Hu & Bentler, 1999). As the $SRMR_{between}$ is < 0.05, this is also true for the fit at the classroom level, where the main hypotheses were tested. Results are shown in Table 4. The descriptive statistics are available in the online supplement.

6.1 Results for RQ 1: teaching quality PD and children's mathematical competence

Total effects for both PD programs (a_3 and b_3) were not significant. Neither the achievement gains of children taught by teachers who participated in the macro-adaptive PD program nor those of teachers who participated in the micro-adaptive PD program differed significantly from those of the teachers of the control group.

6.2 Results for RQ 2: mediation by macro- and/or micro-adaptive learning support

As the presence of a significant total effect is not a precondition for any potential mediation effect (O'Rourke & MacKinnon, 2015; MacKinnon, 2008), we also tested the two postulated indirect effects.

As hypothesized, the PD programs designed to improve macro- and micro-adaptive learning support showed significant positive effects on the latent change scores of the respective group's learning support. The non-standardized regression coefficient for the effect of the macro-adaptive PD program on macro-adaptive learning support (a_1) was $b = 1.03$ ($SE = 0.47$, $p_{ts} = 0.028$, $p_{ss} = 0.014$). For the effect of the micro-adaptive PD program on micro-adaptive learning support (b_1), it was $b = 0.81$ ($SE = 0.40$, $p_{ts} = 0.041$, $p_{ss} = 0.021$). The effect size of 0.43 SD for the macro-adaptive support PD program and 0.44 SD for the micro-adaptive one, both as compared to the control group, approached the threshold for medium effects (0.5) according to Cohen (1988).

The cross-path effects when testing for the impact of macro-adaptive PD program on change in micro-adaptive learning support (x_1) and that of the micro-adaptive PD program on change in macro-adaptive learning support (y_1), were, however, not significant. This means that the micro-adaptive program did not affect macro-adaptive support and vice versa.

Looking at the relationship between the two types of adaptive learning support modeled as latent change and the latent change in children's mathematical competency at the classroom level, only the change in micro-adaptive learning support (b_2) had a significant effect ($b = 0.05$, $SE = 0.02$, $p_{ts} = 0.015$, $p_{ss} = 0.008$). The effect size was, with $\beta = 0.31$, small (Cohen, 1988).

Both partial path coefficients (b1 and b2) were significant for the indirect effect of the micro-adaptive learning support PD program on the change in children's mathematical competence, mediated by change in micro-adaptive learning support. However, neither the indirect effect (b1*b2), nor, as stated above, the total effect (b1*b2 + b3) was significant[1].

The only significant effect of the macro-adaptive learning support PD was on macro-adaptive learning support (a_1). The indirect ($a_1 * a_2$) and total ($a_1 * a_2 + a_3$) effect of the

[1] For the indirect effect ($b_1 * b_2$), the single-sided error probability reached $p_{ss} = 0.07$ showing a tendency towards a significant indirect effect.

Table 4 Results of the multilevel latent change model (focus on research questions at the between level)

Effect Type	Label	Exogenous Variable	Endogenous Variable	b	SE	p_{ts}[2]
Direct	a_1	Macro PD[1]	Change Macro	**1.03**	**0.47**	**0.028**
Direct	x_1	Macro PD[1]	Change Micro	0.49	0.36	0.176
Direct	a_2	Change Macro	Change Children	-0.02	0.02	0.369
Direct	a_3	Macro PD[1]	Change Children	0.13	0.01	0.160
Indirect	$a_1 * a_2$	Macro PD[1]	Change Children	-0.02	0.02	0.427
Total	$a_1 * a_2 + a_3$	Macro PD[1]	Change Children	0.11	0.09	0.207
Direct	b_1	Micro PD[1]	Change Micro	**0.81**	**0.40**	**0.041**
Direct	y_1	Micro PD[1]	Change Macro	0.19	0.51	0.705
Direct	b_2	Change Micro	Change Children	**0.05**	**0.02**	**0.015**
Direct	b_3	Micro PD[1]	Change Children	-0.05	0.10	0.640
Indirect	$b_1 * b_2$	Micro PD[1]	Change Children	0.04	0.03	0.140
Total	$b_1 * b_2 + b_3$	Micro PD[1]	Change Children	-0.00	0.10	0.969

Note Macro PD = Macro-adaptive Learning Support Professional Development; Micro PD = Micro-adaptive Learning Support Professional Development; Change Micro = Change in Micro-adaptive Learning Support; Change Macro = Change in Macro-adaptive Learning Support; Change Children = Change in Children's Mathematical Competency

$Chi^2 = 9.49$, df = 14, $p = .800$; RMSEA = 0.000, CFI = 1.000, TLI = 1.000; $SRMR_{within} = 0.002$, $SRMR_{between} = 0.032$

[1]vs. control group; [2]two-sided error probabilities; single-sided error probabilities (p_{ss}) are mentioned in the running text

macro-adaptive PD program and the effect of the macro-adaptive learning support on the change in children's mathematical competency (a_2) were all not significant.

7 Discussion

PD of teachers is assumed to lead to better teaching quality, which in turn will be positively reflected in learner achievement gains (e.g. Desimone, 2009; Egert et al., 2018). Applying this general proposition to this study leads to the assumption that PD programs designed to improve kindergarten teachers' mathematical learning support should result in improved teaching quality and consequently have a positive effect on children's mathematical competency. This study investigated whether two PD programs administered to two groups of kindergarten teachers had a significant effect on the development of their children's mathematics compared to a materials-only control group (RQ 1), and whether this relationship is mediated by two crucial aspects of teaching quality, the teachers' macro- and micro-adaptive learning support (RQ 2).

In answer to RQ 1, the effect of the two PD programs, the mathematical competency of the children in all three groups improved but neither of the two programs had a significant effect when compared to the control group. Our results do not agree with Nelson and McMaster (2019).

Our second research question, RQ 2, addressed the mediating role of teaching quality. Little is known about the hypothetical mediating role of teaching quality (Whittaker et al., 2020), which in our study is operationalized as macro- and micro-adaptive learning support. However, the differentiated assessment of teaching quality could not explain the relationship between PD programs and the change in children's mathematical competency. There are two other possible explanations for the program not having a significant total effect and the lack of mediation by teaching quality: First, the lack of any overall effect on children's mathematical competence might be due to the intensity of the PD program. Compared to the typically shorter PD programs in the German-speaking regions (Barenthien et al., 2020), ours had more hours and was of a longer duration. However, the program was less intense than some others (e.g., Clements et al., 2011). Although we encouraged the participants to transfer the PD content into their daily activities, a more compact, intensive program could have been more effective. Second, it is possible that participants require more time to modify their teaching quality to the point where changes are observable (Whittaker et al., 2020).

There were other results of note, however, which we would like to discuss. First, the findings of Wullschleger et al. (2022), who modeled the impact of the PD program on kindergarten teachers' teaching quality using the same dataset but with less sophisticated methods, were confirmed. That the two different analyses both yielded a significant positive relationship between the macro- and micro-adaptive PD programs and teaching quality adds credibility to our findings.

A second interesting finding concerns the different effects of changes in macro- and micro-adaptive learning support on children's development. Contrary to our expectations, there was a non-significant relationship between the change of quality in macro-adaptive learning support and the change in children's mathematical competency. Fostering children's academic competency in early education is a fairly new topic in German-speaking countries, and kindergarten teachers need specific mathematical expertise to plan and reflect on learning opportunities. Kindergarten teachers may simply not yet be familiar with this type of task. Further research should include a follow-up study to see whether the impact of PD becomes more apparent when kindergarten teachers have more experience providing macro-adaptive learning support. However, a significant positive relationship was found between the change in the quality of micro-adaptive learning support and the changes in children's mathematical competency. This finding highlights the importance of domain-specific learning support for this aspect of teaching quality in ECEC. Our study complements the work of Brunner (2018), which highlights the importance of domain-specific learning support in school. Furthermore, the results provide evidence that domain-specific skills are key to improving teaching in kindergarten, in addition to the already established importance of improving teaching quality in general (Egert et al., 2020).

The different effects of changes in macro- and micro-adaptive learning support on children's development could be attributed to less effective implementation of the PD content by teachers in the macro-adaptive group. Other studies report similar problems (Gerholm et al., 2019). Kindergarten teachers in the macro-adaptive group were encouraged to make precise math-related observations of the children and to plan game sessions based on their observations, which was reflected in their macro-adaptive learning support score. Except for the two sessions used for measuring micro- and macro-adaptive learning support, we have no data on how sessions had been planned. Some teachers may have found it difficult to assess children's abilities and plan the game to suit them. Further research to explore the specific challenges teachers face when instituting macro-adaptive learning support in kindergarten is needed.

7.1 Limitations

The study has four limitations. First, as discussed in Wullschleger et al. (2022), the reliability of our instrument for assessing teaching quality in terms of macro- and micro-adaptive learning support is just acceptable. Second, the statistical power of the data set is limited. While the total number of groups in the field study ($n = 122$) is respectable and well above usual recommendations, the power of testing treatment conditions against the control condition is limited to an n of 83 ($n_{treatment}$ = 39 vs. $n_{control}$ = 44) and a fairly low average number of children per group (6.7). In latent aggregation, the reliability of the L2 measure is a function of the variance proportion weighted by the number of observations per group (Lüdtke et al., 2008). The low number of children in each class could therefore have further contributed to the limited power of the analyses.

Third, the implementation of the PD programs was not assessed. However, it is a particular strength of the study that measurements of the mediators are based on reliable and objective ratings. Such measurements have a higher validity than, for example, self-reports.

Fourth, the study combined data from two countries, Germany and Switzerland, which have different educational objectives for kindergarten children and different kindergarten teacher education programs (see Brunner, 2022 for a summary). For example, in Switzerland kindergarten is part of elementary school, and teachers are obliged to follow a curriculum, which is not the case in Germany. We controlled for this by randomly assigning teachers in each country to the three groups. We also included covariates in the analysis. It would have been interesting to not only control for mean differences between the two countries, as in this study, but to also investigate any potential effect-related differences by country by using multiple group comparisons. This was not possible due to the limited number of kindergarten groups and children. The alternative, to introduce (latent) interaction terms to determine potential differential effects by country cannot be combined with modeling latent difference values.

7.2 Conclusions

Our study contributes to understanding how teaching quality mediates the relationship between PD programs for kindergarten teachers and the development of children's mathematical competency. Our results suggest, for micro-adaptive learning support at least, that providing teachers with extra training could be of greater value than exclusively relying on domain-specific teaching materials. Further research can build on our findings and investigate how to improve macro-adaptive teaching through PD.

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Declarations

Competing interests The authors have no competing interests to declare that are relevant to the content of this article.

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